RESEARCH ARTICLE

The Efficacy of "Anatomical Posture Control Orthosis" on the Activity of Erector spinae Muscle, Risk of Falling, Balance Confidence, and Walking Speed in Osteoporotic Hyperkyphotic Subjects

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Abstract

Background: Osteoporosis is a silent and asymptomatic disease that leads to thoracic hyperkyphosis, which can interfere with the normal function of the paraspinal musculature and balance control. There is no evidence regarding the effect of the anatomical posture control (APC) orthosis in older people with osteoporotic thoracic hyperkyphosis. This study aimed to examine the effects of this novel orthosis on the electromyography (EMG) of the erector spinae (ES) and balance control in this group of patients.

Methods: In total, 22 elderly osteoporotic subjects with thoracic hyperkyphosis were enrolled in this study. The participants used the orthosis for 4 weeks. The clinical balance assessment scales assessing fall risk and surface EMG (sEMG) signals were recorded from the erector spinae muscles bilaterally before and after the use of orthosis. The marginal model was used with the generalized estimating equation analysis for investigating the effect of this orthosis on the sEMG of the paraspinal muscles and the balance control in this longitudinal study.

Results: The normalized root mean square of sEMG of the lumbar and thoracic ES muscles reduced significantly ($P<0.05$), and significant improvement was observed ($P<0.05$) in the balance control test when the participants used this new-designed orthosis ($P<0.05$).

Conclusion: APC orthosis can decrease the activity of ES muscles during static standing and improve the static and dynamic balance in the hyperkyphotic osteoporotic subjects.

Level of evidence: II

Keywords: Balance control, EMG, Hyperkyphosis, Orthosis, Osteoporosis

Introduction

Osteoporosis is a silent and asymptomatic disease, characterized by the loss of bone mass and bone strength, which leads to an increased susceptibility to low-energy or fragility fractures.[1] Individuals diagnosed with osteoporosis often experience muscle weakness and have poor balance control, as well as a higher risk of falls.[2,3] Osteoporosis often occurs in the spinal region and may lead to thoracic hyperkyphosis and adverse postural changes.[4] Hyperkyphosis in osteoporotic subjects increases the risk of fractures and even mortality and is associated with impaired physical performance, health, quality of life, and low well-being

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scores; moreover, it plays an important role in poor balance control, gait unsteadiness, and risk of falls in the elderly.[5-7,8,9]

Hyperkyphosis can interfere with the normal function of the paraspinal musculature. This may be due to alterations in the length-tension relationship, moment arm lengths, and force vector orientations of the related muscles.[10] Therefore, older adults have higher levels of trunk muscle activity, compared to young adults in both agonist and antagonist muscles. This indicates that aging affects the neuromuscular control of the trunk.[11]

Rehabilitation is considered for these older subjects with osteoporotic hyperkyphosis, and it is focused on therapeutic exercises for postural training, therapeutic taping, and the use of spinal bracing.[12-16] Different types of spinal orthoses have been developed to manage hyperkyphosis and prevent its adverse consequences. However, each of these treatments has its own limitations.[13,17,18] The new generation of conventional orthosis limited pelvic rotations; accordingly, it reduces the walking speed.[19, 20] Recently, a novel posture control orthosis was designed based on the anatomy of the regional muscles and the preliminary testing on the immediate effect of this orthosis on muscle activity, and the balance control in six elderly hyperkyphotic subjects showed improvement in this group.[21]

Accordingly, anatomical posture control (APC) orthosis is a novel device, and there is no evidence regarding its effect on osteoporotic older people; as a result, understanding the effect of this therapeutic intervention is helpful in choosing the suitable treatment option and may lead to new methods for the treatment of osteoporotic hyperkyphotic subjects and decrease the fall risks and mortality rates that involve high-cost medical interventions.[9]

With this background in mind, this study aimed to evaluate the immediate and long-term effects of this novel orthosis on the electromyography (EMG) of the erector spinae (ES), balance control, and the walking speed in these subjects. It is hypothesized that the use of APC orthosis would improve proprioception and spinal alignment, thereby enhancing muscle performance. Furthermore, it is hypothesized that the improvement in the aforementioned variables would be associated with improvement in balance performance.

Materials and Methods

Patients

In total, 22 elderly subjects (16 females, 6 males) participated in the study [Table 1]. The inclusion criteria were elderly cases with osteoporosis (T-score was ≥-2.6 in the negativity).[22] The thoracic kyphotic angle of greater than 45 degrees was selected for the study.[5] On the other hand, the participants with recent lower limb joint surgery or injury, recent fracture or localized back pain, hyperkyphotic posture from childhood, prior surgery on the vertebral column in the previous year, other spinal deformities, including scoliosis and kyphoscoliosis, and those who used medications over the previous 12 months that could affect the muscle performance or balance control, as well as cognitive impairments were excluded from the study.[18, 23]

Table 1. Descriptive characteristics of the study subjects mean±SD

Subject's Characteristics	Mean and SD
Height(cm)	162.5±7
Weight(kg)	64.5±7.54
Age(years)	68.5±6.44
Kyphosis(deg.)	48.75±2.21
BMI (kg/m^2)	23.99 ±0.799

Intervention

The customized patient-specific orthosis is shown in Figure 1, and its features are described in the authors' previous study.[21] It is worth mentioning that the orthoses were fabricated by a skilled orthotist [Figure1]. The patients were guided to place the orthosis over the spine and adjust the straps. They were instructed to wear the device when ambulating for more than 7 hours per day for 4 weeks.[24] During those 4 weeks, the patients were followed up via phone calls to assure that they were using the orthosis correctly. All the participants voluntarily signed the informed consent form, and the Human Ethics Committee of the Lorestan University of Medical Sciences, (IR.LUMS.REC.1397.002) approved the protocol of this study According to the instructions, the sample size was calculated based on the pilot study on hyperkyphotic elderly subjects.[21]

Data collection

First, the thoracic kyphosis was measured using a Dualer Electric Inclinometer (North American Fork, Utah). An experienced investigator was assigned to manage the intervention according to the instruction manual.[13] The height and weight of all subjects were also recorded before determining the baseline measurements. The participants were informed about the test procedure and were given enough time to learn the evaluation procedure. Before starting the study and immediately after the subjects wore the orthosis, the clinical balance tests and the EMG recordings of the muscles were performed. Subsequently, after 4 weeks, to identify the long-term effects of the orthosis, the participants were

Figure 1. Anterior and posterior views of the orthosis.

asked to return to the hospital for reevaluations. The same therapist performed the EMG recordings and the clinical tests again.

Balance control and walking speed tests

The Timed Up and Go (TUG) test, functional reach test (FRT), and the Berg balance scale (BBS) were used to investigate the dynamic balance; moreover, the static balance was evaluated using the single-leg stance test. To measure the walking speed of the subjects, the 6-meter walking speed test (6MTW) and the Persian version of the activities-specific balance confidence (ABC) scale were employed to quantify the level of the subjects' confidence in performing a specific task without losing balance.

EMG recording

EMG was performed for the lumbar and thoracic ES muscles on both sides with a portable electromyogram (ME3000P, Mega Electronics Ltd., Finland) in static standing positions for one minute.[25] To prepare the patients for the EMG tests, the skin of the lower back was cleaned and shaved. The surface electrodes were placed over the thoracic ES at a point 5 cm lateral to the T9 spinous process and the lumbar ES muscles at a point 3 cm lateral to the L4 spinous process. Each pair of electrodes was spaced 3 cm center-to-center along with the directions of the muscle fibers. A reference electrode was placed laterally over the right 10th rib. The normalization EMG task was the submaximal back-extension in the horizontal position.[26] Each task was performed for 10 sec and repeated three times with 30-sec rest between each repetition. These tests were repeated after the patient put on the orthosis and carried it for at least 10 min. An experienced orthotist instructed the patient regarding the proper usage of the orthosis.

Data processing

The EMG data were analyzed using MegaWin (Mega Electronics Ltd.) software. The sampling rate in the recording was 1000 Hz, and the EMG data were amplified 2000 times and filtered between 20 and 500 Hz. The root mean square (RMS) values of surface electromyography (sEMG) were used in the analyses. The EMG (RMS) amplitude was normalized to submaximal voluntary contraction. In addition, the intraclass correlation coefficient (ICC) was used to examine the repeatability of the EMG amplitudes of muscles. As a result, the recording of ES muscle activity with this new orthosis in elderly subjects had a high relative validity (ICC>0.75).

Data analysis

Data analysis was performed in SPSS software (version 21), and regarding the longitudinal nature of the study, to incorporate the data correlation structure into the data modeling, a marginal model was fitted, and the generalized estimation equation (GEE*)* approach was used for estimating the parameters of marginal models. A *P-value* of less than 0.05 was considered statistically significant.

Results

The marginal model with GEE analysis was used for investigating the effect of this novel orthosis on the sEMG of the paraspinal muscles and the balance control in this longitudinal study.

The sEMG results of ES muscles

The mean and maximum of the RMS value of the sEMG of paraspinal muscles at baseline, immediately after using orthosis, and 4 weeks of using orthosis are summarized in [Table 2]. The results indicated that the RMS values of the sEMG of the thoracic and lumbar ES muscles by the GEE model were significantly different before and after the intervention in the three stages of the study.

Data obtained from the analysis of the marginal model for the right thoracic ES muscle indicated that the RMS activity of this muscle decreased by 3.294 μV immediately

Table 2. The mean RMS sEMG values (SE) of the paraspinal muscles of the subjects in three stages of study

Muscle	Side		Mean RMS value(SE)(μV)			*P value*
			Baseline	Immediately	After 4 Weeks	
Thoracic Erectorspinae	Right	Av.	37.132(0.76)	33.838(0.65)	31.544±(0.46)	*P<0.001
		Max.	205.88(7.98)	183.99(6.30)	158.117(10.58)	
	Left	Av.	37.159(0.91)	34.041(0.78)	31.747(0.57)	*P<0.001
		Max.	203.7(8.86)	185.95(8.03)	157.89(9.90)	
Lumbar Erectorspinae	Right	Av.	40.595(1.25)	36.771(1.42)	34.829(1.33)	*P<0.001
		Max.	223.51(11.32)	194.57(13.27)	186.28(15.66)	
	Left	Av.	39.046(1.07)	33.870(1.20)	31.223(1.30)	*P<0.001
		Max.	225.54(10.40)	190.43(12.89)	169.07(12.90)	

*significant difference between conditions (*P< 0.05*).

after wearing the orthosis, and after 4 weeks of using the orthosis, it decreased by 5.588 µV, compared to the preintervention, and both decreases were statistically significant (*P<0.001*). In addition, the RMS activity of the muscles 4 weeks after the intervention decreased by 2.294 µV, compared to the immediate effect of the intervention (P<0.001).

Data obtained from the analysis of the marginal model for the left thoracic ES muscle showed that the RMS activity of this muscle decreased by 3.118 µV immediately after wearing the orthosis, and after 4 weeks of using the orthosis, it decreased by 5.412 µV, compared to preintervention, and both decreases were statistically significant (*P<0.001*). In addition, the RMS activity of the muscles decreased by 2.294 µV 4 weeks after the intervention, compared to the immediate effect of the intervention (*P<0.001*).

Data from the analysis of the marginal model for the right lumbar ES muscle revealed that the RMS activity of this muscle decreased by 3.824 µV immediately after wearing the orthosis, and after 4 weeks of using the orthosis, it decreased by 5.765 µV, compared to preintervention, and both decreases were statistically significant (*P<0.001*). In addition, the RMS activity of the muscles 4 weeks after the intervention decreased by 1.941 µV, compared to the immediate effect of the intervention (*P<0.001*).

Data from the analysis of the marginal model for the left lumbar ES muscle showed that the RMS activity of this muscle decreased by 3.176 µV immediately after wearing the orthosis, and after 4 weeks of using the orthosis, it decreased by 4.824 µV, compared to preintervention, and both decreases were statistically significant (*P<0.001*). In addition, the RMS activity of the muscles 4 weeks after the intervention decreased by 1.647 µV, compared to the immediate effect of the intervention (*P<0.001*).

Results of the clinical balance tests

The results of the clinical balance tests, as shown in Table 3, indicated improvement in the clinical balance and walking speed tests immediately and after 4 weeks of wearing the orthosis [Table 3].

Timed Up and Go test

As can be observed from the data in Table 3, the analysis of the marginal model indicates that the mean time of the TUG balance test after wearing the orthosis was 1.62 sec, and after 4 weeks, it decreased by 2.44 sec, compared to preintervention (*P<0.001*). In addition, the mean duration time of this test after 4 weeks of intervention decreased by 0.81 sec, compared to the immediate effect of the orthosis (*P=0.002*).

Berg balance scale

The statistical analysis indicated that the mean score of the BBS test after wearing the orthosis was 1.08 (*P<0.001*), and after 4 weeks, the scores increased to 2.66, compared to preintervention. In addition, the mean score of this test after 4 weeks of intervention increased by 1.58, compared to the immediate effect of the orthosis.

Functional reach test

The mean score of the FRT after wearing the orthosis was 0.89 cm, and after 4 weeks, it increased to 1.87 cm, compared to preintervention (*P<0.001*). In addition, the mean score of this test after 4 weeks of intervention increased by 0.97 cm, compared to the immediate effect of the orthosis.

Unilateral stance test

The UST results indicated that the mean time of this test after wearing the orthosis was 4.62 sec, and after 4 weeks, it increased to 6.48 sec, compared to preintervention (*P<0.001*). In addition, the mean score of the UST after 4 weeks of intervention increased by 1.85 sec, compared to the immediate effect of the orthosis (*P=0.017*).

Six-meter walking speed test

The mean time of the 6MWS test after wearing the orthosis was 0.86 sec, and after 4 weeks, it increased to 1.45 sec, compared to preintervention (*P<0.001*). In addition, the mean score of this test after 4 weeks of intervention, compared to the immediate effect of the orthosis, increased by 0.59 sec (*P=0.002*).

Activities-specific confidence scale

It is apparent from Table 3 that the mean score of the ABC questionnaire after wearing the orthosis was 3.12%, and after 4 weeks, it increased to 8.22%, compared to preintervention (*P<0.001*). In addition, the mean score of this test after 4 weeks of intervention increased by 5.10%, compared to the immediate effect of the orthosis (*P<0.001*).

Table 3. Mean and standard error (SE) of clinical balance and walking speed tests in baseline, immediately and after 4 weeks put on the orthosis

Clinical Test	Baseline	Immediately	After 4 weeks	*P value*
TUG(s)	17.2(0.49)	15.40(0.53)	14.58(0.49)	**P<0.001*
BBS(points)	31.17(1.11)	32.25(1.25)	33.84(1.06)	**P<0.001*
US(s)	12.46(1.32)	17.08(1.48)	18.94(1.56)	**P<0.001*
FR(CM)	21.05(0.88)	22.39(0.92)	23.37(0.84)	**P<0.001*
WS(m/s)	10.75(0.19)	9.88(0.20)	9.29(0.24)	**P<0.001*
ABC(%)	55.62±1.50	58.75(1.77)	63.85(1.79)	**P<0.001*

*significant difference between conditions (*P< 0.05*).

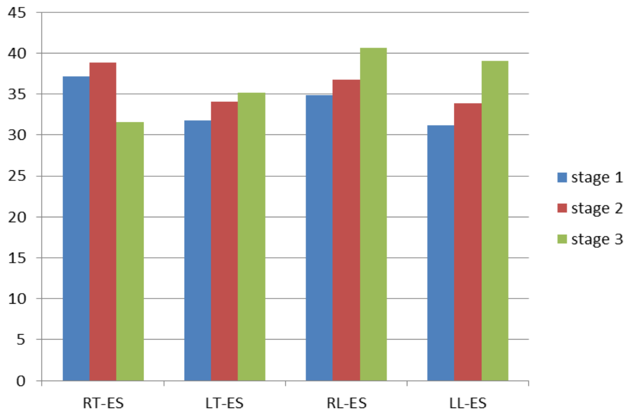

Figure 2.

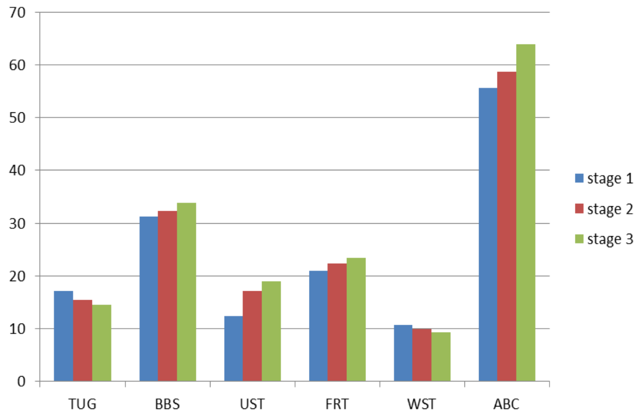

Figure 3.

Discussion

The main findings in this trial were the decrease of the thoracic and lumbar ES activities and improvement in the balance control after using this orthosis for 4 weeks. A systematic review reported that wearing a lumbosacral orthosis (LSO) alone could not decrease the low back load.[27] However, Cholewicki et al. reported that wearing an LSO could decrease the ES activity during a postural control task, such as sitting on an unstable seat. Typical orthoses do not show the biomechanical effect of decreasing the low back load during level walking because most of them only correct the abdominal region with compressive force or support the pelvis, thorax, and lower back with small resistive force.[28] In a previous study, only two types of orthoses (e.g., the rucksack-type orthosis and orthosis resistive force) were found to decrease the ES activity in older people during level walking.[19, 29] The rucksack-type orthosis controls the magnitude of force using weights to move the center of gravity of the upper body, thereby decreasing the ES activity. Both orthoses can control a relatively large magnitude of force applied to the upper trunk.

There are various hypotheses about the reduction in the electrical activity of the extensor muscles as a result of using the APC orthosis. The decrease in the electrical activity of the muscles might be due to the reduction in the kyphotic angle and the biomechanical changes caused by using the orthosis, which increases the ability of the muscles to support the spine. It seems that following the reduction in the kyphotic angle and the placement of the trunk in the appropriate position, the stretching and strain on the muscles and tendons are reduced, and the muscle functions and force generation are improved. Being in the wrong position changes the force vector orientations and the moment arm lengths of the paraspinal muscles and increases the activity of these muscles in order to maintain the upright posture of the trunk, thereby causing fatigue in the trunk extensor.[30] Another hypothesis is that the device produces a considerable force over the shoulders and reduces the anterior compressive force exerted on a kyphotic spine. This would maintain the center of gravity within the base of support.

Moreover, the elements of our orthosis may increase proprioceptive input and enhance the patient's ability to sense the position of the spine. An enhancement in the somatosensory feedback induced by the orthoses facilitates postural control, which in turn tends to become more stable.[31] In this study, according to the clinical balance test scores, the functional mobility and balance improved immediately and after 4 weeks of using the orthosis. Statistically, significant improvements were observed in the mean scores of all the measures of balance (*P<0.05*). Several different balance tests were used to examine different aspects of balance control.

According to the TUG and BBS test scores in the elderly, before and after the intervention, the use of this orthosis can be effective in the dynamic balance of the elderly; however, there is still a risk of falling in these participants since research has suggested that the cut-off time ≥13.5 sec should be used as a threshold for identifying persons with an increased risk of falling for the TUG test, and for the BBS, the cut-off score is 46 and above.[32,33]

Their values for the FRT appear to be much better (about 6 sec) with this orthosis than those reported with the weighted kypho-orthosis (WKO).[34] The WKO increased the duration of FRT by 2 sec, which is very small, compared to the result of the present study and shows the superiority of our orthosis in controlling the static balance.[34] In general, the results of these two clinical balance tests (FRT and UST) showed that using this orthosis improves the static balance in the elderly.

The results of the present study regarding the effect of this orthosis on balance improvement in older subjects were consistent with the findings of the studies by Azadinia and Raeissadat.[20,34] The spinomed orthosis allows the biofeedback activation of the dorsal lumbar musculature. It is similar to our orthosis to some extent;

however, APC orthosis has no rigid immobilization, and its straps were designed based on the anatomy of the back muscles.

Raeissadat reported that wearing WKO for 4 weeks improves the balance control in osteoporotic subjects according to the TUG test and FRT.[34] Nonetheless, the UST results were contrary to the present results, which can be due to the difference in the design of the orthosis and the thoracic kyphotic angle. In this study, according to the 6MWS test, walking speed improved significantly (*P<0.05*) after the use of the orthosis, and it was consistent with the result of a study by Sinaki et al. on elderly women with osteoporosis and hyperkyphosis. It should be noted that the improvement of the balance score and gait efficiency was attributed to the use of posture training support and participating in sports programs.[18]

The improvement in balance control and walking speed by using this orthosis can be explained from two aspects. The first is postural control via keeping the body center of mass within the base of support in the dynamic and static tasks, and the second is the enhanced proprioception of postural muscles exerted by an orthosis.[28] According to the Persian version of the ABC scale, the confidence in performing a specific task without losing balance improved immediately and after 4 weeks of using the orthosis

There are two strong determinants of balance confidence in elderly people. First, proprioception deficits may lead to balance confidence impairments, and older adults with higher proprioceptive performance had a decreased self-reported fear of falling.[35,36] Second, balance performance is another determinant, and there is a strong association between the ABC scale and BBS scores, as well as the TUG score.[37] Therefore, it seems that this intervention may improve balance control, as well as proprioception and body awareness, thereby increasing balance confidence in these participants.

In conclusion, it was demonstrated that the APC orthosis can decrease the ES muscle activity during static standing and improve the static and dynamic balance in the hyperkyphotic osteoporotic subjects. The present study suggests that the elderly with osteoporotic and hyperkyphotic postures might be able to stand and walk more efficiently when wearing this novel orthosis because it is inexpensive, has no rigid elements, and can be easily applied in the daily living of osteoporotic subjects.

Limitations

Regarding the limitations in this study, one can refer to the lack of a control group and relatively medium-term follow-up are as the main weaknesses of this study. Second, it is possible that the participants have not followed the orthotic wearing schedule. Long-term evaluation is recommended as a future study, and more comprehensive analysis on trunk muscle strength and walking parameters (e.g., temporal-spatial parameters, kinematics, kinetics, energy consumption, and posture) are also warranted.

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