To Crunch or Not to Crunch: An Evidence-Based Examination of Spinal Flexion Exercises, Their Potential Risks, and Their Applicability to Program Design

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The crunch and its many variations have long been considered a staple exercise in fitness programs. These exercises involve dynamic flexion of the spine in the sagittal plane, and are performed to increase abdominal strength and development (125), particularly in the rectus abdominis and obliques musculature. Strength and conditioning coaches frequently include such exercises as a component of athletic routines designed to enhance sporting performance (45).

Recently, however, some fitness professionals have questioned the wisdom of performing flexion-based spinal exercises such as the crunch (74; 23; 111). Concerns are usually predicated on the belief that the spine has a finite number of bending cycles, and that exceeding this limit will hasten the onset of disc damage (74). Proponents of the theory claim that spinal flexion therefore should be saved for activities of daily living such as tying one's shoes rather than "wasted" on crunches and other flexion-based abdominal exercises. Opponents of the theory counter that an alarming discrepancy exists between laboratory results and what is occurring in gyms and athletic facilities around the world with respect to total flexion cycles and spinal injury, and cite a lack of evidence showing any detriments. Therefore, the purpose of this paper will be threefold: First, to review the relevant research pertaining to the risks of performing dynamic spinal flexion exercises; second, to explore the potential benefits associated with spinal flexion exercises; and third, to discuss the application of these findings to exercise program design.

Overview of Degenerative Disc Disease

The intervertebral discs form cartilaginous joints between adjacent vertebrae, which stabilize the the spine by anchoring the vertebrae to one another. The discs also facilitate multi-planar spinal movement and help absorb vertebral shock. Discs are comprised of three distinct portions: an outer layer annular fibrosus, a central nucleus pulposus, and two hyaline cartilage endplates (64). The annulus, which has an inner and outer component, consists of multiple layers of fibrocartilage, primarily a combination of Type I and Type II collagen (39). The annulus serves to resist outward pressure, also known as tensile or hoop stresses, during axial compression and to stabilize the vertebral joint during motion (139). The annulus also serves to contain the inner nucleus, which is a gel-like structure comprised of a mixture of chondrocytes, collagen, elastin, and proteoglycans (131). Proteoglycans serve to resist compressive loading due to their glycosaminoglycan (GAG's) content (115). GAG's are long-branch polysaccharides that attract and bind to water and provide osmotic pressure. The nucleus functions as a "water pillow," helping to cushion the vertebrae from axial loads and distribute pressures uniformly over adjacent vertebral endplates (112). The endplates contain primarily type II collagen (55), are less than 1 mm thick, and contain fibers that extend into the disc (139). In addition to preventing the nucleus from protruding into adjacent vertebrae, the endplates also help to absorb hydrostatic pressure caused by spinal loading (26; 81) and allow for nutrient diffusion (132).

Degenerative disc disease is a multifactorial process involving genetic, mechanical, biological, and environmental factors (59). The first common signs of disc degeneration often appear between 11-16 years of age, with approximately 20% of teenagers displaying mild disc degeneration (79). However, minor signs of degeneration such as mild cleft formation and granular changes to the nucleus appear in disc of 2 year-olds (21). Discs tend to progressively deteriorate with age, with a majority of discs showing signs of degeneration by the time a person is 70 years-old (79). Age-related degeneration involves a reduction in proteoglycan and collagen levels (115), a five-fold reduction in the fixed charge-density – a measure of mechanoelectrochemical strength – of GAG's in the nucleus (60), and a two-fold decrease in hydration between adolescent discs and 80 year-old discs (130), which diminishes the disc's height and load-bearing capabilities (5; 22). Males tend to exhibit more disc degeneration than females, which is thought to be due to a combination of increased trunk strength, increased resistance lever arms that heighten spinal forces and stresses, increased heavy-loading, and increased distance for nutrient-travel (79).

Intervertebral disc degeneration can manifest from a structural disturbance in the annulus, nucleus, or endplate (8). Aging, apoptosis, collagen abnormalities, vascular ingrowth, mechanical loading, and proteoglycan abnormalities can all contribute to disc degeneration (71). As discs degenerate, focal defects arise in the cartilage endplate, the nuclei become increasingly more consolidated and fibrous, and the number of layers in the annulus diminishes (119). This has been shown to alter disc height, spinal biomechanics, and load bearing capabilities (99), and ultimately can lead to spinal stenosis – an advanced form of degenerative disc disease that causes compression of the contents of the spinal canal, particularly the neural structures (93). Endplate calcification also contributes to disc degeneration by decreasing nutrient diffusion which interferes with the pH balance and increases inflammatory responses in the nucleus (34). Yet despite a clear association between degenerative spinal changes and an increased incidence of lower back pain (LBP) (66), many afflicted individuals are nevertheless asymptomatic (20; 19; 140).

Does Spinal Flexion Cause Disc Injury?

A variety of research approaches have been employed to elucidate spinal biomechanics and their impact on disc pathophysiology, including the use of animal and human in vivo (i.e. within the living) models, animal and human in vitro models (i.e. within the glass), and computer-based in silico models (63). In particular, in vitro research has implicated repetitive lumbar flexion as the primary mechanism of disc herniation (protrusion of disc material beyond the confines of the annular lining) and prolapse (a bulging of nucleus pulposus through annulus fibrosus), as evidence shows that these pathologies proceed progressively from the inside outwards through nuclear migration toward the weakest region of the annulus – the posterolateral portion (62; 128).

Most in vitro studies on spinal biomechanics that are applicable to the crunch exercise have used cervical porcine models (30, 35, 124, 36, 70). These models involve mounting spinal motion segments in custom apparatuses that apply continuous compressive loads combined with dynamic flexion and extension moments. Total bending cycles have ranged from 4,400 to 86,400, with compression loads equating to approximately 1,500N. Considering that Axler and McGill (13) found that a basic crunch variation elicited around 2,000N of compression, the amounts of compression in the various studies is reasonable for making comparisons with the crunch exercise. In each of the aforementioned studies, a majority of the discs suffered either complete or partial herniations, particularly to the posterior annulus. This suggests a cause-effect relationship between spinal flexion and disc damage. The results of the studies are summarized in Table 1.

TABLE 1

Study	Type of Spine	# of Subjects	Amount of Compression	# of Cycles	# of Herniations
Callaghan & McGill (2001)	Porcine Cervical	26	260-1,472N	86,400	**15**
Drake et al. (2005)	Porcine Cervical	9	1,472	6,000	**7**
Tampier et al. (2007)	Porcine Cervical	16	1,472N	4,400 – 14,00	**8**
Drake & Callaghan (2009)	Porcine Cervical	8	1,500N	10,000	**8**
Marshall & McGill (2010)	Porcine Cervical	10	1,500N	6,000	**4**

Although the aforementioned studies seem to lend credence to the potential risks of repeated spinal bending, there are several issues with attempting to extrapolate conclusions from a laboratory setting to the gym. First and foremost, the studies in question were performed in vitro, which is limited by the removal of musculature and does not replicate the in vivo response to the human spine during normal movement (148; 142; 98; 143, 144). As with all living tissue, the vertebrae and its supporting structures remodel when subjected to applied stress (24). Consistent with Wolff's and Davis's Laws, deformation of cellular tissues are met by a corresponding increase in the stiffness of the matrix, which in turn helps to resist future deformation (103; 102). The vertebrae and intervertebral discs are no exception as they have been shown to adaptively strengthen when exposed to progressive exercise (92; 65; 1; 24). Cadaveric tissue does not have the capacity to remodel.

Another important point to consider when interpreting results of in vitro studies involving cyclic spinal loading is that natural fluid flow is compromised. Van der Veen et al. (133) found that while porcine lumbar motion segments showed outflow of fluid during loading, inflow failed to occur during unloading, thereby decreasing disc height and interfering with normal disc biomechanics.

In vitro comparisons are further complicated by the use of animal models. While animal models do have structural similarities to the human spine (147; 29), especially the porcine cervical spine in comparison to the human lumbar spine, numerous anatomical and physiological variations nevertheless exist (131). Of particular relevance to flexion studies is the fact that the absolute ranges of motion are smaller in porcine subjects compared to humans (10). These variations are most prominent in flexion and extension, which may mitigate the ability to draw applicable conclusions to human dynamic spinal exercise.

Furthermore, the studies in question attempted to mimic loading patterns of occupational workers by subjecting spinal segments to thousands of continuous bending cycles, which is far beyond what is normally performed in the course of a dynamic exercise program. Typical core strengthening routines employ a limited number of dynamic repetitions, and upon completion of a set, trainees then rest for a given period of time before performing another set. Thus, total bending cycles per session ultimately amount to a fraction of those employed in the cited research protocols and these cycles are performed intermittently rather than continuously. Rodacki et al. (97) found that despite the moderate values of compression associated with the traditional crunch; the transient nature of the load (i.e. the short peak period of compressive spinal force) did not induce fluid loss. In fact, abdominal flexion exercise was actually found to be superior to the Fowler's position – a semi-recumbent position used in therapy to alleviate pressure on the spine – with respect to spinal unloading, presumably mediated by a greater fluid influx rate than when sustaining a static recumbent posture (97).

It also should be noted that following an exercise bout spinal tissues are allowed to recuperate until the next training session, thereby alleviating disc stress and affording the structures time to remodel. Exercise-induced disc damage results when fatigue failure outpaces the rate of adaptive remodeling, which depends on the intensity of load, the abruptness of its increase, and the age and health of the trainee (1). Provided that dynamic spinal exercise is performed in a manner that does not exceed individual disc loading capacity, the evidence would seem to suggest a positive adaptation of the supporting tissues. In support of this contention, Videman et al. (136) found that moderate physical loading resulted in the least disc pathology, with the greatest degeneration seen at extreme levels of activity and inactivity.

In addition, the role of genetics needs to be taken into consideration. Despite the commonly held belief that spinal degeneration is most often caused by the wear and tear from mechanical loading, this appears to play only a minor role in the process (16). Instead, it has been shown that approximately 74% of the variance is explained by hereditary factors (15). Battie et al. (16) identified specific gene forms associated with disc degeneration that hasten degenerative vertebral changes in the absence of repetitive trauma. Hereditary factors such as size and shape of the spinal structures, and biochemical constituents that build or break down the disc can highly influence disc pathology, as can gene-environment interactions (16).

In a case-control study involving 45 monozygotic male twin pairs, Battie et al. (17) found that subjects who spent over five times more hours driving and handled over 1.7 times more occupational lifting showed no increases in disc degeneration compared to their twin siblings and, although values did not reach statistical significance, actually displayed fewer lower lumbar disc herniations. In addition, Varlotta et al. (134) found that the relative risk of lumbar disc herniation before the age of twenty-one years is approximately five times greater in subjects who have a positive family history. Furthermore, physically active individuals appear to suffer from less back pain than sedentary individuals (44; 77).

Moreover, the studies in question do not necessarily replicate spinal motion during dynamic lumbar flexion exercise. For example, the traditional crunch exercise involves flexing the trunk to approximately 30 degrees of spinal flexion so that only the head and shoulders are lifted from the floor, making the thoracic spine the region of greatest flexion motion (105; 118). Further, Adams and Hutton (7) showed that taking a flexed lumbar spine from an end-range of flexion at 13 degrees to 11 degrees of flexion, a two-degree differential, resulted in a 50% reduction in resistance to bending moment and therefore a 50% reduction in bending stress to the posterior annulus and intervertebral ligaments. Thus, both the location and degree of flexion will have a significant impact on spinal kinetics.

Finally, although abdominal exercises create compressive forces by way of muscular contraction, they also increase intra-abdominal pressure (IAP) (32). Three-dimensional biomechanical models predict reductions in compressive forces of approximately 18% when IAP is factored into spinal flexion efforts (120). Hence, IAP produced during spinal flexion exercise may serve to moderate compressive forces, helping to unload the spine and facilitate fluid absorption in the discs (97). Since in vitro research models to date have not incorporated IAP, conclusions drawn may be limited with respect to the safety of spinal flexion exercises. It should be noted, however, that the unloading effects of IAP may be diminished with high levels of abdominal muscle co-activation (12). Additional research is needed to shed further light on this topic with particular attention focused on evaluating the effects of IAP on compressive forces in subjects performing spinal flexion exercise including the crunch.

It also should be noted that some epidemiological studies show an increased risk of spinal injuries in athletes involved in sporting activities that require repeated spinal flexion. Injuries to the spinal column, including disc degeneration and herniations, have been found to occur with greater frequency in gymnasts, rowers, and football players (123; 121; 137; 145). Furthermore, elite athletes suffer such injuries more frequently than non-elite athletes (121; 88). However, a cause/effect relationship between spinal flexion and injury in these athletes has not been established, and the ballistic nature of such sporting activities has little applicability to controlled dynamic abdominal exercises.

Benefits of Spinal Flexion Exercises

If dynamic flexion exercises in fact do not pose a significant injury risk in the absence of spinal pathology, the natural question then is whether performing these movements confers benefits over and above static-based exercises. The following potential benefits can be identified.

First, spinal motion has been shown to facilitate nutrient delivery to the intervertebral discs (51; 50). The mechanism of action is theorized to be related to a pumping action that augments transport and diffusion of molecules into discs. Motion causes more fluid to flow out of the disc, which is reversed when the spine is unloaded (6). Fluid flow is better at transporting large molecules, while diffusion is better at transporting smaller molecules (129). This has particular significance for spinal tissue given that age-related decreases in disc nutritional status is considered a primary cause of disc degeneration, leading to an accrual of cellular waste products, degradation of matrix molecules, and a fall in pH levels that further compromise cell function and possibly initiate apoptosis (52; 27; 71; 131).

Postures involving flexion of the spine are superior to neutral and extended postures in terms of promoting increased fluid exchange in the disc, especially the nucleus pulposus (6). One deficiency of neutral posture is that it favors diffusion in the anterior portion of the disc over the posterior portion. Flexed postures reverse this imbalance by stretching the posterior annulus, thereby decreasing the distance for nutrients to travel. The posterior region of the disc contains a region that is deficient of nutrient supplement from all sources (69), and flexion reduces the thickness of the posterior portion of the disc by 37% which ensures sufficient supply of glucose to the entire posterior region of the disc (6). Flexion increases diffusion of small solutes and fluid flow of large solutes. This is important considering that disc degeneration has been linked to inadequate metabolite transport (51; 83), and that populations adopting flexed postures show less incidence of disc disease (40). The crunch exercise produces tensile stresses on the posterior annulus – in flexion the posterior annulus has been shown to extend up to 60% of its original height (90), and tensile stress has shown to exert a protective effect on disc cells by decreasing the expression of catabolic mediators during inflammation (107). By enhancing nutrient uptake and limiting inflammatory-based catabolism, regimented flexion exercise may actually confer a positive effect on long-term spinal health and promote disc healing in the periphery (9). In fact, research suggests that spinal flexion and extension exercises can be valuable in reducing low back pain (96; 38; 43). Although pain or lack of pain is not necessarily an indicator of spinal health, it nevertheless is interesting to speculate that spinal flexion movements may actually confer therapeutic benefits provided exercise does not exceed the adaptive capacity of the tissue.

In addition, spinal flexion exercises may help to improve functional spinal flexibility and thereby reduce the onset of LBP. Multiple studies have found that a lack of sagittal plane spinal flexibility is associated with an increased incidence of LBP (73; 89; 28; 37). Resistance exercise has been shown to serve as an active form of flexibility training, helping to improve joint mobility within a functional range of motion (14; 106; 80), and spinal flexion exercises have been shown to increase sagittal plane spinal mobility (38). Improved flexibility associated with resistance training has been attributed to increased connective tissue strength, increased muscular strength, and improved motor learning and/or neuromuscular coordination (80). At the same time, dynamic strengthening of the supporting musculature and ligamentous tissue may attenuate spinal hypermobility in those afflicted, which also has been implicated as a cause of LBP (119). Hence, a case can be made that a well-designed resistance training program that includes dynamic spinal flexion may bestow a preventative effect against LBP. It should be noted, however, that some studies have failed to reveal significant differences in sagittal plane spinal flexibility between pain free subjects and those with LBP (94), and one study indicated that lumbar spinal flexibility is associated with disc degeneration (48). Moreover, we cannot necessarily determine a cause/effect relationship between an increased risk of injury in those with poor spinal flexibility. Further research is warranted to draw pertinent conclusions on the topic.

Finally, flexion-based spinal movements help to optimize hypertrophy of the rectus abdominis muscle. The crunch exercise and its variations have been shown to target the rectus abdominis to a much greater extent than the other core muscles. McGill (76) found that a variant of the crunch activated 50% of maximal voluntary contraction (MVC) of the rectus abdominis, but only 20%, 10%, 10%, and 10% of MVC of the external obliques, internal obliques, transverse abdominis, and psoas major, respectively. Given that a direct association has been noted between muscle cross sectional area and muscle strength (72; 42), muscle hypertrophy has specific relevance to athletes who require extensive core strength. Moreover, muscle hypertrophy of the rectus abdominis also is integral to aesthetic appearance of the abdominal musculature and is therefore highly desired by bodybuilders and other fitness enthusiasts.

The hypertrophic superiority of dynamic movement can be partly attributed to the eccentric component, which has been shown to have the greatest effect on promoting muscle development (41; 49, 53, 100). Eccentric exercise has been linked to a preferential recruitment of fast-twitch muscle fibers (113, 122; 85) and perhaps recruitment of previously inactive motor units (78; 84). Given that fast twitch fibers have the greatest growth potential, their recruitment would necessarily contribute to greater increases in muscle cross sectional area.

Eccentric exercise also is associated with greater muscle damage, which has been shown to mediate a hypertrophic response (78; 109). Muscle damage induced by eccentric exercise upregulates MyoD mRNA expression (57) and has been implicated in the release of various growth factors that regulate satellite cell proliferation and differentiation (127; 138).

In addition, dynamic muscle actions have been shown to induce significantly greater metabolic stress than static contractions (25). Specifically, the buildup of metabolites such as lactate, hydrogen ion, and inorganic phosphate has been shown to mediate a hypertrophic response (101; 110; 117), and some researchers have speculated that metabolic stress may be more important than high force development in optimizing muscle development (114). The stress-induced mechanisms theorized to increase muscle hypertrophy include alterations in hormonal milieu, cell swelling, free radical production, and increased activity of growth-oriented transcription factors (109). Russ (104) displayed that phosphorylation of Akt, a protein kinase associated with mTOR pathway signaling and thus regulation of protein synthesis, is significantly greater in eccentric contractions compared to isometric contractions. This may be due to heightened metabolic stress, greater muscle damage, or a combination of both.

Practical Applications

Taking all factors into account, it would seem that dynamic flexion exercises provide a favorable risk/reward ratio provided that trainees have no existing spinal injuries or associated contraindications such as disc herniation, disc prolapse, and/or flexion intolerance. However, several caveats need to be taken into consideration in order to maximize spinal health.

First and foremost, since hereditary factors have a tremendous impact on disc degeneration, it is difficult to know the precise amount of volume, intensity, and frequency sufficient to stimulate soft-tissue strengthening adaptations without exceeding the recovery ability of the spine. It has been theorized that a "safe window" of tissue mechanical loading exists that facilitates healthy maintenance of spinal discs (119). There is evidence supporting this theory as it pertains to spinal compression (146), however further research is needed to determine whether this applies to other types of spinal loading including flexion.

An epidemiological study by Mundt et al. (82) found that participation in sports such as baseball, softball, golf, swimming, diving, jogging, aerobics, racquet sports, and weight lifting are not associated with increased risk of lumbar disc herniation, and they even may offer a protective effect against herniation. Kelsey et al. (58) reported similar findings with respect to disc prolapse. Many of these sports involve a high frequency of spinal motion including flexion, which casts doubt on the theory that humans have a limited number of flexion cycles. Unfortunately, there is no way to determine when an individual's training volume and/or intensity falls outside this range and thus predispose the spine to localized overload injury.

Given that the spine and core musculature are loaded during non-machine based exercise performance such as during squats, deadlifts, chin ups, and pushups, most training can be considered "core training." It is therefore best to err on the side of caution and limit the amount of lumbar flexion exercise in order to ensure that the tissue remains in "eustress" and doesn't become "distressed." Based on current data, the authors recommend that a sound core strengthening routine should not exceed approximately 60 repetitions of lumbar flexion cycles per training session. Untrained individuals should begin with a substantially lower volume. A conservative estimate would be to start with 2 sets of 15 repetitions and gradually build up tolerance over time.

In addition, it is important to allow for sufficient rest between dynamic spinal flexion sessions. The time course of post-exercise muscle protein synthesis lasts approximately 48 hours (67). Training a muscle group before protein synthesis has completed its course can impair muscle development (47) and potentially lead to localized overtraining. Thus, the notion that it is optimal to perform dynamic abdominal exercises on a daily basis is misguided. Since the intervertebral discs are poorly vascularized with low levels of metabolite transport, their rate of remodeling lags behind that of other skeletal tissues (69; 116), which may necessitate even greater time for recuperation. Taking all factors into account, a minimum of 48 hours should be afforded between dynamic spinal flexion exercise sessions, and it may be prudent to allow 72 hours or more depending on individual response.

Although some core training programs include ultra-high repetition sets of crunches, for example multiple sets of a hundred repetitions or more, this type of protocol has little functional applicability. After all, when does an individual need to continuously flex the spine in everyday life? It is therefore recommended that flexion based spinal exercises be reserved for improving strength and/or hypertrophy of the abdominal musculature as opposed to heightening muscular endurance. A repetition range of approximately 6 to 15 repetitions is advised for achieving this goal (109). External resistance should be employed when necessary to elicit an overload response within this target repetition range. Those seeking improvements in local muscular endurance would be best served by performing static, neutral posture exercises that are held for extended periods of time. Specific guidelines will vary dramatically according to the individual's needs and abilities, but a general recommendation for untrained individuals would be to perform 3-4 sets of 10-15 seconds holds in multiple planes. Advanced exercisers seeking increases in static endurance might perform 3-4 sets of 60 seconds or more in multiple planes, whereas advanced exercisers seeking increases in static power could stick to the 10-15 second holds but perform more challenging variations or increase external resistance in order to promote further adaptation. Athletes who engage in sports where spinal flexion exercise or other inherently dangerous motions for the discs such as spinal rotation is prominent and volumes of flexion cycles and training frequencies above our recommendations are exceeded should consider the possibility of excluding spinal flexion exercise from their routines.

Exercise tempo is another important consideration. Several studies have shown that repetitions performed at a speed of one-second elicit greater muscle activation than those performed more slowly (135), and faster repetitions may selectively recruit the rectus abdominis (Norris, 2001). Given the principle of specificity, rapid speeds of movement also would tend to have greater transfer to athletic activities that require dynamic core power such as wrestling (Iwai et al. 2008), throwing a baseball (56), tennis (33), gymnastics (91), soccer (126), swimming (68), and track and field (46). However, an increased repetition speed could subject the spinal tissues to excessive forces that may lead to injury (7; 86). For non-athletic populations, the risks of faster repetitions would appear to outweigh the potential rewards and thus a slightly slower tempo of approximately two seconds may be more appropriate with respect to maintaining spinal health. As for athletic populations, more research is needed to show whether explosive dynamic core exercises lead to positive adaptations that strengthen tissues and prevent injury, or whether they subject the athlete to greater risk of injury by adding more stress to the tissues.

It also is important to consider the effects of diurnal variation on spinal kinetics. During sleep, loading on the discs is reduced, allowing them to absorb more fluid and increase in volume (130). Fluid is then expelled throughout the day as normal daily spinal loading ensues. In the early morning, intradiscal pressure is 240% higher than prior to going to bed (141), and bending stresses are increased at the discs by 300% and at the ligaments of the neural arch by 80% due to hydration and absence of creep (2). As the day goes on, discs bulge more, become stiffer in compression, become more elastic and flexible in bending, affinity for water increases, and the risk of disc prolapse decreases (3). After just 30 minutes of waking, discs lose 54% of the loss of daily disc height and water content and 90% within the first hour (95). For this reason, spinal flexion exercises should be avoided within at least 1 hour of rising. To be conservative, athletes may want to allow a minimum of 2 hours or more before engaging in exercises that involve spinal flexion.

There is some evidence that spinal flexion exercises should also be avoided following prolonged sitting. It has been shown that discs actually gain height after sitting (11; 61) and decrease lumbar ROM (31), which reduces slack in the flexion-resisting structures including ligaments and the posterior annulus while increasing the risk of injury to those structures (2; 18). However, as noted by Beach et al. (18), individual differences in sitting posture lead to large variations in tissue response. Some individuals actually gain lumbar ROM from sitting which can also increase the risk of injury due to viscoelastic creep (75), stress-relaxation (4), or fluid loss (6), which increases joint laxity (2). Considering that approximately 50% of stiffness is regained within 2 minutes of rising after 20 minutes of full flexion (75), it seems prudent to allow at least several minutes to elapse, perhaps 5 or more, before engaging in spinal flexion exercises following a period of prolonged sitting, and to walk around to facilitate dehydration of the disc.

Conclusion

Based on current research, it is premature to conclude that the human spine has a limited number of bending cycles. The claim that dynamic flexion exercises are injurious to the spine in otherwise healthy individuals remains highly speculative and is based largely on extrapolation of in vitro animal data that is of questionable relevance to in vivo human spinal biomechanics. While it appears that a large number of continuous bending cycles may ultimately have a detrimental effect on spinal tissues, no evidence exists that a low volume, strength-based exercise routine that includes dynamic spinal flexion movements will hasten the onset of disc degeneration, and a case can be made that such exercises may in fact produce a beneficial effect in terms of disc health. Contraindications for spinal flexion movements would only seem applicable with respect to those with existing spinal pathology such as disc herniation/prolapse or flexion intolerance.

To date, the authors are not aware of any study that has investigated the effects of spinal flexion exercise on human spines in vivo. Further research is needed to evaluate both the acute and chronic effects of dynamic spinal flexion exercises in human subjects in vivo so that more definitive conclusions can be drawn on the topic. This research should include magnetic resonance imaging of intervertebral discs to assess disc health preceding and following human spinal flexion protocols of varying loads, repetitions, tempos, and ranges of motion. Hopefully this paper will serve to spark new research in this area.

With respect to program design, basic core strength and endurance will be realized through performance of most non-machine based exercises such as squats, rows, deadlifts, and push-ups. That said, targeted core exercises may serve to enhance sports performance, functional capacity, and physique aesthetics. Consistent with the principle of specificity, core program design should take into account the individual goals and abilities of the exerciser with respect to their need for muscular hypertrophy, power, strength, and/or endurance, and the types of joint actions involved in their sport. A variety of abdominal exercises are necessary to sufficiently work the abdominal musculature and these exercises will differ based on training objectives (13). Variety in spinal loading is associated with lower risk of spinal pathology (136). A balanced, multi-planar approach to core training that incorporates a combination of isometric and dynamic exercises is warranted to prevent any particular spinal segment from accentuated stress and to ensure proper spine stabilizing biomechanics.

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