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Research Article

Sagittal Spinal Mobility and Back Extensor Muscle Function in Older Females with Age-Related Hyperkyphosis

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ABSTRACT

Introduction: Spinal range of motion (ROM) is a potential and modifiable variable that may contribute to the maintenance of upright sagittal alignment. The present study aimed to compare spinal ROM in older females with and without hyperkyphosis and investigate associations between thoracic kyphosis and spinal ROM, back extensor strength (BES), and back extensor endurance (BEE).

Materials and Methods: Sagittal spinal curvature and ROM were measured with the Spinal Mouse. Also, BES and BEE were assessed with a load cell. Variables were compared between older females with and without hyperkyphosis with the independent sample t test. We used the Pearson correlation coefficient to calculate associations between variables. Multiple linear regression was used to find which variable is best associated with kyphosis.

Results: Lumbar and total spinal ROM were lower in the hyperkyphosis compared to the normal group (P<0.05). Thoracic kyphosis was associated with total lumbar ROM (r=-0.30, P=0.03), total spinal ROM (r=-0.35, P=0.01), BES (r=-0.73, P< 0.001), and BEE (r=-0.60, P< 0.001). Multiple linear regression analysis after adjusting for age, weight, and BMI showed that BES (P<0.001) and BEE (P=0.01) but not spinal ROM (P=0.16) were significantly associated with thoracic kyphosis.

Conclusion: Females with hyperkyphosis had lower spinal ROM than those with normal kyphosis. While thoracic kyphosis was significantly associated with total lumbar ROM, total spinal ROM, BES, and BEE, multivariate regression showed that ROM was not a significant contributor to thoracic kyphosis. BES and BEE were significant contributors to thoracic kyphosis and should be targeted in the rehabilitation of hyperkyphosis.

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1. Introduction

After the fourth decade of life, thoracic curvature worsens and increases above 40 degrees, known as „age-related hyperkyphosis.“ Hyperkyphosis affects up to 40% of older adults and impacts both sexes [1]. The condition is more common in females than males [2]. Age-related hyperkyphosis has been associated with poor pulmonary function, impaired physical function, reduced quality of life (QOL), and increased risk for early mortality [3]. Thus, health care providers should attend to this condition as a major health concern. Normal bone and muscle interaction, the foundation for postural alignment, can be altered by age-related decreased bone and muscle mass and strength. Several musculoskeletal impairments have been associated with age-related hyperkyphosis in cross-sectional and longitudinal ways and characterize the ability to develop and maintain upright sagittal alignment. Low bone mineral density, vertebral compression fractures, and decreased back extensor strength are well-established causes of hyperkyphosis [4] but do not fully explain contributing modifiable variables.

Spinal range of motion (ROM) is an essential prerequisite for preserving functional independence and a firm base for limb movements [5]. Decreased spinal ROM may lead to weakness of back extensors and decreased spinal stability [6], although the specific effect of spinal ROM on thoracic kyphosis is unknown. In a cross-sectional study, Saimon et al. examined 26 older adults with spinal deformity and low back pain, measured spinal mobility by occiput-wall distance, and found a significant association with thoracolumbar kyphosis [7]. Miyakoshi et al. investigated the spinal range of motion (ROM) in osteoporotic females. They reported significant correlations between age, kyphosis angle of lumbar area (decreased lordosis), back extensor strength, the thicknesses of paravertebral lumbar muscle, and the number of vertebral fractures with total spinal ROM ($P<0.05$). They showed that back extensor strength was the most significant contributor to the total spinal ROM [6]. This result was confirmed by Hirano et al., who reported a significant association between back extensor strength and lumbar kyphosis angle and lumbar ROM in older females with the locomotive syndrome [8]. Also, sagittal balance (thoracic/lumbar angle ratio), lumbar lordosis, and spinal ROM are reported as essential predictors of QOL in middle-aged to elderly adults [9, 10], suggesting these variables should be investigated in the context of other modifiable factors for age-related hyperkyphosis. While studies have investigated the effect of spinal ROM on thoracic kyphosis in females with age-related hyperkyphosis [9], none has explored the specific contribution of spinal ROM, back extensor strength, and endurance on thoracic hyperkyphosis outcome and determined which variable is best associated with kyphosis. According to the previous studies on the musculoskeletal origin of age-related hyperkyphosis, physical therapy is the first-line approach to treatment [4]. Physical therapists strive to apply evidence-based approaches to treat hyperkyphosis, and there is growing evidence of the benefits of treating these musculoskeletal impairments of aging. Hyperkyphosis can be affected with exercise interventions targeting spinal extensor strength, although effect sizes are small [11]. Identifying additional modifiable variables and quantifying their contribution could help prioritize prevention strategies and enhance current interventions that target only back extensor strength.

The present study compared spinal ROM, including total spinal, thoracic, and lumbar ROM, in older females with and without hyperkyphosis. Also, we investigated the association between thoracic kyphosis and spinal ROM, back extensor strength, and endurance in older females independent of other contributors.

2. Materials and Methods

Study Design

This research is an analytic cross-sectional study carried out in the biomechanics laboratory of Shahid Beheshti University in 2018. Prior study data were used to compare back extensor strength and endurance in females with hyperkyphosis and those with normal thoracic kyphosis [12]. Forty-eight community-dwelling ambulatory older females aged 60-80 years with the ability to stand and walk independently were recruited for participation in this study. Detailed inclusion and exclusion criteria and classification of participants were reported previously [12]. According to measured thoracic kyphosis using the Spinal Mouse, the eligible females were categorized at enrollment into two groups: hyperkyphosis group with kyphosis ≥ 50 degrees [13] ($n=24$) and normal group with kyphosis < 50 degrees ($n=24$). All enrolled participants completed the testing. The study was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences (Number: SBMU.REC.1393.617). Each participant signed written informed consent.

Measurement of Spinal Curvature and ROM:

Study Instrument:

We used Spinal Mouse (Idiag, Voletswil, Switzerland) to measure thoracic kyphosis and lumbar lordosis curvatures, and spinal ROM. We recorded thoracic flexion, extension, and total thoracic ROM; lumbar flexion, extension and total lumbar ROM; and total spinal ROM in degrees. Available validity studies for Spinal Mouse showed a high correlation with radiographically measured lordosis (r = 0.73) and kyphosis (r = 0.76) angles [14]. Also, Spinal Mouse has excellent intrarater reliability for measuring sagittal spinal curvature and mobility in older females [15].

Procedure

Measurements were taken in 3 test positions: neutral standing, maximal flexion, and maximal extension. Thoracic kyphosis and lumbar lordosis were measured in neutral standing. Maximal flexion, maximal extension, and total ROM were calculated based on mobility in the sequence of full flexion minus the full extension. The total spinal range of motion was calculated based upon the total range of motion of the thoracic and lumbar. The spinous process of C7 and top of the anal crease (approximately S3) were marked, and the Spinal Mouse was placed at C7 and manually guided along the midline of the spine to the top of the anal crease at a slow and constant speed, with both wheels of the Spinal Mouse in contact with the skin (Figure 1 a and b). Three sets of measures in each position were carried out 1-2 minutes apart. The average value was recorded in degrees.

For achieving accurate recordings, both wheels of the Spinal Mouse remain in contact with the skin at all times.

Measurement of Back Extensor Strength and Endurance

Instrumentation

A set-up, an "S" shape load cell (H3-C3-100 kg-3B-D55, Zemic, China) attached on a vertical bar, was used to quantify force as a measure of isometric strength and endurance (Figure 2 A and B). Reliability of this set-up was previously reported for females with and without hyperkyphosis as ICC=0.96 to 0.97 and SEM=0.99 to 1.41 kg for back extensor muscle force, ICC=0.82 to 0.89, and SEM=24.97 to 27.05 s for back extensor muscle endurance [16].

Procedure

The protocol was described previously [12]. Briefly, participants sat in a neutral, upright posture facing the load cell, with hips and knees flexed 90 degrees, thighs parallel to seat, and arms crossed on the abdomen. Restraints over the abdomen, pelvis, and thighs prevented vertical or forward movement. The load cell was adjusted with the superior border of the manubrium in midline according to the participant's height and connected to the front of a vest worn over the trunk (Figure 2c). For spinal extensor strength, the participants performed one warm-up trial followed by three successive maximum efforts for 5 s after 60 s rests, and the mean peak force was recorded as a measure of spinal extensor strength (kg). For back extensor endurance, the participants performed one warm-up trial of a sustained contraction at 50% of maximum force followed by 3 endurance efforts at 50% of maximum force after 30 s rests. The maximum time in seconds was recorded as a measure of spinal extensor endurance (s).

Additional Measurements

Height (cm) and weight (kg) values were collected with standard stadiometer and scale devices, then body mass index (BMI) was computed (kg/m^2).

Statistical Analysis

Analyses were performed with SPSS v. 16.0 (SPSS, Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to determine the normality of distribution for all variables in both groups (P>0.05). An independent sample t test compared differences between the two groups regarding the spinal curvature and ROM, back extensor strength, and endurance. The associations between variables for all participants were analyzed using the Pearson correlation. Correlations ranging from 0.00 to 0.25 indicate little or no relationship; those from 0.25 to 0.50 suggest a fair relationship; values from 0.50 to 0.75 are moderate to good, and values above 0.75 are considered good to excellent [17]. A multiple linear regression model was used to estimate and quantify which variables are associated with kyphosis. The significance level was set at 0.05.

A sample size formula for comparing the mean of two groups was used to extract statistical parameters (mean, standard deviation) of dependent variables from similar studies [13, 18]. According to α=0.05, ß=0.01, and power=90%, a sample size of 24 for each group was

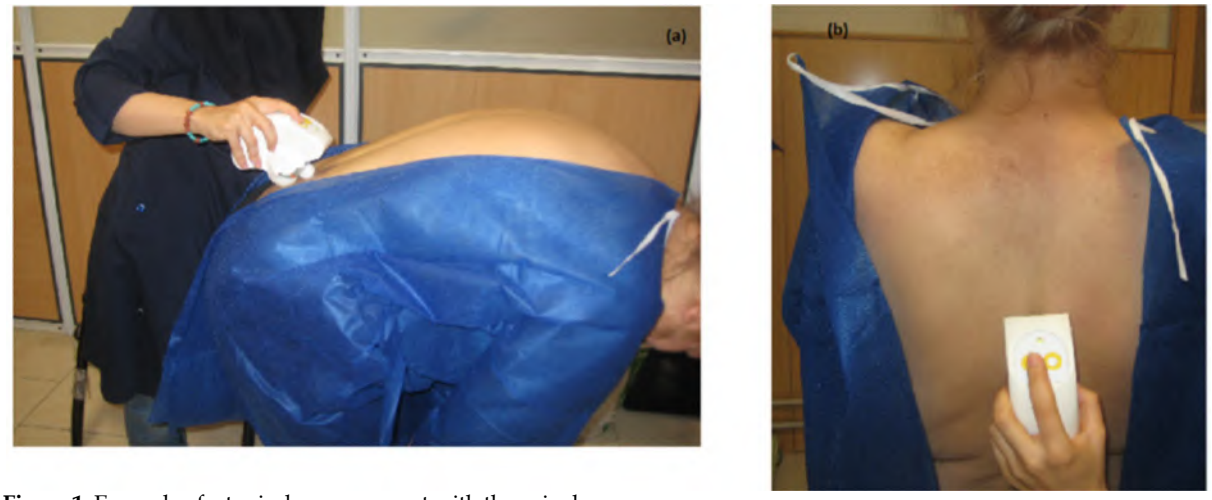

Figure 1. Example of a typical measurement with the spinal mouse

a: Full Flexion, b: Full Extension

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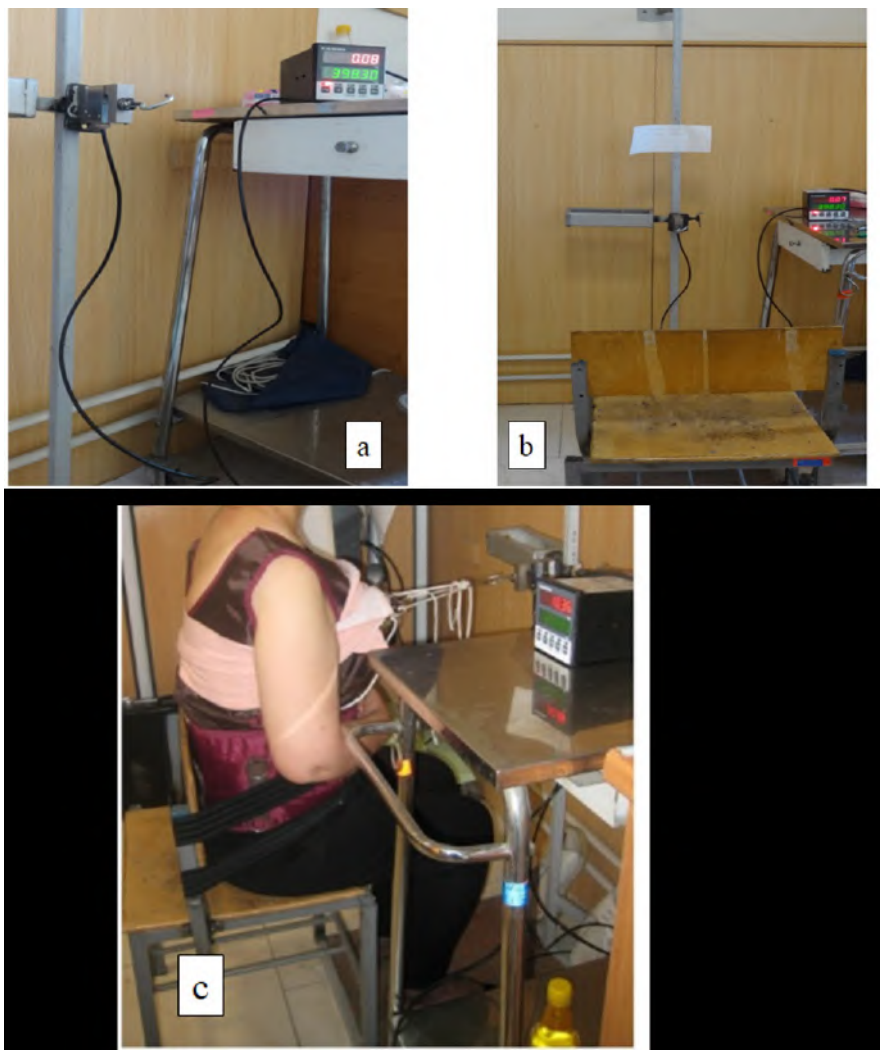

Figure 2. Pulling apparatus set-up

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a: An „S" shape load cell attached on vertical bar for isometric force and endurance measurements; b: An apparatus to assess maximum static extensor force in sitting; C: The load cell aligning with the midline, superior border of manubrium and subject pulling trunk maximally.

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Figure 3. Body composition measurements

a) A Stadiometer Used for Height Measurement, B) A Scale Used for Weight Recording

estimated. The sample size was calculated using Pass11 software (PASS 11. NCSS, LLC, Kaysville, UT, USA).

3. Results

The study sample consisted of two groups of community-dwelling older females: 24 hyperkyphosis (mean kyphosis 54.16± 2.27 degrees, mean age 65.00 ± 4.40 years) and 24 normal (mean kyphosis: 40.00 ± 2.43 degrees, mean age 63.00 ± 4.30 years) (P<0.001). BMI was greater in the hyperkyphosis group compared to the normal group, 27.57 ±2.94 kg/m^2 versus 24.94 ±1.75 kg/m2, P=0.001 (Table 1).

None of the thoracic ROM variables differed between groups (P>0.05). There was no difference in lumbar lordosis (P=0.15), but lumbar extension ROM, total lumbar ROM, and total spinal ROM were lower in the hyperkyphosis compared to the normal group (P=0.04, P=0.02, and P=0.01, respectively). Back extensor strength and endurance were lower in the hyperkyphosis compared to the normal group, P<0.001 (Table 1).

Significant correlations were found between thoracic kyphosis with total lumbar ROM (r=−0.30, P=0.03), total spinal ROM (r=−0.35, P=0.01), back extensor strength (r=-0.73, P<0.001), and endurance (r=-0.60, P<0.001) (Table 2). There were no significant correlations between back extensor strength and spinal ROM. Significant correlations were found between back extensor endurance with total lumbar ROM (r=0.37, P=0.009), and total spinal ROM (r=0.27, P=0.04) (Table 2).

The results of multiple linear regression analysis indicated that BES (P < 0.001) and BEE (P=0.01) but not spinal ROM (P=0.16) remained significant contributors to thoracic kyphosis after adjusting for age, weight, and BMI (Table 3).

4. Discussion

This study compared spinal ROM in older females with and without hyperkyphosis and investigated the associations of spinal ROM, back extensor strength, and endurance with thoracic kyphosis by multivariate analysis. Older females with hyperkyphosis had significantly

Table 1. Comparison of variables between groups

Variables	Mean±SD				P[a]
	Hyperkyphosis (n=24)	Normal Group (n=24)	Mean Difference (SE)	%95CI (lower-upper)	
Age (y)	65.00±4.40	63.00±4.30	2.0±1.2	0.67-5.74	0.07
Height (cm)	156.00±4.54	154.08±5.30	1.92±1.42	0.54-5.77	0.07
Weight (kg)	67.87±7.47	59.08±3.82	8.79±1.71	5.34-12.24	< 0.001*
BMI (kg/m2)	27.57±2.94	24.94±1.75	2.63±0.69	1.22-4.04	0.001*
Thoracic kyphosis (degree)	54.16±2.27	40.00±2.43	14.16±0.68	12.80-15.53	< 0.001*
Lumbar lordosis (degree)	-35.08±7.31	-31.62±9.01	-3.45±2.36	-8.22-1.31	0.15
Flexion ROM thoracic (degree)	3.59±2.2	6.23±4.5	-2.64±2.7	-8.05-2.77	0.33
Extension ROM thoracic (degree)	-12.44±8.0	-13.22±8.12	0.77±2.37	-3.90-5.46	0.74
Total ROM thoracic (degree)	16.35±9.00	19.58±10.00	-3.23±3.20	-9.70-3.24	0.32
Flexion ROM lumbar (degree)	42.51±12.22	47.13±10.41	-4.61±3.27	-11.21-1.98	0.16
Extension ROM lumbar (degree)	-2.10±1.00	-6.00±3.22	-3.90±1.65	-0.02-6.65	0.04*
Total ROM lumbar (degree)	44.37±12.62	52.41±11.53	-8.04±3.5	-15.06 - -1.01	0.02*
Total spinal ROM (degree)	60.04±16.16	72.00±16.20	-11.96±4.67	-21.27- -2.5	0.01*
Back extensor strength (kilogram)	27.11±6.71	41.23±4.88	-14.12±1.7	-17.53- -10.71	< 0.001*
Back extensor endurance (s)	151.00±57.93	247.33±66.63	-96.33±18.02	-132.100- -60.43	< 0.001*

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BMI: Body Mass Index; ROM: Range of Motion. [a]P-value of independent-t-test; *Significant difference between groups.

lower lumbar extension ROM, total lumbar ROM, and total spinal ROM compared to older females with normal kyphosis. There were fair associations between thoracic kyphosis with total lumbar ROM and total spinal ROM, as well as good associations with static back extensor strength and endurance. However, in multiple linear regression, after controlling for age, weight, and BMI, only strength and endurance were significant predictors of thoracic kyphosis.

Spinal ROM in older females with hyperkyphosis was lower compared to those with normal kyphosis, consistent with previous studies reporting lower ROM of the spine in older females with postural deformities [7, 9]. Miyakoshi et al. measured spinal ROM (from T4 to L5) during maximum flexion and extension with radiographs in 157 postmenopausal females (mean age 69.5 ± 6.6 years). They found lower total spinal ROM in those with sagittal spine deformities compared with normal postural alignment [9]. However, only lumbar kyphosis was associated with spinal ROM. Kasukawa et al. also found lower lumbar ROM and higher lumbar kyphosis (decreased lordosis) in a cross-sectional study of older adults with a history of falls compared to non-fallers when comparing spinal kyphotic angles and spinal ROM in both groups. The findings suggest that decreased lumbar kyphosis and sagittal spinal inclination may be important in postural control [19]. Previous investigators also found that spinal ROM is associated with health-related QOL (HRQOL) [7] and physical performance [5] in the middle-aged and elderly population. These findings support the importance of spinal ROM in the maintenance of HRQOL and physical performance but may not specifically affect thoracic kyphosis.

Table 2. The Pearson correlation coefficients for sagittal spinal rom, sagittal spinal alignment, and muscle function

Variables	Thoracic Kyphosis	Lumbar Lordosis	Thoracic FROM	Thoracic EROM	Thoracic TROM	Lumbar FROM	Lumbar EROM	Lumbar TROM	Spinal ROM	BES	BEE
Thoracic kyphosis		-0.24	-0.18	-0.02	-0.13	-0.19	-0.25	-0.30*	-0.35*	-0.73***	-0.60***
BES	-0.73***	0.28*	0.10	0.13	0.17	0.20	0.11	0.24	0.24		0.54***
BEE	-0.60***	0.13	0.14	0.08	0.05	0.27*	0.25	0.37**	0.27*	0.54***	

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FROM, flexion range of motion; EROM: extension range of motion; TROM: total range of motion; BES: back extensor strength; BEE: back extensor endurance. * P<0.05, ** P<0.01, ***P<0.001.

The significant association between thoracic kyphosis and spinal ROM was fair (r=-0.30 to -0.35), whereas the associations with BES and BEE were good and moderate (r=-0.73, r=-.60, respectively). These results are consistent with previous studies that report BES as an underlying cause of age-related hyperkyphosis [20, 21], and numerous exercise interventions targeting BES and reported improved thoracic kyphosis [22-24].

Interestingly, in this study, when examining the effect of spinal ROM, BES, and BEE in a multivariate model, after adjusting for age, BMI and weight, only BES and BEE remained significant predictors. Recently, it was found that thoracic kyphosis is associated with back extensor muscle strength and endurance [12], and the current results confirmed these associations in a broader model, including spinal ROM. The current results demonstrate that both back extensor strength and endurance have strong positive associations with thoracic kyphosis, and only BES had a small but significant association with lumbar lordosis. Back extensor endurance was also associated with measures of lumbar flexion ROM, total lumbar, and spinal ROM. Therefore although BES in older females may significantly affect spinal alignment by maintaining lumbar lordosis, BEE is associated with lumbar ROM and total spinal ROM, which may contribute to the spine's ability to compensate for the loss of lumbar lordosis with aging and maintenance of normal thoracic kyphosis. A recent systematic review and meta-analysis investigated the effects of combined spinal strengthening and stretching exercise on sagittal thoracic and lumbar curvatures of the spine. While the results suggest that exercise programs may positively affect thoracic kyphosis curvature, the review suggests that strengthening could be more relevant than stretching exercises for kyphosis [25]. Both types of exercise were important for lordosis, supporting the need for ongoing investigation of exercises for improving both thoracic and lumbar spine alignment.

It is plausible that loss of lumbar ROM affects the ability to distribute forces throughout the spine [19], pro-

Table 3. Multiple Linear Regression Analysis on Thoracic Kyphosis

Variables	Standardized coefficients	%95 CI		P
	Beta	Lower bound	Upper bound	
Lumbar TROM	0.10	-0.11	0.23	0.48
Spinal ROM	-0.29	-0.22	0.04	0.16
BES	-0.46*	-0.58	-0.17	<0.001
BEE	-0.29	-0.05	-0.00	0.01
Age	-0.10	-0.59	0.25	0.42
Weight	0.13	-0.28	0.55	0.51
BMI	0.13	-0.68	1.42	0.48

h; BEE: Back Extensor Endurance; BMI: Body Mass Index.

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* Higher value of Beta, the most important predictor of thoracic kyphosis

duce excessive compensation in the thoracic spine, and encourage the development of hyperkyphosis. It is well established that there is an overall loss of spinal ROM, decrease in lumbar lordosis, and increased thoracic kyphosis with aging [26], but the causal pathways are not explicitly defined. Age-related changes in disk height [4, 27] and calcification of the anterior longitudinal ligament [28] are associated with thoracic hyperkyphosis and can reduce mobility throughout the spine. However, spinal radiographs were not obtained, which could have elucidated age-related changes in the spine that explain these group differences in lumbar ROM despite lumbar curvature being the same in both groups, consistent with previous research [29, 30]. Miyakoshi reported that back extensor strength was the most significant contributor to the total spinal ROM [6], and longitudinal studies may be needed to explain whether the group differences in BES may impact spinal ROM over time.

Standard therapies for age-related hyperkyphosis are not fully elucidated, and there is limited evidence on the effects of different exercise regimes on age-related hyperkyphosis; thus, applying evidence-based recommendations is essential. Multiple measures of spinal ROM and both muscle strength and endurance were included, which enabled a better understanding of possible targets for future intervention. Results suggest back muscle strength, endurance, and spinal ROM are associated with thoracic kyphosis. However, only BES and BEE may be the best targets in the rehabilitation of thoracic hyperkyphosis.

This study has several limitations. It was a cross-sectional study which does not allow us to infer causality. Spinal imaging was not included, limiting the ability to explain group differences in spinal ROM. A small sample of community-dwelling older females was enrolled, and results are not generalizable for males or other older adults. There was a group difference in BMI; however, multiple regression analyses on thoracic kyphosis revealed that back extensor strength and endurance were significant contributors to thoracic kyphosis, and adjusting for BMI did not affect the finding. Lastly, ROM measurements were limited to the sagittal plane thoracic and lumbar spine and did not include a hip range of motion and sacral inclination, which have been implicated in sagittal alignment.

5. Conclusion

Females with hyperkyphosis had lower spinal ROM compared to those with normal kyphosis. While thoracic kyphosis was significantly associated with spinal ROM, back extensor strength, and endurance, spinal ROM had no significant effect on kyphosis in multiple linear regression. These results suggest that back muscle strength and endurance significantly affect kyphosis and should be considered in the rehabilitation of older females with hyperkyphosis.

Ethical Considerations

Compliance with ethical guidelines

The study was approved by the Ethical Committee of Shahid Beheshti University of Medical Sciences (Code: SBMU.REC.1394.617). Each participant signed written informed consent.

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Authors' contributions

Conceptualization: Tayebeh Roghani and Minoo Khalkhali Zavieh and Saeed Talebian and Wendy B. Katzman; Methodology: Tayebeh Roghani and Minoo Khalkhali Zavieh; Formal analysis and interpretation: Tayebeh Roghani and Minoo Khalkhali Zavieh and Saeed Talebian and Wendy B. Katzman and Amy Gladin and Hoda Niknam; Writing of the first draft of manuscript: Tayebeh Roghani and Wendy B. Katzman and Amy Gladin; Review and editing of the manuscript: Tayebeh Roghani and Minoo Khalkhali Zavieh and Saeed Talebian and Wendy B. Katzman and Amy Gladin and Hoda niknam; Approval of the final version of manuscript: Tayebeh Roghani and Minoo Khalkhali Zavieh and Saeed Talebian and Wendy B. Katzman and Hoda Niknam and Amy Gladin. Guarantor: Tayebeh Roghani

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Takahashi T, Ishida K, Hirose D, Nagano Y, Okumiya K, Nishinaga M, et al. Trunk deformity is associated with a reduction in outdoor activities of daily living and life satisfaction in community-dwelling older people. Osteoporosis International. 2005; 16(3):273-9. [DOI:10.1007/s00198-004-1669-3] [PMID]

[2] Fon GT, Pitt MJ, Thies AC Jr. Thoracic kyphosis: Range in normal subjects. AJR. American Journal of Roentgenology. 1980; 134(5):979-83. [DOI:10.2214/ajr.134.5.979] [PMID]

[3] Roghani T, Zavieh MK, Manshadi FD, King N, Katzman W. Age-related hyperkyphosis: Update of its potential causes and clinical impacts-narrative review. Aging Clinical and Experimental Research. 2017; 29(4):567-77. [DOI:10.1007/s40520-016-0617-3] [PMID] [PMCID]

[4] Katzman WB, Wanek L, Shepherd JA, Sellmeyer DE. Age-related hyperkyphosis: Its causes, consequences, and management. The Journal of Orthopaedic and Sports Physical Therapy. 2010; 40(6):352-60. [DOI:10.2519/jospt.2010.3099] [PMID] [PMCID]

[5] Schenkman M, Shipp KM, Chandler J, Studenski SA, Kuchibhatla M. Relationships between mobility of axial structures and physical performance. Physical Therapy. 1996; 76(3):276-85. [DOI:10.1093/ptj/76.3.276] [PMID]

[6] Miyakoshi N, Hongo M, Maekawa S, Ishikawa Y, Shimada Y, Okada K, et al. Factors related to spinal mobility in patients with postmenopausal osteoporosis. Osteoporosis International. 2005; 16(12):1871-4. [DOI:10.1007/s00198-005-1953-x] [PMID]

[7] Saimon Y, Goh AC, Momose K, Ryuzaki D, Akahane H, Oba A, et al. Correlation between radiographic sagittal alignment, range of motion, muscle strength, and quality of life in adults with spinal deformities. Journal of Physical Therapy Science. 2020; 32(2):140-7. [DOI:10.1589/jpts.32.140] [PMID] [PMCID]

[8] Hirano K, Imagama S, Hasegawa Y, Wakao N, Muramoto A, Ishiguro N. Impact of back muscle strength and aging on locomotive syndrome in community living Japanese women. Nagoya Journal of Medical Science. 2013; 75(1-2):47-55. [PMID]

[9] Miyakoshi N, Itoi E, Kobayashi M, Kodama H. Impact of postural deformities and spinal mobility on quality of life in postmenopausal osteoporosis. Osteoporosis International. 2003; 14(12):1007-12. [DOI:10.1007/s00198-003-1510-4] [PMID]

[10] Imagama S, Hasegawa Y, Matsuyama Y, Sakai Y, Ito Z, Hamajima N, et al. Influence of sagittal balance and physical ability associated with exercise on quality of life in middle-aged and elderly people. Archives of Osteoporosis. 2011; 6(1-2):13-20. [DOI:10.1007/s11657-011-0052-1] [PMID] [PMCID]

[11] Bansal S, Katzman WB, Giangregorio LM. Exercise for improving age-related hyperkyphotic posture: A systematic review. Archives of Physical Medicine and Rehabilitation. 2014; 95(1):129-40. [DOI:10.1016/j.apmr.2013.06.022] [PMID] [PMCID]

[12] Roghani T, Khalkhali Zavieh M, Talebian S, Akbarzadeh Baghban A, Katzman W. Back muscle function in older women with age-related hyperkyphosis: A comparative study. Journal of Manipulative and Physiological Therapeutics. 2019; 42(4):284-94. [DOI:10.1016/j.jmpt.2018.11.012] [PMID]

[13] Granito RN, Aveiro MC, Renno AC, Oishi J, Driusso P. Comparison of thoracic kyphosis degree, trunk muscle strength and joint position sense among healthy and osteoporotic elderly women: A cross-sectional preliminary study. Archives of Gerontology and Geriatrics. 2012; 54(2):E199-202. [DOI:10.1016/j.archger.2011.05.012] [PMID]

[14] Cohen L, Kobayashi S, Simic M, Dennis S, Refshauge K, Pappas E. Non-radiographic methods of measuring global sagittal balance: A systematic review. Scoliosis and Spinal Disorders. 2017; 12:30. [DOI:10.1186/s13013-017-0135-x] [PMID] [PMCID]

[15] Roghani T, Khalkhali Zavieh M, Rahimi A, Talebian S, Dehghan Manshadi F, Akbarzadeh Baghban A, et al. The reliability of standing sagittal measurements of spinal curvature and range of motion in older women with and without hyperkyphosis using a skin-surface device. Journal of Manipulative and Physiological Therapeutics. 2017; 40(9):685-91. [DOI:10.1016/j.jmpt.2017.07.008] [PMID]

[16] Roghani T, Khalkhali Zavieh M, Rahimi A, Talebian S, Manshadi FD, Akbarzadeh Baghban A, et al. The reliability and validity of a designed setup for the assessment of static back extensor force and endurance in older women with and without hyperkyphosis. Physiotherapy Theory and Practice. 2018; 34(11):882-93. [PMID] [PMCID]

[17] Portney LG, Watkins MP. Foundations of clinical research: Applications to practice. New Jersey: Prentice Hall Health; 2000. https://www.google.com/books/edition/Foundations_of_Clinical_Research/zzhrAAAAMAAJ?hl=en

[18] Cunha-Henriques S, Costa-Paiva L, Pinto-Neto AM, Fonsechi-Carvesan G, Nanni L, Morais SS. Postmenopausal women with osteoporosis and musculoskeletal status: A comparative cross-sectional study. Journal of Clinical Medicine Research. 2011; 3(4):168-76. [DOI:10.4021/jocmr537w] [PMID] [PMCID]

[19] Kasukawa Y, Miyakoshi N, Hongo M, Ishikawa Y, Noguchi H, Kamo K, et al. Relationships between falls, spinal curvature, spinal mobility and back extensor strength in elderly people. Journal of Bone and Mineral Metabolism. 2010; 28(1):82-7. [DOI:10.1007/s00774-009-0107-1] [PMID]

[20] Mika A, Unnithan VB, Mika P. Differences in thoracic kyphosis and in back muscle strength in women with bone loss due to osteoporosis. Spine (Phila Pa 1976). 2005; 30(2):241-6. [DOI:10.1097/01.brs.0000150521.10071.df] [PMID]

[21] Kado DM, Prenovost K, Crandall C. Narrative review: Hyperkyphosis in older persons. Annals of Internal Medicine. 2007; 147(5):330-8. [DOI:10.7326/0003-4819-147-5-200709040-00008] [PMID]

[22] Greendale GA, Huang MH, Karlamangla AS, Seeger L, Crawford S. Yoga decreases kyphosis in senior women and men with adult-onset hyperkyphosis: Results of a randomized controlled trial. Journal of the American Geriatrics Society. 2009; 57(9):1569-79. [DOI:10.1111/j.1532-5415.2009.02391.x] [PMID] [PMCID]

[23] Katzman WB, Vittinghoff E, Lin F, Schafer A, Long RK, Wong S, et al. Targeted spine strengthening exercise and posture training program to reduce hyperkyphosis in older adults: Results from the study of hyperkyphosis, exercise, and function (SHEAF) randomized controlled trial. Osteoporosis International. 2017; 28(10):2831-41. [DOI:10.1007/s00198-017-4109-x] [PMID] [PMCID]

[24] Katzman WB, Parimi N, Gladin A, Poltavskiy EA, Schafer AL, Long RK, et al. Sex differences in response to targeted kyphosis specific exercise and posture training in community-dwelling older adults: A randomized controlled trial. BMC Musculoskelet Disord. 2017; 18(1):509. [DOI:10.1186/s12891-017-1862-0] [PMID] [PMCID]

[25] González-Gálvez N, Gea-García GM, Marcos-Pardo PJ. Effects of exercise programs on kyphosis and lordosis angle: A systematic review and meta-analysis. PloS One. 2019; 14(4):e0216180. [DOI:10.1371/journal.pone.0216180] [PMID] [PMCID]

[26] Hinman MR. Comparison of thoracic kyphosis and postural stiffness in younger and older women. The Spine Journal. 2004; 4(4):413-7. [DOI:10.1016/j.spinee.2004.01.002] [PMID]

[27] Goh S, Price RI, Leedman PJ, Singer KP. The relative influence of vertebral body and intervertebral disc shape on thoracic kyphosis. Clinical Biomechanical. 1999; 14(7):439-48. [DOI:10.1016/S0268-0033(98)00105-3]

[28] Nardo L, Lane NE, Parimi N, Cawthon PM, Fan B, Shepherd J, et al. Diffuse idiopathic skeletal hyperostosis association with thoracic spine kyphosis: A cross-sectional study for the Health Aging and Body Composition Study. Spine (Phila Pa 1976). 2014; 39(24):E1418-24. [DOI:10.1097/BRS.0000000000000615] [PMID]

[29] Drzal-Grabiec J, Snela S, Rykala J, Podgorska J, Banas A. Changes in the body posture of women occurring with age. BMC Geriatrics. 2013; 13:108. [DOI:10.1186/1471-2318-13-108] [PMID] [PMCID]

[30] Singh DK, Bailey M, Lee R. Biplanar measurement of thoracolumbar curvature in older adults using an electromagnetic tracking device. Archives of Physical Medicine and Rehabilitation. 2010; 91(1):137-42. [DOI:10.1016/j.apmr.2009.08.145] [PMID]