ARTICLE

Yoga, Vertebral Fractures, and Osteoporosis: Research and Recommendations

Eva Norlyk Smith, PhD, RYT-500,[1] Anita Boser, LMP, CHP, RYT[2,3]
1. YogaUOnline.com, 2. Vital Self, Inc., 3. Essential Yoga Therapy

Abstract

Background: Osteoporosis is characterized by decreased bone density that leaves bones fragile and highly susceptible to fracture. Globally, 1 in 3 women and 1 in 5 men older than 50 will suffer from an osteoporotic fracture, and those individuals will experience a considerably higher risk of postfracture mortality than will the general population. Gentle, weight-bearing exercises such as yoga can help prevent or cease the progression of osteoporosis; however, there is insufficient data regarding which yoga poses present the least risk and are most beneficial to individuals with reduced bone density. **Objectives:** Review the extant literature about the risks and benefits to the spine of particular forms of movement and consider recommendations relative to the practice of yoga. **Methods:** A review of the PubMed, Medline, and Cochrane databases was conducted that identified manuscripts published between 1966 and 2011 about topics related to osteoporosis and spinal movement. **Conclusions:** Movements involving spinal flexion can increase risk for vertebral compression fractures; however, a combination of mild spinal flexion and extension may prove beneficial. Moderate, weight-bearing activities that strengthen the muscles supporting the spinal column, promote balance, improve posture, and enhance quality of life appear to be of greatest benefit. Ample evidence supports the importance of varied spinal movement for preserving the health and strength of the vertebral bodies. Exercise modifications suitable for high-risk individuals may be counterproductive for those at low risk for vertebral fractures. Yoga therapists are cautioned to not apply a one-size-fits-all approach when working with this population. Well-designed empirical studies are needed to further our understanding of which yoga poses present the least risk and are of greatest benefit to individuals with osteoporosis.

Key Words: yoga, osteoporosis, yoga therapy, vertebral fractures, safe movements for the spine, yoga and osteoporosis

Corresponding author: Eva Norlyk Smith, PhD,
evanorlyksmith@gmail.com

Osteoporosis is characterized by excessive loss of bone protein and mineral content, particularly calcium, that leads to decrements in bone mass and strength. As bones weaken they become fragile, brittle, and highly susceptible to fracture. In the case of severe osteoporosis, the event precipitating a fracture is often unknown (National Osteoporosis Foundation, 2008).

Osteoporosis represents a considerable public health problem, with 44 million people in the United States being at risk for developing the disease. Globally, 1 in 3 women and 1 in 5 men older than age 50 will eventually experience an osteoporotic fracture. The risk of fracture increases with age, with 3 of 4 fractures of the hip, spine, or wrist occurring in people age 65 and older (International Osteoporosis Foundation). In the United States, 50% of the 1.35 million fractures reported annually are vertebral compression fractures (Longo, Loppini, Denaro, Maffulli, & Denaro, 2011). Osteoporotic fractures of the hip and spine have been linked to higher mortality rates, but it remains unclear whether this is an independent effect or a function of comorbid illness and poor health status commonly found in elderly persons with osteoporosis (Teng, Curtis, & Saag, 2008).

Osteoporotic fractures of the hip and wrist are most commonly precipitated by trauma, such as a fall (Nguyen, Pongchaiyakul, Center, Eisman, & Nguyen, 2005). In contrast, the vertebral bodies of individuals with osteoporosis are very fragile, such that even a nontraumatic event, such as a sneeze, can result in a vertebral compression or wedge fracture. The risk of fracture is even greater for those who have incurred previous vertebral fractures (Briggs, Greig, & Wark, 2007).

Gentle, weight-bearing exercise can help prevent or cease the progression of osteoporosis (Sinaki, Fitzpatrick, Ritchie, Montesano, & Wahner, 1998). Weight-bearing and strength-building activities stimulate new bone growth and help improve posture, balance, and range of motion. There is considerable controversy as to which exercises are beneficial and which constitute a risk for injury, however. Individuals with osteoporosis are often instructed to avoid flexion or twisting of the spine during exercise, and even in activities of daily living. Because spinal flexion and twisting commonly occur in yoga classes, there is a pressing need for yoga therapists and yoga teachers to understand which types of movements are safe for people with osteoporosis and osteopenia and to communicate this knowledge to their students.

The goals of this literature review were to (a) review the literature about the risks and benefits to the spine of particular forms of movement, (b) examine the importance of spinal movement for health, and (c) present an overview of recommendations for exercises targeting spinal movement for individuals with osteoporosis and osteopenia.

Literature Review

Spinal Movement, Posture, and Risk for Vertebral Fracture

We used the PubMed, Medline, and Cochrane databases to conduct a comprehensive search for pertinent manuscripts published between 1966 and 2011. Publications in which various combinations of the key words *osteoporosis, vertebral compression fractures, axial rotation, flexion, twisting, torque, extension, back extensors, vertebral loading, trabecular bone,* *exercise,* and *rehabilitation* were considered. All relevant articles were examined and their bibliographies were searched for additional references.

This investigation revealed that the majority of osteoporosis research has focused on drug interventions intended to reverse or prevent the loss of bone mass. Surgical interventions, such as kyphoplasty and verteplasty, which are often used to treat pain resulting from vertebral compression fractures, have also been widely studied. In addition, the role of exercise relative to building bone mass or preventing bone loss has received attention.

Relative to the overall literature, very little research has been conducted to examine the effectiveness of physical rehabilitation measures designed specifically to prevent spinal fractures for individuals with osteoporosis. The majority of proposed exercise strategies have been designed to elicit a sufficient weight-bearing load on the bones to stimulate growth without creating excessive strain or risk for fracture (Sinaki, 2007). Although physical activity is recognized as central to maintaining musculoskeletal health, strong bones, and balance among those with osteoporosis, a great deal remains to be learned about which types of spinal movement constitute a risk for fracture and which provide the greatest benefit (Pratelli, Cinotti, & Pasquetti, 2010).

In this review of the literature we report what is known regarding the safety of various types of spinal movements (i.e., flexion, extension, axial rotation, lateral side bending) for individuals with osteoporosis.

Spinal flexion. Before the mid-1980s, spinal flexion exercises were often recommended to alleviate back pain related to vertebral fractures (Sinaki, 2007). Flexion of the spine was thought to be useful to relieve contractions of the paraspinal muscles that surround the vertebral bodies. This belief was challenged by a study that demonstrated that flexion exercises (e.g., forward bending with a rounded spine, abdominal crunches from a supine position) were associated with an increased incidence of vertebral fractures (Sinaki & Mikkelsen, 1984). In the study, 59 women age 49 to 60 years with osteoporosis of the spine and back pain were divided into four groups. The first group performed spinal extension exercises, the second engaged in spinal flexion exercises, the third conducted a combination of spinal extension and flexion exercises, and the fourth was a no-exercise group who received heat and massage. Comparison of pre- and postexercise radiographs revealed a statistically significant between-groups difference in the number of spinal fractures. In the flexion-only group, 89% of participants incurred new fractures, compared with 67% of participants in the no-exercise group, 53% in the combined extension and flexion group, and 16% in the extension-only group (Sinaki & Mikkelsen, 1984). These findings suggest that an exercise regimen characterized exclusively by flexion exercises increases the risk for development of spinal fractures for women with osteoporosis.

The morphology of vertebrae helps explain this finding. Spinal flexion increases anterior vertebral compression; studies have shown that the anterior structure of a vertebra is weak relative to the overall vertebral body, making it vulnerable to compression fractures (Papadakis, Sapkas, Papadopoulos, & Katonis, 2011). Spinal flexion also leads to increased pressure in the vertebral discs, which can be translated to the anterior portion of the vertebral bodies, thus increasing the risk of wedging and fracture in people with osteoporosis (Sinaki, 2007). These biomechanical properties of the vertebrae may cause movements that involve spinal flexion to increase the risk of vertebral fractures (Duan, Seeman, & Turner, 2001).

There is some evidence that older adults with reduced bone density may be vulnerable to spinal fracture during yoga poses that involve spinal flexion. In a recent case study, 3 healthy individuals age 61, 70, and 87 with reduced bone mass who reported yoga-induced pain or vertebral compression fractures were assessed. All practiced *Halasana* (plow pose), during which the weight of the lower extremities and pelvis was distributed toward a flexed thoracic spine and neck. The author concluded that reduced bone mineral density could account for less than 50% of fracture risk, with the remaining risk being associated with posture, degenerative changes of the spine, torque of the spine, muscle weakness, and falls (Sinaki, 2012).

Spinal extension. Spine extensor muscle strength is important for retaining healthy posture and normal spinal curves (Sinaki, Itoi, Rogers, Bergstralh, & Wahner, 1996). Strong back extensor muscles provide extrinsic support for the spine, and there is evidence that strengthening the back extensors may decrease the long-term risk of vertebral fractures (Sinaki et al., 2002). Excessive thoracic kyphosis may also be linked to weakening of spinal extensor muscles (Mika, Unnithan, & Mika, 2005). Several studies provide evidence that strengthening the spinal extensor muscles is associated with decreased thoracic kyphosis, which can be an independent risk factor for fractures (Itoi & Sinaki, 1994; Sinaki et al., 2002).

Spinal extensor muscles tend to be compromised in women with osteoporosis, suggesting that weakness of back extensors may precede and/or contribute to compression fractures of the spine (Sinaki, Khosla, Limburg, Rogers, & Murtaugh, 1993). Strong spinal extensor muscles have been shown to be a significant contributor to spinal range of motion (Miyakoshi et al., 2005). Low-intensity, back-strengthening exercises are associated with reported quality of life improvement for people with osteoporosis (Hongo et al., 2005), with higher quality of life being related to stronger spinal extensor muscles and inceased range of motion.

Most important, strengthening the back extensors may provide long-term protection against vertebral fractures, independent of bone mineral density. Sinaki et al. (2002) examined the effects of a back-strengthening program on bone mineral density for a group of healthy, Caucasian, postmenopausal women. Although no significant differences in bone mineral density were detected for those who exercised and those who did not during the initial 2-year study, data obtained during an 8-year follow-up, when the women were between ages 58 and 75, revealed that those in the back-strengthening group had fewer fractures than did those in the control group (Sinaki, 2007). At the 8-year mark, individuals in the no-exercise control group evidenced 3 times the rate of vertebral compression fractures than did those in the exercise group. As a result, investigators posited that bone mineral density might not be the only predictor of vertebral fractures, and that the strength of the muscles supporting the spine may be another significant contributing factor.

Rotation and lateral side bending. Very little data exist about specific types of exercise that might be most beneficial for individuals with compromised bone density (Pratelli et al., 2010). This lack of empirical evidence is most pronounced with regard to effects and safety of axial rotation and lateral flexion of the spine.

Studies designed to assess the effects of axial rotation on intervertebral discs have linked axial rotation to an increased risk of low back strain or intervertebral disc injury, particularly when combined with flexion and weight bearing, for example while bending over and lifting combined with spinal rotation (Kumar, 2004; Kumar & Narayan, 2006).

Professionals in the yoga or fitness community who work with individuals with osteoporosis often strongly advise against axial rotation, even to the point of avoiding it in daily activities (Hathaway, 2012; Meeks, 2012). However, although axial rotation has been shown to increase the risk of low back strain or intervertebral disc injury, there is no empirical evidence of a link between axial rotation performed during exercise and the risk for vertebral fractures. Tangentially, one case study found a potential link between the sudden twist of a golf swing and fracture risk (Ekin & Sinaki, 1993), but the biomechanics of golfing are vastly different than those used in yoga or other exercises involving axial rotation.

Researchers conducting an ongoing study of the effects of yoga practice for individuals with osteoporosis are examining weight-bearing yoga postures that involve axial rotation. The sample includes more than 500 registered participants with more than 30,000 cumulative practice hours. To date, no vertebral fractures resulting from the yoga practice have been reported (Fishman, 2012).

Postural alignment as an independent risk factor for spinal fracture. It is important to examine the safety of spinal movements relative to postural alignment. Postural misalignment can independently exacerbate spinal flexion and increase the risk for vertebral compression fractures (Keller, Harrison, Colloca, Harrison, & Janik, 2003).

Many individuals with osteoporosis exhibit increased thoracic kyphosis, or hyperkyphosis. This pronounced flexion of the thoracic spine increases the vertebral compression load and the risk for compression fractures (Pfeifer et al., 2004). As the degree of kyphosis increases, the compressive stress on the anterior portion of the vertebrae is magnified. Kyphosis of 41.7 degrees is associated with a 19% increase in compressive force and a 40% increase in spinal extensor force at T7/T8 (Papadakis et al., 2011). Hyperkyphosis was previously thought to be caused by osteoporotic vertebral fractures; however, it is also prevalent in people without vertebral fractures, and the condition is also frequently associated with degenerative disc disease and muscle weakness (Schneider, von Muhlen, Barrett-Connor, & Sartoris, 2004).

Hyperkyphosis is an independent risk factor for vertebral and hip fractures, particularly for elderly women (Katzman, Wanek, Shepherd, & Sellmeyer, 2010). It is also associated with reduced breath capacity and increased mortality. There is good evidence that hyperkyphosis and activities involving spinal flexion are associated with an increased risk for vertebral fractures, irrespective of bone loss (Campbell, Robertson, Gardner, Norton, & Buchner, 1999). In individuals with hyperkyphosis, exercises involving flexion are likely to further intensify the anterior compression of thoracic vertebrae, yielding an elevated risk for fractures. As such, postural forces can predispose an individual to vertebral fractures when the anterior translation of the upper part of the spine increases the compressive load.

Movement and Spine Health

There is general consensus that frequent, gentle to moderate weight-bearing activity offers the greatest benefit to individuals with bone loss (Chan, Anderson, & Lau, 2003). Some have recommended gentle spinal rotation as an important contributor to spine health (Fishman & Saltonstall, 2012). The literature reviewed in the following sections provides evidence that varied movements of the spine are critical to maintaining overall spine health and to reducing vertebral fractures.

Activity, bone loss, and regeneration. Bones conform to the environmental conditions placed upon them. Osteoblasts lay down new bone material, and osteoclasts reabsorb unhealthy tissue (Turner, 1999; Turner & Pavalko, 1998). Bone strength is linked to bone mass and to the internal structure of trabecular bone. Trabecular bone constitutes the major portion of the bone and is the inner part that surrounds marrow spaces (Kreider & Goldstein, 2009). The structure of trabecular bone is influenced by mechanical stress and is sensitive to the nature and quality of the forces placed upon it (Barak, Lieberman, & Hublin, 2011). It is quite porous, not as strong as cortical bone, and more susceptible to the effects of osteoporosis.

Osteogenic loading refers to the use of impact force to stimulate the development of bone tissue and muscle fiber. It is highly site specific. In one study of the effects of osteogenic loading, participants performed weight-lifting exercises on one side of the body. An increase of 3% to 4% in bone mass of the wrist and hip was found on the weight-lifting side after 12 months, compared with the no-exercise side (Kerr, Morton, Dick, & Prince, 1996). Site-specific effects of osteogenic loading on the spine have also been found. Increased lumbar trabecular bone mineral density was detected for individuals participating in a 1-year training program for the psoas muscles, compared with those performing exercises that targeted the deltoids only (Revel, Mayoux-Benhamou, Rabourdin, Bagheri, & Roux, 1993). These results suggest that exercises intended to strengthen muscles that support the spine may be useful to prevent or ameliorate the effects of vertebral bone loss.

Wolff's Law posits that the internal structure of bone adapts commensurate with the form and function of each of the stressors placed upon it (Frost, 1994). There is evidence that bone is anisotropic, meaning that its physical strength varies along different axes. Increased physical activity places a mechanical load on bones, which stimulates bone tissue formation. Conversely, inactivity is associated with bone loss (Frost

1997; Takata & Yasui, 2001). The microarchitecture of the trabecular bone within the vertebrae is constantly remodeling based on the demands placed upon it. This remodeling enables bones to optimally withstand loads associated with habitual use (Homminga et al., 2004).

According to the Utah Paradigm of Skeletal Physiology (Jee, 2000), inactivity leads to reduced bone mass and bone strength. In the absence of sufficient use, bone remodeling turns off and disuse-mode remodeling turns on (Frost, 1997). Immobility has been linked to local bone loss (Alexandre & Vico, 2011; Saltzstein, Hardin, & Hastings, 1992), which is evidenced dramatically in astronauts, for example, who demonstrate bone loss during long-duration spaceflights. The majority of astronaut bone loss occurs in heavy load-bearing areas, such as the hip and spine, which are exposed to the greatest mechanical stress under the earth's gravity (Lang et al., 2004; Zhao et al., 2010).

Muscle strength is also a protective factor against fracture, with muscle contraction relieving some of the strain of overloading, thus protecting bone from fracture (Burr, 2011). Studies have found site-specific positive exercise effects in bone mass density from weighted exercise (Zehnacker & Bemis-Dougherty, 2007), suggesting that weak or atrophied muscles around the spine might leave the vertebrae more vulnerable. Similarly, low-back extensor strength has been shown to have an inverse relationship with high bone mass density (Briggs, Greig, Wark, Fazzalari, & Bennell, 2004). A German study of 237 postmenopausal women with osteoporosis found significant associations between trunk muscle strength and reductions in the Spine Deformity Index, which is a measure of the number and severity of vertebral fractures (Pfeifer et al., 2001).

In short, there is considerable evidence that load-bearing activities are essential for bone and spine health. Inactivity and limited spinal movement are likely to weaken the internal trabecular structure of the vertebrae and result in greater risk for vertebral fractures. Immobility has been linked to localized bone loss, and lack of trunk muscle strength has been linked to an increased number of vertebral fractures.

The site-specific nature of bone regeneration, along with the anisotropic properties of the vertebrae, suggest that limiting the normal repertoire of spinal movement might weaken the capacity of vertebrae to withstand movement and make them more susceptible to fracture.

Movement and intervertebral disc health. Preserving the health of the intervertebral discs is critical to avoiding common age-related impairments (Buckwalter, 1995). The loss of integrity of the intervertebral discs can potentially contribute to vertebral fracture risk by causing abnormal load distributions in adjoining vertebrae (Briggs et al., 2004).

As with the bony vertebrae, the intervertebral discs require motion for optimal health. These discs are the largest avascular structures in the body, meaning that nutrients and waste products are exchanged through diffusion from the vertebrae rather than blood exchange (An, Masuda, & Inoue, 2006). This process is facilitated during sitting or standing load-bearing activities, during which fluid and molecules are transferred from the discs into the vertebrae. Fluid and molecules flow back into the discs in supine positions. Changes in pressure that occur between lying down, standing up, and sitting create a dynamic exchange between the vertebral discs and vertebrae.

Discs require varied movement and dynamic loading of the spine for optimal health. There is evidence that vertebral loading that occurs during activity may improve disc metabolism (Chan, Ferguson, & Gantebein-Ritter, 2011). Although in vivo measurement of disc pressure is difficult, preliminary experiments indicate that muscle activity increases disc pressure, and that frequently changing bodily positions promotes the flow of fluids to and from discs. In the absence of sufficient pressure or movement, the nucleus pulposus, or center of the vertebral disc, loses valuable proteins (Chan et al., 2011). As with bones, intervertebral discs benefit the most from dynamic, moderate, weight-bearing exercise.

Trunk flexibility. Most fractures are the result of falls (Bell, Talbot-Stern, & Hennessy, 2000). There is a higher correlation between falls and fractures than between low bone density and fractures, suggesting that the relationship between osteoporosis and fractures is complex (Jarvinen, Sievanen, Khan, Heinonen, & Kannus, 2008). Stiffness of the trunk is associated with reduced postural control, reduced balance, and increased risk for falls (Reeves, Everding, Cholewicki, & Morrisette, 2006). In addition, the combined inflexibility of hip and trunk muscles is related to loss of balance (Gruneberg, Bloem, Honegger, & Allum, 2004).

One factor influencing loss of trunk mobility is lack of movement, suggesting that activities that benefit hip and trunk flexibility may improve postural control and balance.

Summary

Spinal mobility is a significant factor in maintaining the health of the spine's components, including the vertebrae, muscles, discs, and joints. Spinal articulation is central to reducing the risk of fractures, and movement of the spine is necessary for keeping the trunk muscles strong and flexible to maintain balance and diminish the risk of falls. Movement of the spine is also important for maintaining functional health, range of motion, and the ability to perform activities of daily living.

Recommendations for Spinal Movements in Current Therapeutic Practice

The Canadian Medical Association's clinical practice guidelines for people with osteoporosis include resistance training and/or weight-bearing aerobic exercises, movement to enhance core stability to counteract the effects of postural abnormalities or weakness, and exercises that focus on balance control or balance and gait training (Papaioannou et al., 2010). These recommendations were based partly on a study of physiotherapist-supervised group exercises that included regular stretching of the hip flexors, hip extensors, lumbar extensors, and the vertebral column, along with strength, posture, and balance exercises (Angin & Erden, 2009). In this study, 43.8% of the women who had osteoporosis-level bone density at the beginning of the program had increased bone density to osteopenia levels by the end of the 21-week program. Although exercise must be modified for those with osteoporosis, results of this study suggest clear benefits of regular movements that emphasize spinal strength, flexibility, posture, and balance.

On the basis of the literature reviewed, we recommend specific approaches to exercises and modifications for individuals with osteopenia or osteoporosis. They are described in the following paragraphs.

There is sufficient evidence to support the contention that yoga teachers and therapists must exercise caution when working with individuals with reduced bone density. Movements emphasizing flexion of the thoracic spine are contraindicated for people with osteoporosis (Chan et al., 2003; Papaioannou et al., 2010; Sinaki, 2012; Sinaki & Mikkelsen, 1984). This is particularly the case for individuals with hyperkyphosis.

Although there are risk factors associated with spinal flexion in standing or seated forward-bending yoga poses, the risk can be minimized if flexion occurs at the hip joint with the spine kept straight. One yoga intervention designed for individuals with osteoporosis and osteopenia provides excellent examples of modified postures in which flexion occurs at the hip rather than the spine, reducing the potential for vertebral compression fractures (Fishman & Saltonstall, 2012). Because many individuals do not have the body awareness needed to distinguish between forward flexion from the hip versus from the spine, great care should also be taken to first teach awareness of the difference between these two movements when working with at-risk individuals.

It is important to consider that individuals with a severe hyperkyphotic posture are in permanent spinal flexion. Instructions to bend forward from the hip instead of the spine will not afford the necessary protection for these individuals. At the same time, postures using hip flexion that stretch the hamstrings are an important component of preventing hyperkyphosis and other postural imbalances, because tight hip extensors distort the alignment of the pelvis, which often results in a compensatory increase in kyphosis (Benedetti, Berti, Presti, Frizziero, & Giannini, 2008). The focus should be on supine poses involving hip flexion, which can better isolate hip flexors (Shipp, 2012).

Exercise programs that combine spinal flexion and extension have been shown to be beneficial to individuals with osteoporosis (Sinaki & Mikkelsen,1984). This suggests that the relationship between movement involving spinal flexion and fracture risk is complex, and that more research is needed to fully understand the unique and conjunct risks and benefits of these movements. The literature suggests that people with osteoporosis can benefit from strengthening spinal extensor muscles, which may also prevent hyperkyphosis and its concomitant risk of vertebral compression fractures. Gentle prone or standing yoga postures involving spinal extension can offer a beneficial weight-bearing challenge for individuals with osteoporosis and hyperkyphosis.

The literature does not provide sufficient or conclusive evidence regarding the risks and benefits of spinal movement involving rotation relative to the risk of vertebral fracture for individuals with osteoporosis or osteopenia. This suggests that the most prudent approach for yoga teachers, therapists, and practitioners is to exercise a considerable degree of caution. Concurrently, it is important to consider extant findings that inactivity and lack of movement of the spine can contribute to the risk of fracture vis-a-vis muscle weakness, lack of spinal mobility, and compromised balance. The absence of loading of the spine in certain directions may further weaken the internal structure of the vertebral bodies and compromise their strength. As such, varied spinal movement appears to be essential for spine health and maintenance of the vertebral strength.

Based on this understanding, it is important to consider that some form of spinal movement is needed to retain vertebral strength, trunk flexibility, spinal range of motion, and the strength of the muscles supporting the vertebrae. People with lower degrees of fracture risk may be adversely served by recommendations to avoid movement of the spine (including axial rotation) that are a part of of daily living (Shipp, 2012).

Conclusions

Shipp (2012) suggests the following criteria to identify individuals with higher risk of vertebral fractures. First, individuals with osteoporosis who have lost more than 1.5 inches in height are likely to have prevalent vertebral fractures, which in turn will put them at much greater risk for subsequent fractures. Second, as noted earlier, those with marked hyperkyphosis who are unable to perform flexion poses with a straight spine should be considered at high risk for vertebral fractures. Supine, non-weight-bearing movements of the spine are the best course of action for these individuals.

There is no one-size-fits-all approach when working with individuals with osteopenia or osteoporosis. Individuals with low risk for spinal fractures, such as those with osteopenia or without a history of vertebral fractures, might be ill served by eliminating yoga postures necessary to maintain the health and strength of the vertebral bodies. At the same time, extreme care should be taken when working with individuals who are at high risk for fractures.

Although preliminary studies have shown yoga to improve balance for older adults (Schmid, van Puymbroeck, & Koceja, 2010) and for postmenopausal women with osteoporosis (Tuzun, Aktas, Akarirmak, Sipahi, & Tuzun, 2010), well-designed empirical studies are needed to further our understanding of which yoga poses present the least risk and are of greatest benefit to individuals with osteopenia and osteoporosis. In lieu of these data, moderate weight-bearing activities that strengthen the muscles supporting the spinal column, that improve posture, promote balance, and enhance quality of life are likely to be of greatest benefit.

References

Alexander, C. J. (2003). Utilization of joint movement range in arboreal primates compared with human subjects: An evolutionary frame for primary osteoarthritis. *Annals of the Rheumatic Diseases*, *53*(11), 720–750.

Alexandre, C., & Vico, L. (2011). Pathophysiology of bone loss in disuse osteoporosis. *Joint Bone Spine*, *78*(6), 572–576.

An, H., Masuda, K., & Inoue, N. (2006). Intervertebral disc degeneration: Biological and biomechanical factors. *Journal of Orthopaedic Science*, *11*(5), 541–552.

Angin, E., & Erden, Z. (2009). The effect of group exercise on post-menopausal osteoporosis and osteopenia. *Acta Orthopaedica et Traumatologica Turcica*, *43*(4), 343–350.

Barak, M. M., Lieberman, D. E., & Hublin, J. (2011). A Wolff in sheep's clothing: Trabecular bone adaptation in response to changes in joint loading orientation. *Bone*, *49*(6), 1141–1151.

Bell, A. J., Talbot-Stern, J. K., & Hennessy, A. (2000). Characteristics and outcomes of older patients presenting to the emergency department after a fall: A retrospective analysis. *Medical Journal of Australia*, *173*(4), 176–177.

Benedetti, M. G., Berti, L., Presti, C., Frizziero, A., & Giannini, S. (2008). Effects of an adapted physical activity program in a group of elderly subjects with flexed posture: Clinical and instrumental assessment. *Journal of Neuroengineering and Rehabilitation*, *25*(5), 32.

Briggs, A. M., Greig, A. M., & Wark, J. D. (2007). The vertebral fracture cascade in osteoporosis: A review of aetiopathogenesis. *Osteoporos International*, *18*(5), 575–584.

Briggs, A. M., Greig, A. M., Wark, J. D., Fazzalari, N. L., & Bennell, K. L. (2004). A review of anatomical and mechanical factors affecting vertebral body integrity. *International Journal of Medical Science*, *1*(3), 170–180.

Buckwalter, J. A. (1995). Aging and degeneration of the human vertebral disc. *Spine*, *20*(11), 1307–1314.

Burr, D. B. (2011). Why bones bend but don't break. *Journal of Musculoskeletal and Neuronal Interactions*, *11*(4), 270–285.

Campbell, A. J., Robertson, M. C., Gardner, M. M., Norton, R. N., & Buchner, D. M. (1999). Falls prevention over 2 years: A randomized controlled trial in women 80 years and older. *Age and Ageing*, *28*(6), 513–518.

Chan, M. C., Anderson, M., & Lau, E. M. C. (2003). Exercise interventions: Defusing the world's osteoporosis time bomb. *Bulletin of the World Health Organization*, *81*(11), 827–830.

Chan, S. C., Ferguson, S. J., & Gantebein-Ritter, B. (2011). The effects of dynamic loading on the intervertebral disc. *European Spine Journal*, *20*(11), 1796–812.

Duan, Y., Seeman, E., & Turner, C. H. (2001). The biomechanical basis of vertebral body fragility in men and women. *Journal of Bone and Mineral Research*, *16*(12), 2276–2283.

Ekin, J. A., & Sinaki, M. (1993). Vertebral compression fractures sustained during golfing: Report of three cases. *Mayo Clinic Proceedings*, *68*(6), 566–570.

Fishman, L. (2012). (personal communication).

Fishman, L., & Saltonstall, E. (2012). Yoga for Osteoporosis-Teaching and Practice. Online course. YogaUOnline.com

Frost, H. M. (1994). Wolff's Law and bone's structural adaptations to mechanical usage: An overview for clinicians. *The Angle Orthodontist*, *64*(3), 175–88.

Frost, H. M. (1997). On our age-related bone loss: Insights from a new paradigm. *Journal of Bone and Mineral Research*, *12*(10), 1539–1546.

Gruneberg, C., Bloem, B. R., Honegger, F., & Allum, J. H. (2004). The influence of artificially increased hip and trunk stiffness on balance control in man. *Experimental Brain Research*, *157*(4), 472–485.

Hathaway, S. (December 18, 2011) personal communication.

Homminga, J., Van-Rietbergen, B., Lochmuller, E. M., Weinans, H., Eckstein F., . . . Huiskes, R. (2004). The osteoporotic vertebral structure is well adapted to the loads of daily life, but not to infrequent "error" loads. *Bone*, *34*(3), 510–516.

Hongo, M., Itoi, E., Sinaki, M., Shimada, Y., Miyakoshi, N., & Okada, K. (2005). Effects of reducing resistance, repetitions, and frequency of back-strengthening exercise in healthy young women: A pilot study. *Archives of Physical Medicine and Rehabilitation*, *86*(7), 1299–1303.

International Osteoporosis Foundation. *Exercise recommendations*. Retrieved from http://www.iofbonehealth.org/health-professionals/special-topics/exercise-recommendations.htmlexercise:

Itoi, E., & Sinaki, M. (1994). Effect of back-strengthening exercise on posture in healthy women 49 to 65 years of age. *Mayo Clinic Proceedings*, *69*(11), 1054–1059.

Jarvinen, T. L., Sievanen, H., Khan, K. M., Heinonen, A., & Kannus, P. (2008). Shifting the focus in fracture prevention from osteoporosis to falls. *British Medical Journal*, *336*(7636), 124–126.

Jee, W. S. (2000). Principles in bone physiology. *Journal of Musculoskeletal and Neuronal Interactions, 1,* 11–13.

Katzman, W. B., Wanek, L., Shepherd, J. A., & Sellmeyer, D. E. (2010). Age-related hyperkyphosis: Its causes, consequences, and management. *Journal of Orthopaedic & Sports Physical Therapy*, *40*(6), 352–360.

Keller, T. S., Harrison, D. E., Colloca, C. J., Harrison, D. D., & Janik, T. J. (2003). Prediction of osteoporotic spinal deformity. *Spine*, *28*(5), 455–462.

Kerr, D., Morton, A., Dick, I., & Prince, R. (1996). Exercise effects on bone mass in postmenopausal women are site-specific and load-dependent. *Journal of Bone and Mineral Research*, *11*(2), 218–225.

Kreider, J. M., & Goldstein, S. A. (2009). Trabecular bone mechanical properties in patients with fragility fractures. *Clinical Orthopaedics and Related Research*, *467*(8), 1955–1963.

Kumar, S. (2004). Ergonomics and biology of spinal rotation. *Ergonomics*, *47*(4), 370–415.

Kumar, S., & Narayan, Y. (2006). Torque and EMG in rotation extension of the torso from pre-rotated and flexed postures. *Clinical Biomechanics*, *21*(9), 920–931.

Lang, T., LeBlanc, A., Evans, H., Lu, Y., Genant, H., & Yu. A. (2004). Cortical and trabecular bone mineral loss from the spine and hip in long-duration spaceflight. *Journal of Bone and Mineral Research*, *19*(6), 1006–1012.

Longo, U. G., Loppini, M., Denaro, L., Maffulli, N., & Denaro, V. (2011). Osteoporotic vertebral fractures: Current concepts of conservative care. *British Medical Bulletin*, *102*, 171–189.

Meeks, S. (December 16, 2011). Personal communication.

Mika, A., Unnithan, V. B., & Mika, P. (2005). Differences in thoracic kyphosis and in back muscle strength in women with bone loss due to osteoporosis. *Spine*, *30*(2), 241–246.

Miyakoshi, N., Hongo, M., Maekawa, S., Ishikawa, Y., Shimada, Y., Okada, K., & Itoi, E. (2005). Factors related to spinal mobility in patients with postmenopausal osteoporosis. *Osteoporosis International*, *16*(12), 1871–1874.

National Osteoporosis Foundation. (2008). *Osteoporosis: Is it safe for me to do yoga?* Retrieved from http://www.nof.org/faq.

Nguyen, N. D., Pongchaiyakul, C., Center, J. R., Eisman, J. A., & Nguyen, T.V. (2005). Identification of high-risk individuals for hip fracture: A 14-year prospective study. *Journal of Bone and Mineral Research*, *20*(11), 1921–1928.

Papadakis, M., Sapkas, G., Papadopoulos, E. C., & Katonis, P. (2011). Pathophysiology and biomechanics of the aging spine. *The Open Orthopaedics Journal*, *5*, 335–342.

Papaioannou, A., Morin, S., Cheung, A., Atkinson, S., Brown, J. P., Feldman, S., . . . Leslie, W. D. (2010). 2010 clinical practice guidelines for the diagnosis and management of osteoporosis in Canada: Summary. *Canadian Medical Association Journal*, *182*(17), 1864–1873.

Pfeifer, M., Begerow, B., Minne, H. W., Schlotthauer, T., Pospeschill, M., Scholz, M., Lazarescu, A. D., & Pollahne, W. (2001). Vitamin D status, trunk muscle strength, body sway, falls, and fractures among 237 post-menopausal women with osteoporosis. *Experimental and Clinical Endocrinology & Diabetes*, *109*(2), 87–92.

Pfeifer, M., Sinaki, M., Geusens, P., Boonen, S., Preisinger, E., & Minne, H. W. (2004). Musculoskeletal rehabilitation in osteoporosis: A review. *Journal of Bone and Mineral Research*, *19*(8), 1208–1214.

Pratelli, E., Cinotti, I., & Pasquetti, P. (2010). Rehabilitation in osteoporotic vertebral fractures. *Clinical Cases in Mineral and Bone Metabolism*, *7*(1), 45–47.

Reeves, N. P., Everding, V. Q., Cholewicki, J., & Morrisette, D. C. (2006). The effects of trunk stiffness on postural control during unstable seated balance. *Experimental Brain Research*, *174*(4), 694–700.

Revel, M., Mayoux-Benhamou, M. A., Rabourdin, J. P., Bagheri, F., & Roux, C. (1993). One-year psoas training can prevent lumbar bone loss in postmenopausal women: A randomized controlled trial. *Calcified Tissue International*, *53*(5), 307–311.

Saltzstein, R. J., Hardin, S., & Hastings, J. (1992). Osteoporosis in spinal cord injury: Using an index of mobility and its relationship to bone density. *The Journal of the American Paraplegia Society*, *15*(4), 232–234.

Schmid, A. A., van Puymbroeck, M., & Koceja, D. M. (2010). Effects of a 12-week yoga intervention on fear of falling and balance in older adults: A pilot study. *Archives of Physical Medicine and Rehabilitation*, *91*(4), 576–583.

Schneider, D. L., von Muhlen, M. D., Barrett-Connor, E., & Sartoris, D. J. (2004). Kyphosis does not equal vertebral fractures: The Rancho Bernardo study. *The Journal of Rheumatology*, *31*(4), 747–752.

Shipp, K. (2012). Interview by E. Norlyk Smith [Tape recording] arranged by the National Osteoporosis Foundation.

Sinaki, M. (2007). The role of physical activity in bone health: A new hypothesis to reduce risk of vertebral fracture. *Physical Medicine and Rehabilation Clinics of North America*, *18*(3), 593–608.

Sinaki, M. (2012). Yoga spinal flexion positions and vertebral compression fracture in osteopenia or osteoporosis of spine: Case series. *Pain Practice*, *13*(1), 68–75.

Sinaki, M., Fitzpatrick, L. A., Ritchie, C. K., Montesano, A., & Wahner, H. W. (1998). Site-specificity of bone mineral density and muscle strength in women: Job-related physical activity. *American Journal of Physical Medicine and Rehabilitation*, *77*(6), 470–476.

Sinaki, M., Itoi, E., Rogers, J. W., Bergstralh, E. J., & Wahner, H. W. (1996). Correlation of back extensor strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. *American Journal of Physical Medicine and Rehabilitation*, *75*(5), 370–374.

Si naki, M., Itoi, E., Wahner, H. W., Wollan, P., Gelzcer, R., Mullan, B. P., . . . Hodgson, S. F. (2002). Stronger back muscles reduce the incidence of vertebral fractures: A prospective 10-year follow-up of postmenopausal women. *Bone*, *30*(6), 836–841.

Sinaki, M., Khosla, S., Limburg, P. J., Rogers, J. W., & Murtaugh, P. A. (1993). Muscle strength in osteoporotic versus normal women. *Osteoporosis International, 3*(1), 8–12.

Sinaki, M., & Mikkelsen, B. A. (1984). Postmenopausal spinal osteoporosis: Flexion versus extension exercises. *Archives of Physical Medicine and Rehabilitation*, *65*(10), 593–596.

Takata, S., & Yasui, N. (2001). Disuse osteoporosis. *Journal of Investigative Medicine*, *48*(3-4), 147–156.

Teng, G. G., Curtis, J. R., & Saag, K. G. (2008). Mortality and osteoporotic fractures: Is the link causal and is it modifiable? *Clinical and Experimental Rheumatology*, *26*(S51), 125–137.

Turner, C. H. (1999). Toward a mathematical description of bone biology: The principle of cellular accommodation. *Calcified Tissue International*, *65*(6), 466–471.

Turner, C. H., & Pavalko, F. M. (1998). Mechanotransduction and functional response of the skeleton to physical stress: The mechanisms and mechanics of bone adaptation. *Journal of Orthopaedic Science*, *3*(6), 346–355.

Tuzun, S., Atkas, I., Akarirmak, U., Sipahi, S., & Tuzun, F. (2010). Yoga might be an alternative training for the quality of life and balance in post-menopausal osteoporosis. *European Journal of Physical and Rehabilitation Medicine*, *46*(1), 69–72.

Zehnacker, C. H., & Bemis-Dougherty, A. (2007). Effect of weighted exercises on bone mineral density in post-menopausal women. A systematic review. *Journal of Geriatric Physical Therapy*, *30*(2), 79–88.

Zhao, Q., Li, W., Li, C., Chu, P., Kornak, J., Long, T. F., . . . Lu, Y. (2010). A statistical method (cross-validation) for bone loss region detection after spaceflight. *Australasian Physical and Engineering Sciences in Medicine*, *33*(2), 163–169.