# Low Back Stability: From Formal Description to Issues for Performance and Rehabilitation

*Stuart M. McGill*

Faculty of Applied Health Sciences, Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada

McGILL, S.M. Low back stability: from formal description to issues for performance and rehabilitation. *Exerc. Sport Sci. Rev.* Vol. 29, No. 1, pp. 26–31, 2001. *The concept of stability, together with notions of design and the application of stabilization exercise, is briefly synthesized. The objective is to challenge muscle systems to achieve sufficient functional stability but in a way that spares the spine of excessive exacerbating load.* **Keywords:** low back, injury, lumbar, stability rehabilitation, performance

## INTRODUCTION

Lumbar stability, "core stability," and low back stabilizing exercises have emerged as popular topics related to optimal athletic/occupational performance and to the rehabilitation of painful backs. The objective of such exercise is to enhance the function of the critical torso muscles in a way that spares the spine from damage. The intention of this limited review is to develop a synthesis of the scientific foundation of the notion of stability as it pertains to the lumbar spine and then to provide specific guidelines for enhancing stability to advance rehabilitation and athletic performance. Although a large book could be written to describe ideal exercise programs for the entire population including chronic low back pain sufferers, from adolescents to elderly persons, through to elite athletes, the focus of the exercises briefly discussed here is more toward the beginner's program—developing the safest exercise to enhance stability and for the daily maintenance of low back health. For the interested reader, more extensive references together with tabulated data of specific muscle activation profiles, resultant spine loads, etc., can be found in the authors' review chapters and original papers listed at www.ahs.uwaterloo.ca/kin/kinfac/mcgill.html.

In most traditional approaches to the design of low back exercises, an emphasis has been placed on the immediate restoration, or enhancement, of spine range of motion and muscle strength. Generally, this approach has not been sufficiently efficacious in reducing back troubles; in fact, a review of the evidence suggests those with greater ranges of spine motion have increased risk of future troubles and that endurance, not strength, is related to reduced symptoms (4). Unfortunately, the emphasis on early restoration of spine range of motion continues to be driven by legislative definitions of low back disability, namely, loss of range of motion. It is unfortunate that therapeutic success is often judged on motion restored. The underlying position taken here reflects the developing philosophy based on mechanisms of injury and stability: that a spine must first be stable before moments and forces are produced to enhance performance.

## INSTABILITY AS A CAUSE OF INJURY

Although biomechanists have been able to successfully explain how strenuous exertions cause specific low back tissue damage, explaining how injury occurs from tasks such as picking up a pencil from the floor has been more challenging. Recent evidence suggests that such injuries are real and result from the spine "buckling," or exhibiting unstable behavior. However, this buckling mechanism can occur during far more challenging exertions as well.

A number of years ago, we investigated the mechanics of powerlifter spines while they lifted extremely heavy loads by using videofluoroscopy to view their vertebrae in the sagittal plane. During their lifts, even though the lifters outwardly appeared to fully flex their spines; in fact, their spines remained two to three degrees per joint from full flexion, thus explaining how they could lift magnificent loads without sustaining injury. The risk of disk and ligamentous damage is greatly elevated when the spine is fully flexed (which the lifters skillfully avoid-

ed). An injury incident was captured on the fluoroscopic motion film, the first such observation that we know of. During the injury incident, just as the semisquating lifter had lifted the load about 10 cm off the floor, only the L2-3 joint briefly rotated to the full flexion calibrated angle and exceeded it by one-half degree, while all other lumbar joints maintained their static positions (not fully flexed) (6). The spine buckled! Sophisticated modeling analysis revealed that buckling can occur from a motor control error where a short and temporary reduction in activation to one, or more, of the intersegmental muscles would cause rotation of just a single joint so that passive or other tissues become irritated or possibly injured (7). *In vitro*, a ligamentous lumbar spine buckles under compressive loading of about 90 N (about 20 lb), highlighting the critical role of the musculature to stiffen the spine against buckling (the critical work and analysis of the passive tissues being performed by Crisco and Panjabi [9]). However, given the wide range of individuals and physical demands, questions remain as to what is the optimal balance in terms of stability, motion facilitation and moment generation, if stability is achieved through muscular cocontraction, how much is necessary and how is it best achieved?

## ON STABILITY: THE FOUNDATION

During the 1980s, Professor Anders Bergmark of Sweden very elegantly formalized stability in a spine model with joint stiffness and 40 muscles (3). In this classic work, he was able to formalize mathematically the concepts of "energy wells": stiffness, stability, and instability. This pioneering effort, together with its continued evolution by several others, is synthesized in an attempt to encapsulate the critical notions using commonplace examples and without mathematical complexity (the mathematically inclined reader is directed to references 3 and 7).

The concept of stability begins with potential energy, which for current purposes, is of two basic forms. In the first form, objects have potential energy by virtue of their height above a datum: PE = mass * gravity * height.

Using a pedagogical analogy, if a ball is placed into a bowl, it is stable, or, more precisely, it is stable because if a force were applied to the ball (or a perturbation), the ball will rise up the side of the bowl but then come to rest again in the position of least potential energy at the bottom of the bowl, or the "energy well," As noted by Bergmark, "stable equilibrium prevails when the potential energy of the system is minimum." The system is made more stable by deepening the bowl and/or by increasing the steepness of the sides of the bowl (Figure 1). Thus, quantification of stability requires the specification of the unperturbed energy state of a system followed by study of the system after
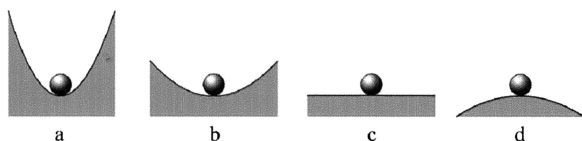


**Figure 2**   A. Increasing the stiffness of the cables (muscles) increases the stability (or deepens the bowl) and increases the ability to support larger applied loads "p" without falling. Spine stiffness (and stability) is achieved by a complex interaction of stiffening structures along the spine (B) and those forming the torso wall (C) (*right*).

perturbation—if the "Joules" of work done by the perturbation are less than the "Joules" of potential energy inherent to the system, then the system will remain stable (i.e., the ball will not roll out of the bowl).

The previous two-dimensional analogy is analogous to a hinged skeletal joint that has the capacity for only flexion/extension. Spinal joints can rotate in three planes and translate along three axes, requiring a six-dimensional bowl for each joint; mathematics enables the examination of a 36-dimensional bowl (six lumbar joints with 6 degrees of freedom) representing the whole lumbar spine. If the height of the bowl were decreased in any 1 of these 36 dimensions, the ball could roll out. In clinical terms, a single muscle having an inappropriate force (and thus stiffness) or a damaged passive tissue that has lost stiffness can cause instability in one or more of these dimensions that is both predictable and quantifiable.

Although potential energy by virtue of height is useful for illustrating the concept, potential energy as a function of the stiffness and storage of elastic energy is actually used for musculoskeletal application. Elastic potential energy is calculated from stiffness ($k$) and deformation ($x$) in the elastic element: PE = $1/2 * k * x^2$.

In other words, the greater the stiffness ($k$), the greater the steepness of the sides of the bowl (from the previous analogy), and the more stable the structure. Thus, stiffness creates stability (Figure 2); it has long been known that joint stiffness increases rapidly and nonlinearly with muscle activation such that only very modest levels of muscle activity create sufficiently stiff, and stable, joints. Furthermore, joints possess inherent joint stiffness as the passive capsules and ligaments contribute stiffness, particularly at the end range of motion. The motor control system is able to control stability of the joints through coordinated muscle coactivation and, to a lesser degree, by placing joints in positions that modulate passive stiffness contribution. However, a faulty motor control system can lead to inappropriate magnitudes of muscle force and stiffness, allowing a "valley" for the "ball to roll out" or, clinically, for a joint to buckle or undergo shear translation. But mechanical systems, and particularly musculoskeletal linkages, are limited to analysis of "local stability" because the energy wells are not infinitely deep and the many anatomical components contribute force and stiffness in synchrony to create "surfaces" of potential energy where there are many local wells. Thus, local minima are located from



**Figure 1**   The continuum of stability: "A" is most stable where "D" is least stable. The ball in the bowl seeks the "energy well" or position of minimum potential energy (m * g * h). Deepening the bowl or increasing the steepness of the sides increases the ability to survive perturbation; this increases stability.
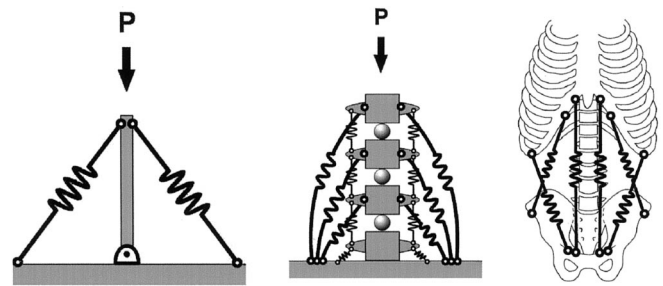
examination of the derivative of the energy surface (see references 3 and 7 for mathematical details). Spine stability, then, is quantified by forming a matrix where the total "stiffness energy" for each degree of freedom of joint motion is represented by a number (or eiganvalue) and the magnitude of that number represents its contribution to forming the "height of the bowl" in that particular dimension. The eigenvector (different from the eigenvalue) can then be formed to identify the mode in which the instability occurred, whereas sensitivity analysis may reveal the possible contributors that allow unstable behavior. Gardner-Morse et al. (10) initiated interesting investigations into eigenvectors by predicting patterns of spine deformation due to impaired muscular intersegmental control) or for clinical relevance: what muscular pattern would have prevented the instability?

"Sufficient stability" is a complex concept and desirable objective that seeks the optimal balance between stability and mobility. However, the objective is constrained by the need for a modest amount of extra stability to form a margin of safety but not so much as to compromise the spine with the additional load. In general, Cholewicki and McGill (7) demonstrated that sufficient stability of the lumbar spine is achieved, in an undeviated spine, in most persons with very modest levels of coactivation of the paraspinal and abdominal wall muscles. Thus, maintaining a stability "margin of safety" when performing tasks, particularly the tasks of daily living, is not compromised by insufficient muscle strength but rather by insufficient endurance.

## EXERCISE FOR THE LOW BACK: A CHANGE IN PHILOSOPHY

Many traditional notions that exercise professionals consider to be principles for exercise prescription, particularly when dealing with the low back, may not be as well supported with data as generally thought (12). For example, there is a widely held view that sit-ups should be performed with bent knees, but it is becoming apparent that the resultant spinal loading (well over 3000 N of compression to a fully flexed L-spine [2]) suggests that sit-ups are not suitable for most persons at all; other abdominal challenges are more effective and safer. Other examples include that contrary to the belief of many, adoption of a posterior pelvic tilt when performing many types of low back exercise actually increases the risk of injury by flexing the lumbar joints and loading passive tissues; having stronger back and abdominal muscles appears to have no prophylactive value for reducing bad back episodes—however, muscle **endurance** has been shown to be protective (4); greater lumbar mobility leads to increased back troubles, not fewer (4)! It is also troubling that replicating the flexion motion and spine loads that occur during the use of many low back extensor machines used for training and therapy produces disk herniations when applied to spines in our laboratory! It is clear that some current "clinical wisdom" needs to be reexamined in the light of relatively recent scientific evidence (those interested in the literature evidence should consult my review in the American College of Sports Medicine textbook [13]). It appears that the safest and mechanically most justifiable approach to enhancing lumbar stability through exercise entails a philosophical approach consistent with endurance, not strength; that ensures a neutral spine posture when under load (or more specifically avoids end range positions) and that encourages abdominal cocontraction and bracing in a functional way. Furthermore, Cholewicki et al. (8) suggests that although steady-state motor patterns are important for daily activity, the health of reflexive motor patterns is critical for maintaining stability during sudden events; achieving a fit and effective motor control system probably requires both perspectives.

## WHAT ARE THE PRIMARY STABILIZERS OF THE LUMBAR TORSO?

Many muscles have been regarded as primary spine stabilizers, but confirmation of their role requires two levels of analysis. First, stability-modelling analysis must be conducted on anatomically robust spine models to document the ability of each component to stiffen and stabilize. Second, electromyographic recordings of all muscles (even deep muscles requiring intramuscular electrodes) are necessary to assess the extent that the motor control system involves each muscle to ensure sufficient stability. From our limited intramuscular electromyographic recordings (11) and stability modeling studies, together with limited evidence from others (1, 15), it appears that most torso muscles are important—their importance depending on the activity. These include muscles that attach directly to vertebra: the unisegmental multifidii and the multisegmented quadratus lumborum, longissimus
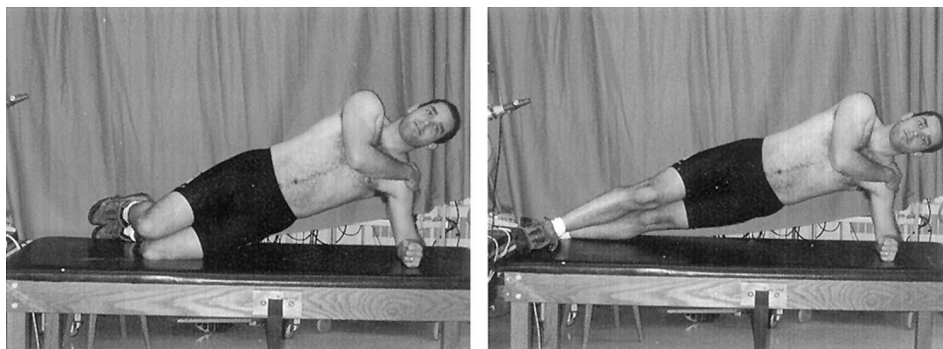


**Figure 3**  The horizontal isometric side bridge. Supporting the lower body with the knees on the floor reduces the demand further for those who are more concerned with safety, whereas supporting the body with the feet increases the muscle challenge but also the spine load.
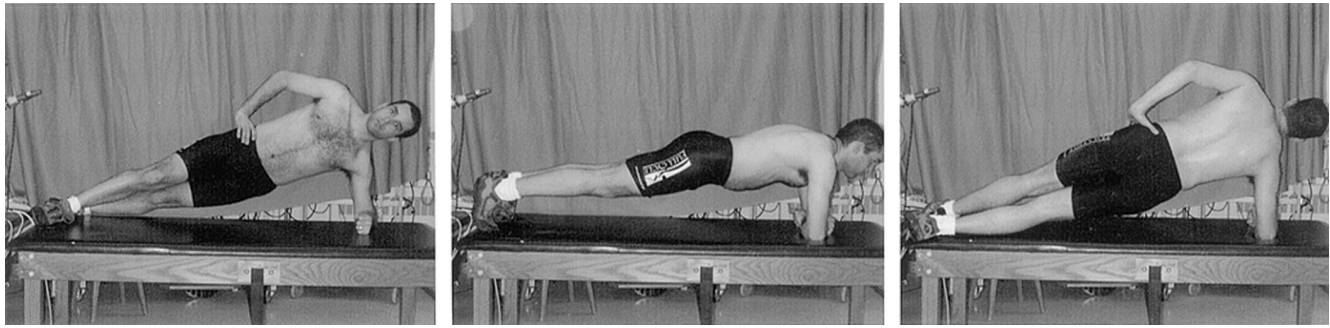
**Figure 4** Advanced side bridge; after each side bridge hold, one "rolls" from one elbow to the other while abdominally bracing locking the pelvis and the rib cage.

and iliocostalis together with the abdominal wall. Psoas activation, we have observed, has little relationship with low back demands—the motor control system activates it when hip flexor moment is required. So which are the wisest ways to challenge and train these identified stabilizers?

## Training Quadratus Lumborum

Given the evidence for quadratus lumborum as a spine stabilizer, the optimal technique to maximize activation but minimize the spine load appears to be the side bridge (Figure 3); beginners bridge from the knees, whereas advanced bridges are from the feet. When supported with the feet and elbow, the lumbar compression is a modest 2500 N, but the quadratus closest to the floor appears to be activated up to about 50% of maximum voluntary contraction (MVC) (the obliques experience a similar challenge). The advanced technique to enhance the motor challenge is to roll from one elbow over to the other while abdominally bracing (Figure 4) rather than repeatedly "hiking" the hips off the floor into the bridge position.

## Training Rectus Abdominis, the Obliques, and Transverse Abdominis

Sit-ups (both straight leg and bent knee) are characterized by higher psoas activation and higher low back compressive loads that exceed NIOSH occupational guidelines, whereas leg raises cause even higher activation and spine compression (the interested reader is directed to references 2, 5, and 11 for actual data on a variety of exercises); generally, these are not recommended. It is also interesting that myoelectric evidence suggests that

there is no "upper" and "lower" rectus abdominis in most persons, but, in contrast, the obliques are regionally activated with "upper" and "lower" motor point areas together with medial and lateral components. Curl-ups excel at activating the rectus abdominis but produce relatively low oblique activity. Curl-ups with a twisting motion are expensive in terms of lumbar compression due to the additional oblique challenge. Transverse abdominis is selectively activated (for muscle reeducation) by dynamically "hollowing" in the abdominal wall (15), whereas an isometric abdominal brace coactivates transverse abdominis together with the external and internal obliques to ensure stability in virtually all modes of possible instability.

There is no single abdominal exercise that challenges all of the abdominal musculature, requiring the prescription of more than one single exercise. A wise choice for abdominal exercises, in the early stages of training or rehabilitation, for simple low back health objectives, would consist of several variations of curl-ups for rectus abdominis and the side bridge for the obliques and quadratus; the variation chosen is commensurate with patient/athlete status and goals.

## Training the Back Extensors (and Stabilizers)

Most traditional extensor exercises are characterized with very high spine loads, which result from externally applied compressive and shear forces (from either free weights or resistance machines). The often performed exercise of laying prone on the floor and raising the upper body and legs off the floor is contraindicated for anyone at risk of low back injury—or reinjury. In this task, the lumbar region pays a high compression
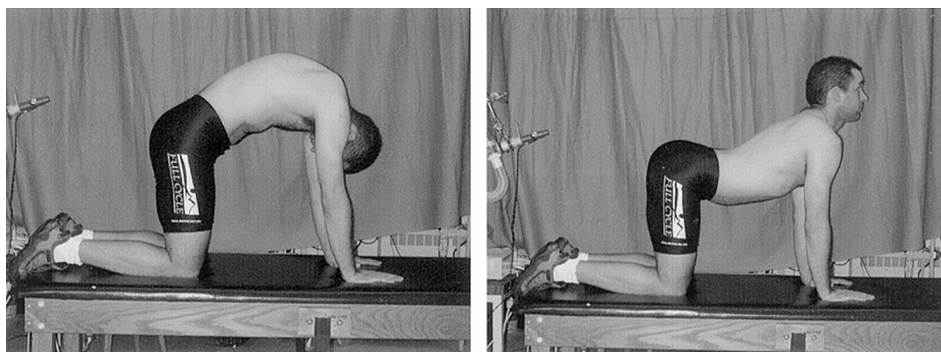


**Figure 5** The flexion-extension motion is performed by slowly cycling through full spine flexion to full extension. Spine mobility is emphasized rather than "pressing" at the end range of motion. This exercise facilitates motion for the spine with very low loading of the intervertebral joints, reduces viscous stresses for subsequent exercise, and "flosses" the nerve roots through the foremenae at each spine joint (hence coordination of full cervical, thoracic, and lumbar flexion-extension).
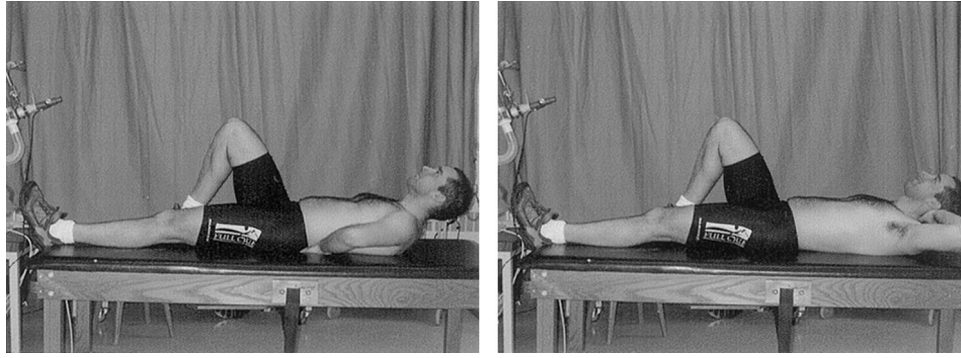
**Figure 6** The curl-up, where the head and shoulders are raised off the ground with the hands under the lumbar region to help stabilize the pelvis and support the neutral spine (do *not* flatten the lumbar spine to the floor). Only one leg is bend to assist in pelvic stabilization and preservation of a "neutral" lumbar curve. Additional challenge can be created by raising the elbows from the floor and generating an abdominal brace or cocontraction.

penalty to a hyperextended spine (usually much higher than 4000 N [4]), which transfers load to the facets and can crush the interspinous ligament. From our search for methods to activate the extensors (including longissimus, iliocostalis, and multifidii) with minimal spine loading, it appears that the single leg extension hold minimizes the spine load (< 2500 N) and activates one side of the lumbar extensors to approximately 18% of MVC. Simultaneous leg extension with contralateral arm raise ("bird-dog") increases the unilateral extensor muscle challenge ( 27% MVC in one side of the lumbar extensors and 45% MVC in the other side of the thoracic extensors) but also increases lumbar compression to well over 3000 N.

## THE BEGINNER'S PROGRAM FOR STABILIZATION

Some specific recommended low back exercises have been shown. We recommend that the program begin with the flexion-extension cycles (cat-camel; Figure 5) to reduce spine viscosity and "floss" the nerve roots as they outlet at each lumbar level, followed by hip and knee mobility exercises. Note that the cat-camel is intended as a motion exercise, not a stretch, so the emphasis is on motion rather than "pushing" at the end ranges of flexion and extension. We have found that five or six cycles is often sufficient to reduce most viscous stresses. This is followed by anterior abdominal exercises; in this case, the curl-up with the hands under the lumbar spine to preserve a neutral spine posture (Figure 6) and one knee flexed but with the other leg straight to lock the pelvis-lumbar spine and help preserve a loss in the neutral lumbar posture. Then, lateral musculature exercises are performed, namely the side bridge, for quadratus lumborum and muscles of the abdominal wall for optimal stability (Figure 3). Advanced variations involve placing the upper leg-foot in front of the lower leg-foot to facilitate longitudinal "rolling" of the torso to challenge both anterior and posterior portions of the wall, together with simultaneous bracing and hollowing. The extensor program consists of leg extensions and the "bird-dog" (Figure 7).

Given the apparent links between torso muscle endurance with reduced incidence of back troubles, "normal" ratios of endurance times have been proposed for the torso flexors relative to the extensors (for example, it is "normal" to hold a flexor posture [14], about 0.98 of the maximum time holding a refer-ence extensor posture) and for the lateral musculature relative to the extensors (0.73) (14) to assist clinicians to identify endurance deficits, both absolute values and for one muscle group relative to another. Finally, as patients progress with isometric stabilization exercises, we recommend conscious simultaneous contraction of the abdominals (either bracing, simply isometrically activating the abdominals for maximum stability, or hollowing, dynamically drawing the navel toward the spine) to enhance motor control and create modest stability using the deeper abdominal wall (transverse abdominis and internal oblique) (see Richardson et al. [15]).

## ADVANCED TECHNIQUES

The beginner's program should be sufficient for daily spine health. Athletic performance demands higher challenges when training the low back but is achieved with much higher risk of tissue damage from overload. Furthermore, specific athletic objectives require specific training techniques; space restrictions do not permit their discussion here, but, for example, torsional moments are often required athletically, but issues remain regarding the method to maximize stability and minimize injury during training for trunk torsion. The fact that generating torque about the twist axis imposes approximately four times the
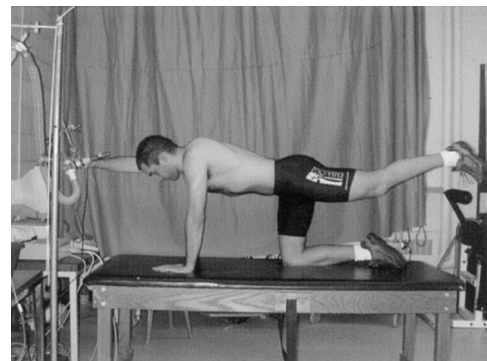


**Figure 7** Single leg extension holds, while on the hands and knees, produces mild extensor activity and lower spine compression (< 2500 N). Raising the contralateral arm increases extensor muscle activity but also spine compression to levels over 3000 N. Sufficient stability is ensured with mild abdominal bracing.
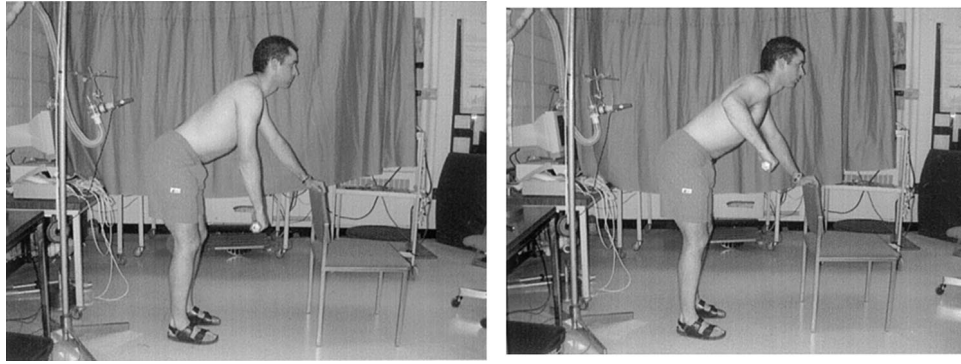
**Figure 8**   The low-level challenge for the torsional components is to support the extensor moment of the flexed torso with one hand while the other raises a modest weight. The lumbar torso is braced in a neutral posture, resisting the twisting moments generated by the weight.

compression on the spine than for an equal torque about the flexion extension axis cannot be dismissed. The safest technique we have found to challenge the torsional moment generators with minimal spine load is to raise a hand-held weight while supporting the upper body with the other arm and abdominally bracing (Figure 8) to resist the torsional torque with an isometrically contracted and neutral spine. Dynamic challenged twisting is reserved for the most robust of athletes' backs.

## MODIFYING ATHLETIC TECHNIQUE TO PROLONG CAREERS

Too many athletes unnecessarily shorten their careers through ill-chosen training techniques and destructive sport moves. Spondylitic fractures from cricket bowling, for example, have led to legislated change in bowling technique together with restrictions on practice in Australia. Similar strategies have been discussed for women's gymnastics. The golf swing is another example where shortening the back swing has spared the spine, with only minor decrements in shot performance, to prolong the careers of professionals and amateurs alike. Conscious abdominal bracing and torso-stabilizing cocontraction will restrict spine range of motion and reduce disabling symptoms. The development of optimal accommodations in the sporting technique often requires collaborative input of the biomechanist and the coach.

## LOOKING FORWARD

Many groups continue to work to understand stability issues with goals of (a) understanding what magnitudes of muscle activation are required to achieve sufficient stability and (b) identifying the best methods to reeducate faulty motor control systems to both achieve sufficient stability and reduce the risk of inappropriate motor patterns occurring in the future. Much remains to be done.

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