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Age-related hyperkyphosis: update of its potential causes and clinical impacts—narrative review

Tayebeh Roghani[1], **Minoo Khalkhali Zavieh**[1], **Farideh Dehghan Manshadi**[1], **Nicole King**[2], and **Wendy Katzman**[2]

[1]Department of Physiotherapy, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[2]Department of Physical Therapy and Rehabilitation Sciences, University of California, San Francisco, CA, USA

Abstract

The present study aims to qualitatively review the contributing factors and health implications of age-related hyperkyphosis. We conducted a narrative review of observational and cohort studies describing the risk factors and epidemiology of hyperkyphosis from 1955 to 2016 using the following key words: kyphosis, hyperkyphosis, posture, age-related hyperkyphosis, kyphotic posture, aetiology and causes. This review included 77 studies. Approximately 60–70 % of the most severe hyperkyphosis cases have no evidence of underlying vertebral compression fractures. Other proposed factors contributing to hyperkyphosis are degenerative disc disease, weakness of back extensor muscles and genetic predisposition. Strength and endurance of back extensor muscles are very important for maintaining normal postural alignment. Recent evidence suggests that age-related hyperkyphosis is not equivalent to spinal osteoporosis. Due to the negative impact of hyperkyphosis on physical function, quality of life and mortality rates, physicians should focus not only on osteoporosis, but also on age-related postural changes. More research about the relationship between spinal morphology and modifiable factors, especially the structural and functional parameters of trunk muscles, could further illuminate our understanding and treatment options for hyperkyphosis.

Keywords

Ageing; Back muscles; Hyperkyphosis; Osteoporosis; Posture

Introduction

Kyphosis is a normal curvature of the thoracic spine, marked by a small anterior concavity resulting from the shape of vertebral bodies and intervertebral discs. In younger adults, the

Correspondence to: Minoo Khalkhali Zavieh.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed conscent For this type of study formal conscent is not required.

"normal" range falls between 20 and 40° of curvature using the Cobb angle measurement of kyphosis. After the fourth decade of life, the kyphosis angle begins to worsen and increase above 40°, leading to an excessive kyphosis curvature, known as "age-related hyperkyphosis" [1]. The prevalence of hyperkyphosis occurs in 20–40 % of older adults above 60 years old [2]. While thoracic kyphosis impacts both sexes, the condition increases at a higher rate in women, particularly during the menopause years when compared with men [1, 3]. Additionally, there is growing evidence to suggest that women with hyperkyphosis experience higher incidence of functional disorders, poor health conditions and earlier mortality [4]. Thus, due to the complications that can arise in people with age-related hyperkyphosis, it is crucial to provide significant attention to this condition. Age-related hyperkyphosis is currently attributed to underlying osteoporosis and vertebral fractures. However, only one-third of those with severe kyphosis measurements have had radiographic confirmation of vertebral fractures [5]. Unfortunately, this incorrect notion is perpetuated by the lack of sufficient knowledge about the role of non-vertebral factors in hyperkyphosis.

Our objectives are to discuss the terminology, aetiology and health implications of age-related hyperkyphosis. We will examine the various causes of hyperkyphosis and focus on the modifiable factors that affect its manifestation, particularly the role that back extensor muscles play in hyperkyphosis. We will describe the gaps in the knowledge about modifiable risk factors for hyperkyphosis and ideas for future studies.

Search strategy

We conducted a narrative review of observational and cohort studies describing the risk factors and epidemiology of hyperkyphosis that were investigated between 1955 and 2016. The information was collected through a database search of PubMed, Google scholar, Ovid and Science direct using the following key words: kyphosis, hyperkyphosis, posture, age-related hyperkyphosis, kyphotic posture, aetiology and causes. Within this time range, we reviewed available abstracts (8178 for kyphosis, 202 for hyperkyphosis, 158 for kyphotic posture, 14 for age-related hyperkyphosis, aetiology and causes). We excluded overlapping articles between citations, non-English reports, books, hyperkyphosis related to children and adolescents, hyperkyphosis caused by trauma or chronic disease, and other excessive spinal curvatures, like scoliosis and kyphoscoliosis. The articles were classified into three separate categories: definition, complications and causes of age-related hyperkyphosis.

Definition of age-related hyperkyphosis

The degree of curvature in thoracic kyphosis is related to both age and sex factors [1]. Although Cobb angle measurement from lateral spine radiograph is the current gold standard for quantifying thoracic kyphosis [6], several non-invasive, skin-surface methods have been used for clinical measurement including the Debrunner's kyphometer (Fig. 1), Flexicurve (Fig. 2a, b) and Spinal Mouse (Fig. 3). A systematic review reported high to very high levels of reliability of the Flexi-curve index, Debrunner's kyphometer and Spinal Mouse, and validity of the Flexicurve index (Table 1) [7].

In younger individuals, the normal range of kyphosis falls between 20 and 40° of curvature measured by the Cobb angle of kyphosis [2]. Progressive thoracic curvature is a feature of ageing [1]. Bartynski et al. reported a mean kyphotic angle of 26.8° in the younger demographic compared to a larger mean of 41.9° in patients who were 65 years or older [8]. Older individuals may be at greater risk of developing hyperkyphosis due to age-related decrease in muscle mass [9], muscle strength [10], muscle quality [11], bone mineral density [12] and increased fragility of connective tissue [13]. Furthermore, women develop hyperkyphosis earlier than men and have greater degree of kyphosis in general [12, 14]. Women may be at higher risk of greater kyphosis due to more associated factors including poor posture, changes in connective tissue, ligament and muscle tone loss [12], poorer spinal extensor muscle quality [11] and strength [9], lower bone mineral density and more vertebral fractures [15], a lower physical activity level and the weight of hanging breasts [1]. In the Rancho Bernardo cohort of older men (mean age 73 SD = 2.4 years) and women (mean age 74 SD = 2.8 years), men had less kyphosis, approximately 44 (SD = 13) degrees compared to women approximately 49 (SD = 16) [5]. A longitudinal study including 100 healthy men and women at least 50 years or older reported a mean thoracic kyphosis angle rate that increased 3° per decade [16]. In a 15-year retrospective cohort study of older women, kyphosis progressed 2.6° between the baseline and 3-year follow-up and an even greater 7.1° between the baseline and 15-year follow-up measurement [4].

Currently, there is no accepted threshold differentiating hyperkyphosis from the normal kyphotic angle, although greater than 40° of kyphosis, the upper 95 percentile of normal for young adults, is often used to define hyperkyphosis [1]. Further work needs to be conducted with a larger sample of the general population to determine a threshold of kyphosis that predicts adverse health outcomes.

Complications of hyperkyphosis

We investigated the negative effects of hyperkyphotic posture on personal health.

Pulmonary function

Increased thoracic kyphosis creates a mechanical restriction that can limit vital capacity [17]. Oxygen expenditure during walking has been correlated with kyphosis [18]. Older adults, especially women with hyperkyphotic posture, tend to have impaired respiratory function that places them at greater risk of earlier mortality due to pulmonary disorders such as pneumonia and chronic obstructive pulmonary disease [19].

Physical function

It has become generally accepted knowledge that in order to maintain good health, it is important to lead a physically active lifestyle. Chow reported lower physical activity levels among women with greater degree of kyphosis [20]; however, Mika reported that active women had better range of spinal motion but no difference in severity of kyphosis compared to sedentary women [21]. Better spinal motion may allow women the freedom to be physically active in contrast to a less mobile spine that may restrict physical activity. Several studies have reported impaired physical function as the degree of kyphosis increases [18, 22, 23].

Katzman et al. assessed whether kyphosis predicts worsening physical function over time. While multivariate cross-sectional analyses showed greater magnitude of kyphosis associated with lower grip strength, there were no significant findings associated with functional status, gait speed or timed chair stand. In multivariate longitudinal analysis, a greater degree of baseline kyphosis was associated with decline in functional status, gait speed and time to complete chair stand. A greater degree of baseline kyphosis did predict worse lower extremity function over 15 years [24].

Additionally, numerous studies have reported that women with hyperkyphotic posture demonstrated greater difficulty in reaching and performing heavy housework as well as scoring lower on activities of a daily living scale than did their non-hyperkyphotic peers [22, 23, 25].

Falls and fractures

Excessive kyphosis has detrimental effects on erect posture that can lead to impaired balance and an increased risk of falling. In a prospective study, Van der Jagt-Willems et al. [26] reported that older adults with increased thoracic kyphosis were more likely to fall within the next year (self-reported falls were adjudicated by monthly phone contact for the duration of 12 month). Postural alterations that are associated with hyperkyphosis can increase flexion bias around the shoulder and hip joints as well as interfere with normal joint mechanics and movement patterns [3]. Hyperkyphotic posture also causes anterior movement of the centre of gravity [27]. As a result, this imposes an increased postural sway and fall risk. Yet, there is inconsistent evidence available regarding the relationship between kyphosis and balance. Some studies showed that hyperkyphotic posture impairs a person’s balance [27, 28], but others did not find such an effect. One study reported a significant relationship between vertebral fractures and impaired balance, but not between kyphosis and balance [29]. One possible explanation is weakness of the spinal extensor muscles. Since hyperkyphosis has been associated with weakness of the spinal extensor muscles, this could explain the effect on balance. A systematic review reported that spinal muscle weakness, rather than kyphosis, is associated with impaired balance [30]. Another possible reason for impaired balance among those with hyperkyphosis could be fear of falling [17]. Individuals with hyperkyphosis may feel more vulnerable and more likely to be cautious about physical activities that may lead to falls.

While it is also plausible that hyperkyphosis increases risk of fractures in the spine by increasing spinal load during daily bending activities, this has only been demonstrated in biomechanical analysis [31]. Recent study in a cohort of 3018 older women with low bone mineral density reported that kyphosis is not an independent predictor of future fractures [32]. The risk of incident fractures was explained by prevalent vertebral fractures. However, repetitive poor posture and excessive spinal flexion during activities of daily living could cause vertebral fractures, particularly when there has been a past vertebral fracture and or low bone mass, irrespective of the degree of kyphosis. Ongoing research is currently investigating the effects of exercise including spinal muscle strengthening on incident vertebral fractures in older adults with prevalent fractures [33].

Quality of life

Postural changes in sagittal plane alignment can lead to limitations in performing daily activities [23], lung function, physical function, falls and fractures that can negatively impact health-related quality of life. Older women with hyperkyphosis report greater difficulty in performing activities of daily living and outdoor activities [22, 23], greater fears [34], limitation in social life and less satisfaction with life in general [23].

Mortality

Hyperkyphosis itself may be a risk factor for premature death. As the kyphotic angle increases, the mortality rate inflates. Some studies have attributed this increase to pulmonary death [35, 36]. Kado et al. [36] suggested that women with hyperkyphosis and those who have also sustained a vertebral fracture have a greater risk of mortality than women affected by either hyperkyphosis or vertebral fractures alone. Hyperkyphosis could be an indicator of other physical dysfunctions, mobility impairments, falls and fracture risk that increase in the geriatric population and incur increased risk of mortality.

Causes of age-related hyperkyphosis

Currently, the aetiology of hyperkyphosis has not been fully established. However, studies have illuminated several risk factors (Fig. 4). These studies were reviewed in six sections: vertebral factors, degenerative disc disease, decreased mobility, proprioceptive deficits, genetic basis and the role of spinal extensor muscles.

Vertebral factors: bone mineral density, vertebral fractures and age-related hyperkyphosis

When performing daily activities, the repeated load on an osteoporotic vertebral column can progressively affect vertebral wedging and increase the incidence of vertebral compression fractures [37]. The severity of vertebral wedging increases as bone mineral density decreases [12, 38], which can result in an increased number of vertebral compression fractures and excessive thoracic kyphosis. Increased kyphosis has a stronger correlation with the number of thoracic vertebral fractures compared to lumbar vertebral fractures [14].

Several authors reported a relationship between bone mineral density, vertebral fractures and thoracic kyphosis [38, 39]. In comparing kyphosis angle between persons with and without vertebral fractures, those with prior fractures had a higher kyphosis angle measurement [5, 14]. In a 15-year retrospective cohort study, vertebral fracture and bone mineral density loss were both associated with baseline kyphosis as well as a risk factor for worsening progression over time [4]. On the other hand, differing results have also been reported. For example, Balzini et al. investigated the correlation between the severity of flexed posture, vertebral fragility and functional condition in sixty elderly women (aged 70–93). Subjects were categorized into 3 groups of kyphosis according to the distance between the occiput to wall measurement: mild (distance ≤5 cm), moderate (5.1–8 cm) and severe (distance >8 cm). The measurements included the presence and number of any vertebral fractures from spinal radiographs; bone mineral density testing (at the lumbar spine and proximal femur); and muscle strength of the back extensors and abdominals. The severe group had the least amount of back extensor strength, but there was no statistically significant difference in back extensor strength between the mild and moderate groups. Additionally, there was no significant association between the number of vertebral fractures and the severity of flexed posture. These data indicate that deficits in age-related hyperkyphosis may be more dependent on muscular performance than osteoporosis or vertebral fractures [22].

Another study, including a sample of 1407 individuals between the ages of 50–96 years, used the modified Cobb method from lateral thoracolumbar spine radiographs to measure the degree of kyphosis. Within this study, approximately 21 % of men and 22 % of women were affected with one or more thoracic vertebral fracture. The mean Cobb angle in individuals with a vertebral fracture was greater than those without fractures. However, men and women with the most severe Cobb angle had no evidence of osteoporosis or presence of a vertebral fracture, suggesting that hyperkyphosis does not always predict osteoporosis or fracture [5]. In 2005, Mika et al. conducted a study measuring bone mineral density, thoracic kyphosis angle and back extensor strength in women. Participants were 189 women between 50 and 80 years old, categorized into 3 groups based upon bone mineral density and level of back extensor strength. While there was no difference in thoracic kyphosis in the groups defined by bone mineral density, there was a difference in kyphosis in groups when comparing back extensor strength. The mild back extensor strength group had significantly higher thoracic kyphosis. This implies that the severity of kyphosis may be more related to muscle weakness as opposed to underlying fracture. Thus, despite having poor bone mineral density, good back extensor muscle strength may prevent or improve hyperkyphosis and, in turn, decrease the likelihood of vertebral deformities [40]. However, this idea needs further investigation.

Moreover, another study examined the distribution of hyperkyphotic older adults without former vertebral abnormalities compared with younger adults and found higher kyphosis angle by age group among adults. The Cobb angle was measured in adults older than 65 years ($n = 90$), adults 51–65 years ($n = 60$), adults 35–50 years ($n = 67$) and adults 18–35 ($n = 63$). Adults with prior vertebral fractures, vertebral angulation, scoliosis and congenital spinal anomalies were excluded. The thoracic kyphosis angle was not normally distributed in adults older than 65. Two-thirds of elderly women and half of elderly men had a thoracic kyphosis angle higher than 40°. The mean angle was approximately 28° in both the younger and middle-aged groups. The increase in kyphotic angle with age and the absence of vertebral fractures is further evidence of the role other factors serve in affecting hyperkyphosis [8].

Degenerative disc disease and age-related hyperkyphosis

While the shape of the vertebral bodies and intervertebral discs are major components of the spinal curvature, degenerative changes of intervertebral discs are another radiographic finding related to age-related hyperkyphosis. There are few studies about the effect of intervertebral disc changes on kyphosis angle in older people. Nevertheless, several studies reported a significant correlation between anterior height of discs and kyphotic angle [5, 38]. In a study by Schneider et al. [5], degenerative disc disease rather than vertebral fracture was the most common finding associated with kyphosis angle in men and women. It is possible that increased load when the thoracic spine is flexed may contribute to underlying disc degeneration. However, because of the cross-sectional analysis of these studies, it was not clear whether degenerative disc disease was a cause or effect of hyperkyphosis.

Kado et al. conducted a 15-year retrospective cohort study of 1,196 women aged 65 years and older. In this study, although there was a significant correlation between degenerative disc disease and baseline kyphosis, degenerative disc disease was not reported as a cause of hyperkyphosis progression over time [4].

Decreased mobility and age-related hyperkyphosis

Decreased mobility of the spine is another proposed cause of hyperkyphosis [41]. Because of decreased mobility in spinal extension, older women were less capable of attaining an erect position and controlling normal postural alignment compared to younger women [42]. Ligaments are passive stabilizers of the spine that are susceptible to degenerative ageing factors from a decrease in water and potassium levels of cells, slower protein synthesis rate and increased connective tissue fragility [13]. This can result in elasticity loss, calcification and ossification of the ligaments [43].

Calcification and ossification of the anterior longitudinal ligament may contribute to an increase in Cobb angle. A cadaver study reported that anterior longitudinal ligament transection at T3–T7 resulted in a Cobb angle reduction of 16° [44]. This association was strengthened in a cross-sectional study of 1172 older adults in the Health, Ageing and Body composition cohort. This study found that ossification of the anterior longitudinal ligament, the hallmark sign of diffuse idiopathic skeletal hyperostosis (DISH), was associated with greater degree of kyphosis. The ossification of the ligament may prevent erect posture, or a greater degree of kyphosis may stimulate the ligament to ossify [45]. More research on this correlation would help to understand the causal relationship between the anterior ligament ossification and kyphosis.

There is a significant negative correlation between thoracic kyphosis angle and flexibility of trunk flexors, hip flexors, pectorals and scapula flexor muscles in younger and older adults [22, 46, 47]. Normal flexibility of the trunk, hip and shoulder flexor muscles is important for maintaining a normal distance between the lower ribs and pelvis, extension and hyperextension of spine and correct alignment of standing and sitting. It is not clear whether the shortening of these muscles results in hyperkyphosis or whether hyperkyphotic posture is what causes the shorter anterior musculature. Additional longitudinal research is needed to determine this relationship.

Proprioceptive deficits and age-related hyperkyphosis

Ageing leads to decline in proprioceptive input from the joints in the lower extremities [48], vestibular system [49] and visual system [50], which can all negatively impact postural alignment and lead to the loss of upright postural control [48]. Proprioceptive deficits of the vertebral column have been observed in different spinal disorders such as low back pain [51], cervical pain [52] and scoliosis [53].

In a study by Granito et al., researchers compared thoracic kyphosis angle, back extensor strength, and trunk position sense between elderly women with ($n = 10$) and without osteoporosis ($n = 10$). The osteoporotic group had higher kyphotic angles and lower back extensor strength. While the position sense measurement indicated no significant difference between those with and without osteoporosis, there was a significant negative correlation between the measurements of kyphosis angle and trunk position sense [54]. These associations should be explored in a larger sample size to better understand the relative contribution of trunk position sense to kyphosis.

Spinal extensor muscles and age-related hyperkyphosis

Spinal extensor strength: thoracic kyphosis

Although both spinal extensor and flexor muscles are important for stabilizing the spine [17], spinal extensor muscle strength may be more important for muscular support of the thoracic spine [55].

Numerous studies report a negative correlation between spinal extensor strength and kyphosis angle in older women and in adolescence [40, 47, 54, 56]. There are different theories about spinal extensor muscle weakness. Some authors suggest that weakness associated with hyperkyphosis may be part of ageing syndrome [22, 57], although there were controversial results. As some authors suggested an inverse relationship between ankle and grip strength and kyphotic angle [22], most studies report a specific effect in the spinal extensor muscles that is not found throughout the skeletal system. Sinaki and coworkers compared back extensor strength between women with and without osteoporosis and found that back extensor strength was actually lower in the osteoporotic group. In this study, women 40–80 years old were categorized into four age groups (40–59, 60–69, 70–79, and 80 and older) where each group underwent back extensor and grip strength testing and were compared based upon being either “healthy” or “osteoporotic” women. While all groups had an equally significant difference in back extensor strength when comparing the healthy group to the osteoporotic group, grip strength was different only in those 70–79 years old [55]. This decrease in back extensor strength could not be identified as part of the general weakening process of ageing syndrome.

Several studies have reported the effects of targeted spinal extensor strengthening exercise interventions on the degree of kyphosis in older women [58]. One systematic review reported benefits of exercise therapy targeting the spinal extensor muscles in improving age-related hyperkyphosis, especially in the high-quality randomized controlled trials [59]. Clinical trials are currently underway to determine the effect of multi-modal interventions targeting back extensor muscle strength, spinal mobility and postural awareness. This trial will investigate effects of targeted kyphosis-specific exercises on kyphosis, and it will also investigate causal pathways of change to determine whether change in strength and muscle density have a direct effect on change in kyphosis [60].

While there is evidence that hyperkyphosis and spinal extensor weakness are correlated and strengthening spinal extensor muscles may improve already existing hyperkyphosis, the causal association between hyperkyphosis and spinal extensor weakness remains unclear. Two theories have been proposed. First, loss of spinal extensor strength can result in a decreased capability of these muscles to generate extension movement and control anterior shear force that leads to an increase in kyphotic angle [61]. Second, in addition to increased compression and shear forces imposed on spinal functional units [62], an increase in sagittal curvature of spine may compromise spinal extensor muscle strength by reducing the force generation capacity [40] and muscle activity [63] due to alterations in length–tension relationship [64], moment arm and force vector alignments [65].

Since the ability of muscle force generation is affected by structural factors within the muscle such as cross-sectional area and fat-free mass, some studies were conducted regarding the association between spinal muscle density, an index for the amount of fat mass infiltration, and kyphotic angle. In a study of 1172 men and women between ages 70 and 79, the authors investigated the association between muscle area and density parameters with hyperkyphosis. In this study, abdominal CT scans at the L4–L5 level were used to calculate spinal muscle area and density of the abdominal wall, psoas and spinal extensor muscles. Lateral scout CT scan images were used to measure Cobb angle of kyphosis. Thoracic kyphosis 40° or greater was defined as hyperkyphosis, and in this study 21 % of the subjects fit this criteria. For each standard deviation increase in muscle density, there was a 29 % decreased risk of having hyperkyphosis. No association was found between spinal extensor muscles cross-sectional area and kyphosis, whereas lower spinal extensor muscle density was associated with increased risk of hyperkyphosis. Increased fat in the spinal extensor muscle affects the muscle quality and the degree of kyphosis [66]. In another similar study of 475 men 65 and older, muscle area and density parameters were determined with abdominal CT scans at the L4–L5 level. Supine lateral spine radiographs were used to measure Cobb angle of kyphosis. Among men with low BMI, and in the lowest tertile of paraspinal muscle volume (muscle volume and density combined) there was greater adjusted mean kyphosis. In this case, it was the muscle volume not the muscle density that had a significant impact on kyphosis [67]. One cause for these differing results could be the solely male sample, given that men tend to have greater muscular structural parameters compared to their female counterparts. Secondly, there was a different definition for muscle area between both studies. In the previous study, muscle area was defined as “non-bone, no adipose tissue” two-dimensional cross-sectional area, whereas in the 2014 study, muscle area was defined as the three-dimensional volume of muscle, and the inter-muscular adipose tissue was measured not the intra-muscular adipose tissue in the earlier study. Regardless, muscular factors serve a more important role in postural maintenance.

On the other hand, while a decrease in the muscular structural variables of mass and density could result in a loss of force generation capacity of the spinal extensor muscles and an inability to stabilize the spine in an upright neutral posture, hyperkyphosis itself may have an adverse effect on spinal muscle mass and density [66]. Hyperkyphosis could reduce spinal extensor muscle activity level, similar to the flexion relaxation response to prolonged spinal flexion [63, 68] that has been observed in young adults. Decreased activity of the spinal extensor muscles from prolonged stretch could result in structural and histomorphologic changes [69], disuse atrophy, fatty infiltration and finally a loss of muscular strength and performance.

Despite the existence of several studies about hyperkyphotic posture, additional research is needed to better understand the association between spinal muscle morphology and loss of spinal muscle strength, especially in the elderly with hyperkyphosis. Future studies should investigate spinal muscular structural variables with an emphasis on the thoracic region that is most affected by hyperkyphosis.

Spinal extensor endurance: thoracic kyphosis

Another theory suggests that poor posture is attributed to fatigue and loss of muscular endurance in the spinal extensor muscles [61]. Back extensor endurance is an important factor in rehabilitation of the elderly [70]. Prolonged activation of back extensor muscles is needed for maintaining an erect posture in order to perform various activities throughout the day [71]. In comparison with erect posture, poor postures such as slumped sitting are associated with lower levels of spinal extensor muscle activation [63], which may result in damaging the oxygen transport capacity of muscles as well as pain and injury [68]. The relationship between posture and trunk muscle endurance and the relationship between sitting posture and back extensor muscle endurance have been researched in adolescents [72] and younger adults [71]. One study has been conducted investigating the endurance of the spinal extensor muscles in an elderly population with osteoporosis using EMG. Grieg et al. investigated electrical activity of the trunk muscles using needle EMG during voluntary arm movements. Groups were compared by prevalent vertebral fractures (fracture, $n = 10$; no fracture, $n = 14$) and degree of kyphosis (high, $n = 12$; low, $n = 12$). In this study, Cobb angle greater than 40° was defined as high kyphosis. During forward movements, greater co-contraction was observed in subjects with underlying vertebral fractures. The high kyphosis group showed more pronounced bursts of trunk extensor and flexor activation than did the low kyphosis group regardless of underlying vertebral fractures. Increased trunk muscle co-contraction and bursting co-contraction that was observed in those with vertebral fractures and high kyphosis may have several consequences, including altered balance and higher compressive load on the spine, which can make elderly individuals more susceptible to falls and fracture [73].

In other studies, change from erect sitting to short duration slumped sitting results in a significant loss of spinal extensor muscle activation [68, 74]. This decrease in muscle activity during slumped sitting that is known as the “flexion relaxation phenomenon (FRP)” was first explained by Floyd and Silver in 1955 and denotes a sudden loss of electrical activity in spinal extensor muscles during forward bending [68]. Load shifting to passive structures or deeper muscles can also occur with prolonged flexion and is another proposed mechanism for spinal extensor muscular relaxation [75]. While studies have been conducted to understand different factors on the FRP, no research has investigated the flexion relaxation phenomenon in the thoracic and lumbar erector spinal muscles in people with hyperkyphosis.

Genetics and age-related hyperkyphosis

Another theory suggests that age-related hyperkyphosis may be a hereditary condition. Those older people whose parents had hyperkyphosis were statistically more likely to suffer from hyperkyphosis than those without family history. Notably, this higher likelihood was reported independent of family history of osteoporosis, low bone mineral density or vertebral fracture incidence [4]. The lesions of genes important for DNA repair and postponed senility may contribute to hyperkyphosis [2]. Several animal knockout models results in the development of early senescence associated with specified hyperkyphosis [76, 77]. In comparing the postural position of mice, which are prone, with the erect standing posture of humans, this difference challenges the importance of physical agents such as gravitational force, or at least suggests that there may be genetic predispositions to develop hyperkyphosis [2].

Conclusion

Chronic poor habitual postures could lead to various detrimental effects on the muscles such as deactivation, deconditioning, eventual fatty mass infiltration, decreased force generation capacity, loss of strength and endurance of spinal stabilizers. All of these factors cause increased load strain and pain in passive tissue and increase risk of hyperkyphosis. Furthermore, individuals may be pre-disposed to age-related hyperkyphosis by genetics, disc disease and osteoporosis. Future research is needed to investigate the association between spinal extensor muscle strength and endurance, and the electrical activity of the spinal extensor muscles via electromyography in older adults with hyperkyphosis. Understanding greater knowledge of the spinal extensor muscle function in individuals with hyperkyphosis will improve our understanding of the role of the back extensors in the development of postural hyperkyphosis and may lead to new methods for treating age-related hyperkyphosis.

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Fig. 1.
Debrunner's kyphometer measurement of kyphosis, the arms of the device are placed over the interspace of T2 and T3 spinous processes and interspace of T11 and T12 spinous processes

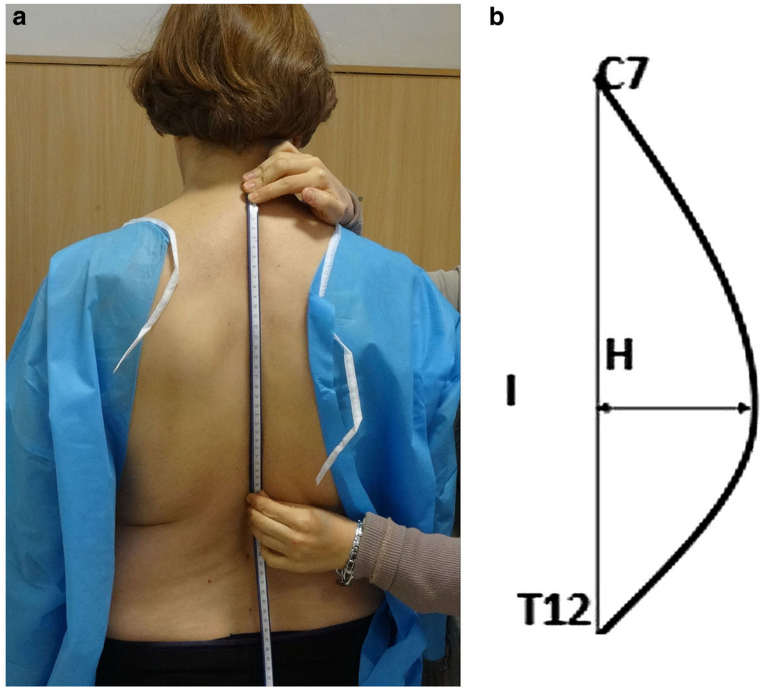

Fig. 2.

a Flexicurve measurement technique, this device is aligned over the C7 spinous process to the T12 spinous process. **b** The thoracic curvature is traced, and by measuring thoracic width (H) and thoracic length (I), kyphosis index is calculated (KI): $(H/I) \times 100$

Fig. 3.

Measurement of spinal curvature with Spinal Mouse, the device is guided along the midline of the spine from the spinous process of C7 to top of the anal crease (approximately S3)

Fig. 4.

Postulated causes of age-related hyperkyphosis

Table 1

Level of reliability and validity of non-invasive methods for measurement of thoracic kyphosis [7]

Method	Reliability	Validity
Debrunner's kyphometer	Very high intra-rater reliability (strong)	Moderate–high validity (conflicting)
Flexicurve index	Very high inter-rater reliability (strong)	Moderate validity (moderate)
Flexicurve angle	High–very high inter + intra-rater reliability (conflicting)	Moderate–high validity (conflicting)
Spinal Mouse	Very high intra + inter-rater reliability (strong)	Low validity (limited)
Manual inclinometer	Very high intra-rater reliability (moderate)	
Digital inclinometer	High intra + inter-rater reliability (limited)	
Goniometer		High validity (limited)
Electrogoniometry	Very high intra-rater reliability (limited)	High validity (limited)
Photogrammetry	Very high inter-rater reliability (limited)	

Level of evidence approach. Strong: consistent findings from 3 or more high-quality studies, moderate: consistent findings from at least 1 high-quality and one or more low-quality studies, limited: consistent findings in 1 or more low-quality studies or only 1 study available, conflicting: inconsistent evidence in multiple studies irrespective of study quality [7]