Research Paper

Effects of Thoracolumbosacral Braces on Gait Knetics and Muscle Activities Before and After Puberty in Kyphosis Child

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ABSTRACT

Purpose: Kyphosis is associated with relatively altered vertebral body shape, reduced bone density and fitness, and decreased muscle strength; accordingly, this study investigates the effects of two types of thoracolumbosacral braces on gait kinetics and muscle activities during walking before and after puberty in kyphosis child.

Methods: A total of 40 (20 boys and 20 girls) with kyphosis volunteered to participate in this study. The participants were divided into four equal groups (boys before and after puberty and girls before and after puberty). Kinetic and electromyography data were recorded during walking.

Results: Significant decreases and medium to large bracing effects for peak vertical and lateral ground reaction forces during heel contact were observed. Meanwhile, there were significant increases and medium to large-sized bracing effects for gas-med and biceps femoris activities during the loading phase of walking.

Conclusion: Lower vertical ground reaction force at brace conditions demonstrates the improvement of gait efficiency before and after puberty.

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Highlights

- This research utilized biomechanical methodologies through muscle activities to understand the difference between simple and sensory thorocolumbosacral braces in males with kyphosis.
- The brace conditions demonstrate an improvement in gait efficiency before and after puberty.
- Thorocolumbosacral braces can decrease the risk factors of deformity in people with kyphosis.
- Due to the higher walking speed, lower vertical ground reaction force, improved muscle activity while using braces, and a lower loading rate in the bracing condition compared with the non-bracing condition, it is advisable to use thoracolumbosacral braces.

Plain Language Summary

The sacrum position, the angle of thoracic kyphosis, and lumbar lordosis change with growth. Postural alterations lead to deformity in children's and adolescents' postures. Increased thoracic kyphosis is related to a decline in physical performance, postural control, lower walking speed, and reduced household activity performance. Bracing has been used as the most effective nonoperative treatment for individuals with mild idiopathic scoliosis and kyphosis. Previous studies have shown improvements in kyphosis angle amon after using braces. However, there is currently limited knowledge about the walking characteristics of people with kyphosis before and after puberty and the effect of a thoracolumbar brace on walking characteristics. Accordingly, this study investigates the effects of two types of thoracolumbosacral braces on gait kinetics and muscle activities during walking before and after puberty in kyphosis children. A total of 40 participants (20 boys and 20 girls) with kyphosis volunteered to participate in this study. The participants were divided into four equal groups (boys before and after puberty and girls before and after puberty). The participants were recruited in December 2019 from the physical therapy clinics in Ardabil City, Iran. To estimate the maturity status of our participants, a maturity index (i.e. timing of maturation) was calculated. This assessment is non-invasive and of high practical relevance to predict years from peak height-velocity as a measure of maturity offset. Kinetic and electromyography data were recorded during walking. Statistical analysis was done via a two-way analysis of variance with repeated measures. Accordingly, significant decreases and medium-to-large-sized bracing effects for the peak of vertical and lateral ground reaction forces during heel contact were observed and there were significant increases and medium- to large-sized bracing effects for gas-med and biceps femoris activities during the loading phase of walking. Higher walking speed, lower vertical ground reaction force, effective muscle activity with braces, and difference in loading rate in the bracing group compared with the without bracing group demonstrate the improvement of gait efficiency in the periods before and after puberty.

Introduction

The spine is a complex structure of the body, consisting of vertebrae, discs, muscles and many ligaments [1]. The weakness of spinal muscles could lead to static, dynamic and stature unbalance in different individuals called misalignment [2]. Spinal alignment in the sagittal plane is altered as a child grows. The sacrum position, the angle of thoracic kyphosis and lumbar lordosis change with growth [3]. Postural alterations lead to deformity in children's and adolescents' posture [4].

Increasing the angle of thoracic kyphosis has unfavorable results for the respiratory system [5]. Moreover, increased thoracic kyphosis is related to a decline in physical performance, postural control, lower walking speed, and reduced household activity performance [6, 7]. Bracing has been used as the most effective nonoperative treatment for individuals with mild idiopathic scoliosis and kyphosis [8, 9]. Previous studies have shown improvements in kyphosis angle after using braces [10, 11].

On the other hand, lower hamstring muscle strength [12] and delayed onset of vastus medialis activation [13] have been observed in girls at later compared to earlier stages of puberty. While these findings indicate that female pubertal development may be associated with po-

tentially suboptimal changes in neuromuscular function, there is a lack of substantive evidence to support these claims [14]. There is currently limited knowledge about the walking characteristics of people with kyphosis before and after puberty and the effect of a thoracolumbar brace on walking characteristics. Accordingly, this study investigates the effects of two types of thoracolumbosacral braces on gait kinetics and muscle activities during walking before and after puberty in kyphosis children.

Materials and Methods

Study participants

A total of 40 participants (20 boys and 20 girls) with kyphosis volunteered and provided their written informed consent to participate in this study. The patients were recruited in December 2019 from physical therapy clinics in Ardabil City, Iran. An orthopedic surgeon in a local clinic assessed all subjects before selection. To estimate the maturity status of our participants, a maturity index (i.e. timing of maturation) was calculated [15]. This assessment is non-invasive and therefore of high practical relevance to predict years from peak height- velocity (PHV) as a measure of maturity offset. Previously, this method has proven to be a valid tool for the estimation of maturity status [16]. According to the analyses, all of the participants were classified as pre-PHV (Table 1). Thus, 40 boys and girls with kyphosis were divided into four groups.

Braces

To design a new corrective and wireless thoracolumbar brace, we made a thoraco-lumbo-sacral support. Its triangular design provides a good distribution of pressure on the shoulder, suitable for all ages, and adjustable hook and loop closure facilitates proper fastening [17]. The support structure of the present brace consists of six straps to adjust, an electronic enclosure, and two local stabilizers in which there is a bending sensor. The mobile application software (mobile app) of the designed brace could find out the bending angle and signal to the patient if the angle is more than the predefined angle by the vibration switch. To do this, the researcher must turn on the electronic circuit, then software and mobile phones connect with Bluetooth. Subsequently, the bending sensor data is transformed into the mobile app and it shows the amount of bending on your mobile phone.

Assessment of walking kinetics

A force plate (Bertec Corporation, Columbus, OH, United States) was used to record ground reaction force (GRF) data during walking at a sampling rate of 1000 Hz. The participants were asked to walk at a constant speed of ~1.00 m/s over an 18-m walkway. Three practice trials were performed to familiarize the participants with the test before performing five test trials with a 5-min rest between each trial to minimize the effects of fatigue. Kinetic data were processed as described by Jafarnezhadgero et al. (2022) [18]. GRFs were low pass filtered at 20 Hz (4th order Butterworth filter, zero lag). Specific gait characteristics (heel strike and toe-off) were identified using the Bertec force plate. For this purpose, a 10-N threshold was used to detect the stance phase of the gait cycle. The following dependent variables were extracted from GRF data Jafarnezhadgero et al. (2022) [18]. First ($FZ_{HC)}$ and second vertical peak force (FZ_{PO}). Braking (FY_{HC}) and propulsion forces (FY_{PO}) were recorded from the anterior-posterior force curve. From the medial-lateral curve, we calculated the positive (lateral) peak (FX_{HC}) which occurs right after heel contact. Moreover, we additionally assessed the negative peak which corresponds to the transfer of body mass to the contralateral limb (FX_{PO}). GRF amplitudes were normalized to body weight (BW) and reported in %BW. The load-

Table 1. Group-specific anthropometric characteristics of the participants

Characteristics	Mean±SD				P (Effect Size)
	Boys Before Puberty	Boys After Puberty	Girls Before Puberty	Girls After Puberty	
Age (y)	11.41±0.96	16.89±1.94	8.12±2.73	12.80±1.31	0.001* (0.990)
Body height (m)	1.23±0.09	1.61±0.07	1.21±0.03	1.53±0.06	0.001* (0.998)
Body mass (kg)	38.91±2.72	60.59±2.06	20.47±1.07	60.52±5.56	0.001* (0.955)
Curvature of kyphosis	46.17±4.28	47.61±13.65	43.36±14.36	48.14±23.21	0.240 (0.016)
Predicted peak height velocity (years from peak height velocity)	-2.16±0.01	4.91±0.06	-1.96±0.03	2.12±0.08	0.001* (0.905)

*P<0.05.

ing rate was defined as the slope between heel contact and FZ_{HC} on the vertical force curve. The free moment (FM) of the foot was also computed. Moreover, FM amplitudes were normalized concerning BW×height. All gait variables were averaged across five trials [19]. For stance phase analysis, GRF data were normalized to 101 data points.

Assessment of muscle activities

A wireless electromyography (EMG) system (EMG Pre-Amplifier, Biometrics Ltd., Nine Mile Point Ind. Est., Newport, United Kingdom) with eight pairs of bipolar Ag/AgCl surface electrodes (25 mm center-to-center distance, the input impedance of 100 MO, and common-mode rejection ratio of >110 dB) was used to record the activity of the tibialis anterior (TA), gastrocnemius medialis (Gas-M), biceps femoris (BF), semitendinosus (ST), vastus lateralis (VL), vastus medialis (VM), erector spinal (ES), and gluteus medius (Glut-M) muscles of the right leg [20]. A die-cut medical-grade double-sided adhesive tape (T350, Biometrics Ltd., Nine Mile Point Ind. Est., Newport, United Kingdom) was used to attach the electrodes to the muscle bellies. The raw EMG signals were digitized at 1000 Hz and streamed via Bluetooth to a computer for further analysis. According to the European recommendations for surface EMG (SENIAM), the skin surface was shaved and cleaned with alcohol (70% Ethanol–C_2H_5OH) over the selected muscles [20]. Thereafter, the skin was gently abraded before electrode placement [20]. GRF and EMG data were synchronized using the Nexus software, version 2.13 (Oxford Metrics, Oxford, United Kingdom). For EMG analyses, the gait cycle was divided into the following phases: Loading phase (0-20% of the gait cycle), mid-stance (20-47% of the gait cycle), and push-off (47-70% of the gait cycle) [21]. Using a handheld dynamometer, maximum voluntary isometric contraction (MVIC) was assessed for each recorded muscle to normalize EMG during walking to MVIC. All normalization procedures were realized following recommendations from a study [22]. For example, the participants were encouraged to perform the tests at maximal effort [23]. Three test trials were conducted with 1-2 min rest periods in between tests [23]. For measuring MVIC, an isometric belt (where the joint is locked) was used (set for zero velocity) [23]. This instrument is important to control testing factors that can influence the output and facilitate the production of maximal contraction. The maximum value of the MVIC test was considered for normalization purposes [22, 23].

Statistical analysis

The prior calculation of the sample size indicated that at least 40 subjects were required. For calculation, G*Power software, version 3.1.2.9, was used with a statistical power of 0.80 at an effect size of 0.80 with an α level of 0.05 and the respective statistical test based on a related study that examined walking in kyphosis patients [24, 25]. The Shapiro-Wilk test was used to confirm the normal distribution of data. The statistical analysis was done by two-way analysis of variance with repeated measures. Additionally, the effect sizes were determined by partial Eta-squared (η^2_p). The significance level was set at $P<0.05$. All analyses were performed using the SPSS software, version 26.

Results

Walking kinetics

The results demonstrated significant main effects of brace for FZ_{HC} (P=0.021, d=0.348), FZ_{PO} (P=0.024, d=0.317), FY_{PO} (P=0.001, d=0.768), FX_{PO} (P=0.001, d=0.513), impulse (imp)fx (P=0.011, d=0.519), Imp_{FZ} (P=0.004, d=0.547), FM_{MAX} (P=0.001, d=0.716), and FM_{Min} (P=0.009, d=0.809). The paired-wise comparison revealed significantly greater FY_{PO}, FX_{PO}, Imp_{FZ}, FM_{MAX}, and FM_{Min} (Table 1). The findings showed significant main effect of group for FZ_{HC} (P=0.021, d=0.348), FZ_{PO} (P=0.024, d=0.317), FY_{HC} (P=0.001, d=0.768), FY_{PO} (P=0.001, d=0.768), FX_{HC} (P=0.001, d=0.513), time to reach the peak FY_{HC} (P=0.001, d=0.513), time to reach the peak FY_{PO} (P=0.001, d=0.513), Imp_{FY} (P=0.011, d=0.519), Imp_{FZ} (P=0.004, d=0.547) and FM_{MAX} (P=0.001, d=0.716). The paired-wise comparison revealed significantly lower FZ_{HC}, FZ_{PO}, and Imp_{FX} activities in the sensory support group than in the non-support group. Furthermore, significant group-by-time interactions were found for all variables (Table 2).

Muscle activities

The results demonstrated significant main effects of brace for gas-med activity during the loading phase (P=0.035, d=0.581). The paired-wise comparison revealed significantly greater gas-med activity with brace increases. The findings showed a significant main effect of the group for glut-mid (P=0.004, d=0.310) and semitendinosus (P=0.021, d=0.204) during the loading phase. Meanwhile, the paired-wise comparison revealed significantly greater TA activity in the sensory support group than in the non-support group. Furthermore, significant group-by-time interactions were found for all muscle activity during the loading phase ($P<0.05$) (Table 3).

Table 2. Ground reaction force amplitudes three condition during walking

Component	Mean±SD							
	Non-support				Simple Support			
	Male		Female		Male		Female	
	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty
FZ_{Hc} (%BW)	946.40±253.36	779.65±201.06	592.06±101.85	665.47±132.79	842.49±248.94	854.97±270.22	582.60±121.17	654.31±109.87
F_{Zpo} (%BW)	909.42±174.28	825.82±177.27	636.69±87.25	717.73±124.77	841.98±153.49	871.19±239.51	630.82±105.75	724.41±114.73
FY_{HC} (%BW)	51.32±20.79	55.36±14.01	46.88±7.23	68.09±17.91	69.98±24.23	48.21±18.78	43.22±13.35	66.77±21.42
FY_{po} (%BW)	78.07±39.49	49.62±27.05	93.06±22.64	104.73±20.38	115.04±95.34	51.06±23.54	88.63±17.63	99.60±20.84
FX_{HC} (%BW)	38.65±28.20	47.99±28.19	25.53±11.51	25.42±16.38	50.04±33.60	61.77±49.20	25.36±13.79	22.94±23.34
FX_{po} (%BW)	46.68±23.53	45.79±52.85	22.74±7.07	28.63±13.20	20.20±97.37	45.46±34.62	27.78±6.27	35.63±22.45
TTP FX_{HC} (ms)	604.69±86.04	364.04±93.25	65.61±38.43	64.70±84.17	308.52±24.56	397.29±96.97	138.40±59.40	38.20±50.56
TTP FX_{po} (ms)	306.40±278.79	265.96±129.86	377.28±185.23	380.10±136.15	330.91±250.39	263.31±203.87	271.40±154.04	294.85±225.64
TTP FY_{HC} (ms)	420.96±280.82	494.59±249.71	131.65±66.75	120.80±26.03	304.91±183.78	471.44±291.21	115.85±43.49	118.80±26.87
TTP FY_{PO} (ms)	490.35±249.51	286.44±184.84	608.71±79.36	593.05±74.18	456.77±230.43	313.06±198.23	574.80±102.13	598.40±55.79
TTP FZ_{HC} (ms)	231.23±59.18	184.33±24.52	193.33±41.70	175.10±31.06	195.68±66.67	195.19±28.40	180.25±46.76	174.35±37.47
TTP FZ_{po} (%BW)	647.43± 97.63	598.47± 64.87	541.03± 79.04	526.45± 57.17	604.05± 104.64	629.06± 145.82	505.25± 90.85	523.60± 47.80
Imp_{FX}	833.85±148.11	737.36±466.73	963.93±149.29	984.27±590.89	839.27±957.89	839.46±469.93	727.21±185.06	983.54±157.19
Imp_{FY}	399.30±33.70	322.31±979.37	894.81±7113.38	897.64±12812.17	634.91±393.28	233.07±49.75	563.97±49.75	950.69±52.15
Imp_{FZ}	573.83±24.26	232.88±76.46	143.51±97.67	247.16±38.81	930.18±37.29	494.26±30.11	762.16±64.14	901.96±90.21
Fm_{max}	19.54±14.60	25.40±18.65	7.24±2.72	10.10±3.63	18.90±12.49	23.33±15.55	9.69±6.29	10.35±5.11
Fm_{min}	4.88±3.87	3.09±2.95	2.37±2.55	1.92±1.57	2.82±2.50	4.13±4.53	2.22±2.68	2.77±2.61

PHYSICAL TREATMENTS

Component	Mean±SD				P (Effect Size)		
	Sensory Support						
	Male		Female				
	Before Puberty	After Puberty	Before Puberty	After Puberty	Main Effect: Brace	Main Effect: Group	Interaction: Group-Time
FZ_{Hc} (%BW)	733.59±227.16	897.69±238.06	792.03± 196.61	585.31±88.06	0.021* (0.348)	0.001* (0.866)	0.001* (0.957)
F_{Zpo} (%BW)	767.10±183.68	890.50±124.84	844.51±173.65	651.81±84.27	0.024* (0.317)	0.001* (0.384)	0.001* (0.976)
FY_{HC} (%BW)	74.78±26.87	54.02±26.66	48.77±17.07	69.66±24.85	0.294 (0.017)	0.014* (0.251)	0.001* (0.933)
FY_{po} (%BW)	81.82±47.62	43.16±32.86	89.40±23.72	105.96±16.15	0.001* (0.768)	0.002* (0.328)	0.001* (0.884)

Component	Mean±SD				P (Effect Size)		
	Sensory Support						
	Male		Female				
	Before Puberty	After Puberty	Before Puberty	After Puberty	Main Effect: Brace	Main Effect: Group	Interaction: Group-Time
FX_{HC} (%BW)	44.25±32.68	62.69±37.67	25.61±12.23	31.99±13.14	0.838 (0.004)	0.013* (0.257)	0.001* (0.746)
FX_{po} (%BW)	51.39±20.51	62.20±33.29	24.23±8.21	29.59±13.69	0.001* (0.513)	0.188 (0.012)	0.001* (0.303)
TTP FX_{HC} (ms)	398.92±287.22	410.28±272.0	30.75±10.32	71.80±53.46	0.396 (0.026)	0.001 (0.536)	0.001* (0.690)
TTP FX_{po} (ms)	267.33±179.62	166.15±152.95	258.55±140.42	360.50±145.34	0.752 (0.005)	0.415 (0.075)	0.001* (0.811)
TTP FY_{HC} (ms)	313.90±38.10	505.29±271.11	91.45±32.75	107.35±26.65	0.311 (0.035)	0.001* (0.541)	0.001* (0.765)
TTP FY_{PO} (ms)	440.86±179.97	334.57±181.13	570.25±68.47	564.80±49.77	0.595 (0.032)	0.001* (0.436)	0.001* (0.935)
TTP FZ_{HC} (ms)	195.35±56.49	193.40±37.05	176.55±26.48	186.10±44.01	0.196 (0.009)	0.174 (0.027)	0.001* (0.978)
TTP FZ_{po} (%BW)	635.16±142.70	619.79±119.09	500.45± 63.71	494.95±52.31	0.472 (0.041)	0.002* (0.344)	0.001* (0.983)
Imp_{FX}	138.95±133.70	682.27±979.37	976.21±722.48	184.66±64.53	0.011* (0.519)	0.257 (0.052)	0.001* (0.629)
Imp_{FY}	612.07±254.45	311.98±355.32	823.93±575.98	762.36±380.41	0.123 (0.012)	0.018* (0.241)	0.001* (0.759)
Imp_{FZ}	708.66±41.49	709.51±26.60	912.03±992.16	397.08±162.50	0.004* (0.547)	0.019* (0.238)	0.001* (0.776)
Fm_{max}	20.09±14.32	23.13±15.49	7.10±2.15	12.22±2.63	0.001* (0.716)	0.001* (0.338)	0.001* (0.751)
Fm_{min}	5.41±4.71	3.84±2.92	2.04±1.50	2.17±1.34	0.009* (0.809)	0.095 (0.160)	0.001* (0.689)

*P<0.05.

PHYSICAL TREATMENTS

Abbreviations: FX_{HC}: Maximum lateral force at heel contact; FX_{PO}: Maximum medial at push off; FY_{HC}: Braking force; FY_{PO}: Push off force; FZ_{HC}: First maximum of vertical force; FZ_{PO}: Second maximum force; TTP: Time to reach peak; FM: Free moment; Imp: Impulse.

The results demonstrated significant main effects of brace for VL (P=0.009, d=0.741) and BF (P=0.046, d=0.861) activity during the mid-stance phase. The paired-wise comparison revealed significantly greater VL and BF activities with brace increases. The findings showed a significant main effect of the group for TA (P=0.003, d=0.317) during the mid-stance phase. Meanwhile, the paired-wise comparison revealed significantly greater TA activity in the Sensory support group than in the non-support group. Furthermore, significant group-by-time interactions were found for all muscle activity during the mid-stance phase (P<0.05) (Table 4).

The findings showed a significant main effect of group for TA (P=0.015, d=0.249), gas-mid (P=0.001, d=0.418), VL (P=0.002, d=0.334), semitendinosus (P=0.001, d=0.375), Gult-Mid (P=0.019, d=0.240) and erector spinal (P=0.013, d=0.257) during push-off phase. The paired-wise comparison revealed significantly greater

Table 3. Muscle activity during three conditions at loading phase

Variables	Mean±SD							
	Non-support				Simple Support			
	Male		Female		Male		Female	
	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty
TA	81.10±16.25	98.50±19.40	92.70±16.10	91.40±15.74	89.50±22.51	93.30±34.80	137.80±57.63	116.30±51.14
Gas-M	85.20±17.39	110.90±67.93	92.70±16.10	91.70±20.45	105.80±28.85	120.70±37.94	106.30±24.94	105.60±15.95
VL	78.81±26.86	87.23±40.11	88.94±26.47	91.57±28.39	85.21±30.89	74.03±33.96	89.71±31.59	96.42±33.94
VM	73.33±31.52	89.86±36.73	71.51±19.34	83.43±28.64	93.81±40.51	93.25±38.32	70.48±20.24	86.93±35.73
BF	70.81±24.76	86.33±25.14	102.30±34.89	98.12±38.54	98.62±49.32	87.98±30.71	82.53±27.44	88.20±41.47
ST	112.33±55.77	102.41±31.58	97.80±24.59	96.53±32.45	130.27±39.19	96.99±44.04	89.70±29.82	98.48±28.11
Glut-M	94.66±42.46	98.54±38.00	83.71±15.80	87.97±28.38	122.95±41.14	96.77±17.83	107.01±55.11	99.52±49.04
Erector spinal	77.42±34.06	81.04±29.49	91.09±13.42	75.73±21.55	89.47±59.55	89.51±42.58	98.36±17.63	82.20±24.00

Variables	Mean±SD				P (Effect Size)		
	Sensory Support						
	Male		Female				
	Before Puberty	After Puberty	Before Puberty	After Puberty	Main Effect: Brace	Main Effect: Group	Interaction: Group- Brace
TA	88.80±16.34	77.40±28.83	135.60±72.67	169.30±88.47	0.084 (0.884)	0.004* (0.310)	0.001* (0.940)
Gas-M	106.40±55.85	93.80±37.38	104.30±23.87	100.20±16.37	0.035* (0.851)	0.791 (0.025)	0.001* (0.953)
VL	64.32±24.93	75.01±24.65	86.52±27.40	96.31±29.54	0.546 (0.026)	0.248 (0.107)	0.001* (0.939)
VM	91.74±32.37	94.11±49.68	82.96±26.96	69.88±30.23	0.704 (0.081)	0.246 (0.107)	0.001* (0.951)
BF	94.18±52.13	75.25±32.11	96.64±38.59	110.14±48.01	0.054 (0.248)	0.511 (0.069)	0.001* (0.939)
ST	105.84±39.26	77.65±38.27	78.11±21.97	85.16±30.06	0.752 (0.084)	0.021* (0.204)	0.001* (0.961)
Glut-M	105.00±30.41	84.06±44.10	90.48±33.47	104.44±30.01	0.095 (0.881)	0.495 (0.063)	0.001* (0.951)
Erector spinal	63.40±29.17	61.65±28.19	99.81±26.02	95.05±15.59	0.065 (0.274)	0.187 (0.087)	0.001* (0.941)

PHYSICAL TREATMENTS

Abbreviations: TA: Tibialis anterior; Gas-M: Gastrocnemius medialis; VM: Vastus medialis; VL: Vastus lateralis; BF: Biceps femoris; ST: Semitendinosus; Glut-M: Gluteus medius; SD: Standard deviation.

*P<0.05.

Table 4. Muscle activity during three conditions at mid-stance phase

Variables	Mean±SD							
	Non-support				Simple Support			
	Male		Female		Male		Female	
	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty
TA	103.03±41.31	102.86±23.63	87.13±21.47	85.28±22.55	92.52±16.64	96.36±18.45	82.61±20.47	89.25±21.07
Gas-M	90.80±18.22	88.85±14.04	99.88±27.80	94.58±19.63	94.65±37.22	96.21±17.86	106.76±26.87	108.55±22.72
VL	72.91±40.29	73.77±15.58	78.44±11.80	77.71±21.27	64.93±27.68	64.41±15.26	79.01±24.36	85.69±20.49
VM	64.48±19.20	66.22±14.75	69.67±10.55	70.52±16.01	83.51±20.48	74.93±17.46	68.61±14.70	71.96±21.98
BF	67.67±26.52	79.03±21.29	70.20±18.73	61.52±16.07	87.87±24.58	74.78±22.16	73.40±8.48	65.46±18.51
ST	65.79±19.36	76.33±21.41	78.68±17.51	65.21±14.17	100.51±39.47	78.35±31.79	88.01±23.01	69.55±17.83
Glut-M	85.61±26.52	72.93±28.74	69.95±15.95	75.02±14.32	110.01±50.34	81.91±19.88	89.76±16.99	70.66±21.99
Erector spinal	61.50±21.81	61.04±14.67	69.48±19.31	56.20±14.89	80.14±32.14	59.61±22.19	85.23±33.29	79.10±30.24

Variables	Mean±SD				P (Effect Size)		
	Sensory Support						
	Male		Female		Main Effect: Brace	Main Effect: Group	Interaction: Group-Brace
	Before Puberty	After Puberty	Before Puberty	After Puberty			
TA	116.37±51.18	97.92±29.40	75.19±25.20	69.56±27.02	0.428 (0.055)	0.003* (0.317)	0.001* (0.974)
Gas-M	118.37±55.66	84.91±31.85	107.87±20.48	115.67±21.79	0.215 (0.048)	0.320 (0.092)	0.001* (0.962)
VL	94.51±47.21	67.99±24.09	82.09±22.51	83.01±21.32	0.009* (0.741)	0.251 (0.106)	0.001* (0.965)
VM	97.21±47.05	68.94±19.47	72.28±13.39	66.07±18.41	0.231 (0.026)	0.142 (0.132)	0.001* (0.971)
BF	82.84±42.84	76.83±30.58	73.71±15.23	71.81±15.29	0.046* (0.861)	0.190 (0.122)	0.001* (0.968)
ST	84.48±47.64	67.65±22.60	81.13±27.61	78.58±16.88	0.193 (0.098)	0.147 (0.137)	0.001* (0.971)
Glut-M	93.38±31.62	90.75±22.01	89.51±13.37	92.39±16.95	0.126 (0.096)	0.111 (0.152)	0.001* (0.968)
Erector spinal	81.61±41.03	61.42±36.25	92.66±30.47	85.61±16.99	0.230 (0.014)	0.146 (0.137)	0.001* (0.933)

PHYSICAL TREATMENTS

Abbreviations: TA: Tibialis anterior; Gas-M: Gastrocnemius medialis; VM: Vastus medialis; VL: Vastus lateralis; BF: Biceps femoris; ST: Semitendinosus; Glut-M: Gluteus medius; SD: Standard deviation.

*P<0.05.

Table 5. Muscle activity during three conditions at push-off phase

Variables	Mean±SD							
	Non-support				Simple Support			
	Male		Female		Male		Female	
	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty
TA	92.96±26.84	103.85±35.38	82.49±23.81	74.13±21.63	100.34±17.22	83.34±18.64	82.49±17.98	80.92±21.55
Gas-M	75.36±21.23	81.59±21.44	106.84±13.19	98.71±24.98	86.96±20.97	87.49±16.32	104.35±12.22	117.23±23.36
VL	58.52±9.41	75.54±16.48	88.76±29.74	84.10±39.04	59.70±12.60	67.21±18.20	94.31±22.28	102.62±29.81
VM	75.81±22.22	91.94±30.00	74.85±20.63	93.71±43.94	55.90±10.96	77.91±29.65	93.20±51.51	97.06±53.11
BF	77.21±25.48	81.15±25.57	96.63±39.66	104.40±78.64	69.67±24.71	83.49±35.36	111.72±48.98	98.91±49.82
ST	54.86±15.51	73.67±22.32	105.61±35.91	111.37±55.53	70.84±32.29	90.22±28.76	145.11±47.92	106.38±30.32
Glut-M	83.57±32.84	83.87±28.94	98.21±30.69	91.84±30.87	76.72±18.41	86.83±16.41	108.79±33.76	83.85±35.11
Erector spinal	59.52±18.88	68.10±17.64	83.13±17.32	77.68±31.51	65.19±35.43	72.27±36.81	74.93±21.80	93.74±43.34

Variables	Mean±SD				P (Effect Size)		
	Sensory Support				Main Effect: Brace	Main Effect: Group	Interaction: Group-Brace
	Male		Female				
	Before Puberty	After Puberty	Before Puberty	After Puberty			
TA	85.48±13.52	93.87±21.04	79.45±20.57	63.06±15.35	0.310 (0.039)	0.015* (0.249)	0.001* (0.970)
Gas-M	80.81±38.34	94.06±18.08	105.83±17.86	112.42±20.60	0.281 (0.036)	0.001* (0.418)	0.001* (0.979)
VL	76.92±31.09	89.20±38.52	94.73±36.35	105.81±20.87	0.050 (0.268)	0.002* (0.334)	0.001* (0.955)
VM	70.41±28.30	73.87±15.34	100.62±44.95	84.90±39.54	0.303 (0.019)	0.148 (0.136)	0.001* (0.921)
BF	78.36±41.64	86.68±31.70	110.46±49.36	110.78±60.53	0.560 (0.098)	0.112 (0.151)	0.001* (0.894)
ST	84.01±52.93	91.72±19.39	106.22±52.92	119.71±26.72	0.503 (0.063)	0.001* (0.375)	0.001* (0.933)
Glut-M	69.33±35.48	65.41±20.01	96.52±28.75	113.10±32.28	0.429 (0.055)	0.019* (0.240)	0.001* (0.955)
Erector spinal	72.19±39.87	71.41±21.14	83.03±21.86	109.31±37.46	0.027* (0.486)	0.013* (0.257)	0.001* (0.948)

PHYSICAL TREATMENTS

Abbreviations: TA: Tibialis anterior; Gas-M: Gastrocnemius medialis; VM: Vastus medialis; VL: Vastus lateralis; BF: Biceps femoris; ST: Semitendinosus; Glut-M: Gluteus medius; SD: Standard deviation.

*P<0.05.

Table 6. Muscle activity during three conditions at swing phase

Variables	Mean±SD							
	Non-support				Simple Support			
	Male		Female		Male		Female	
	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty	Before Puberty	After Puberty
TA	216.78±288.35	117.72±32.58	127.99±66.42	129.86±68.92	117.09±39.57	155.79±30.49	125.20±44.81	116.00±43.63
Gas-M	122.89±32.15	130.64±48.58	161.79±56.90	148.25±68.72	150.39±47.05	143.09±45.26	161.11±50.56	151.30±38.58
VL	104.95±37.62	124.14±55.69	177.97±71.61	152.34±53.23	134.91±55.95	154.23±57.96	165.85±62.65	156.47±55.76
VM	111.27±54.02	132.69±53.65	209.97±66.35	176.59±79.63	147.11±73.44	207.21±83.44	170.00±88.64	164.97±51.19
BF	123.51±46.61	121.62±52.27	214.69±51.65	178.29±59.89	121.31±64.34	166.41±57.85	193.34±54.21	175.89±65.20
ST	127.44±48.88	132.46±65.38	183.01±62.91	173.30±48.47	133.69±45.32	173.71±78.61	181.55±65.04	150.10±61.88
Glut-M	109.29±24.64	111.35±56.87	202.68±72.13	179.41±44.25	154.09±90.26	149.56±51.33	185.38±47.89	178.58±53.05
Erector spinal	108.81±48.46	123.31±45.39	179.01±71.08	165.19±69.68	123.89±43.16	127.81±54.21	172.33±62.54	156.21±43.26

Variables	Mean±SD				P (Effect Size)		
	Sensory Support						
	Before Puberty (Male)	After Puberty (Male)	Before Puberty (Female)	After Puberty (Female)	Main Effect: Brace	Main Effect: Group	Interaction: Group-Brace
TA	105.29±45.74	162.31±60.65	118.33±65.54	81.46±19.57	0.001* (0.578)	0.493 (0.049)	0.001* (0.828)
Gas-M	99.24±40.32	173.17±48.97	187.01±66.99	144.98±58.13	0.514 (0.026)	0.066 (0.179)	0.001* (0.948)
VL	117.91±57.47	181.51±59.08	189.60±79.07	137.79±47.66	0.947 (0.011)	0.050 (0.193)	0.001* (0.925)
VM	113.19±59.86	211.21±79.57	220.62±75.51	177.55±102.36	0.234 (0.089)	0.008* (0.279)	0.001* (0.933)
BF	103.61±43.99	179.43±57.61	223.41±61.37	192.72±81.54	0.360 (0.046)	0.001* (0.463)	0.001* (0.952)
ST	101.11±52.83	189.00±65.61	196.19±85.08	170.58±105.28	0.289 (0.043)	0.038 (0.206)	0.001* (0.919)
Glut-M	92.58±17.79	172.79±65.41	221.61±69.30	191.39±71.67	0.096 (0.889)	0.001* (0.402)	0.001* (0.942)
Erector spinal	88.11±48.47	164.23±66.13	177.73±75.49	175.12±87.77	0.118 (0.097)	0.004* (0.309)	0.001* (0.930)

PHYSICAL TREATMENTS

Abbreviations: TA: Tibialis anterior; Gas-M: Gastrocnemius medialis; VM: Vastus medialis; VL: Vastus lateralis; BF: Biceps femoris; ST: Semitendinosus; Glut-M: Gluteus medius; SD: Standard deviation.

*P<0.05.

Gas-Med, Gult-Mid, and erector spinal activities in the sensory support group than in the non-support group. Furthermore, significant group-by-time interactions were found for all muscle activity during the mid-stance phase (P<0.05) (Table 5).

The results demonstrated significant main effects of the brace for TA activity during the swing phase (P=0.001, d=0.578). The paired-wise comparison revealed significantly lower TA activity with brace increases. Findings showed a significant main effect of group for VM (P=0.008, d=0.279), BF (P=0.001, d=0.463), glut-M (P=0.001, d=0.402), and erector spinal (P=0.004, d=0.309) during swing phase. The paired-wise comparison revealed significantly greater VM, BF, Glut-M, and erector spinal activities in the sensory support group than in the non-support group. Furthermore, significant group-by-time interactions were found for all muscle activity during the swing phase (P<0.05) (Table 6).

Discussion

This study investigates the effects of two types of thrcolumbosacral braces on gait kinetics and muscle activity before and after puberty in kyphosis patients.

Walking kinetics

The results suggest that the bracing decreased GRF during walking. There is sufficient evidence of the association between increased GRF and lower extremity injury [26]. This result is consistent with previous studies suggesting that bracing could decrease GRF during walking [27]. Farahpour et al. argued that increased GRF during walking might lead to lumbar dysfunction [24]. From this point of view, our therapy may result in clinical improvement in patients with kyphosis. The findings demonstrated bracing increases the first lateral ground reaction forces during heel contact and push-off phase by 17.8% and 20.79%, respectively.

Muscle activities

The results of this study showed significant increases in medium- to large-sized bracing effects for gas-med and BF activities during the loading phase of walking and VL, BF, and TA activities at mid-stance, gas-mid, VL, ST, glut-mid, and erector spinal activities at push-off phase, and VM, BF, and erector spinal activities at swing phase. The activity of the TA muscle in this phase was not associated with the strong coupling activation of the tibialis posterior muscle [28]. In a study where electromyography and cinematography were synchronized [29], the authors reported that there was a high level of VL and VM activity at the initial stance phase, followed by a co-contraction of the ankle muscle to ensure stability, allowing for the downward force of the walker to be absorbed and total body stabilization achieved in preparation for the drive phase. On the other these authors also reported increasing EMG activity of the BF in this early support phase, with EMG activity rising to a higher level about middle stance and related to an increase in flexion of knee joint [29] are in consistent with the results of our study.

Also, the results of our study showed significant decreases and large-sized training effects for TA and Glut-M activities during the push-off phase and TA activities during walking at the swing phase.

Conclusion

Higher walking speed, lower vertical ground reaction force, effective muscle activity with braces, and difference loading rate in the bracing group compared with the without bracing group demonstrate the improvement of gait efficiency in the periods before and after puberty.

Ethical Considerations

Compliance with ethical guidelines

Ethical approval for research involving human participants was obtained from the Ardabil University of Medical Sciences, Ardabil, Iran (Code: IR.ARUMS.REC.1399.255).

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Authors' contributions

All authors contributed equally to the conception and design of the study, data collection and analysis, interpretation of the results and drafting of the manuscript. Each author approved the final version of the manuscript for submission.

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Rezvankhah N, Alizadeh M H, Kordi M R. The effect of four months of detraining following eight months of corrective exercises on lumbar lordosis of schoolgirls. Annals of Applied Sport Science. 2013; 1(2):19-24. [Link]

[2] Yazici AG, Mohammadi M. Exercise. The effect of corrective exercises on the thoracic kyphosis and lumbar lordosis of boy students. Turkish Journal of Sport and Exercise. 2017; 19(2):177-81. [DOI:10.15314/tsed.293311]

[3] Cil A, Yazici M, Uzumcugil A, Kandemir U, Alanay A, Alanay Y, et al. The evolution of sagittal segmental alignment of the spine during childhood. Spine. 2005; 30(1):93-100. [DOI:10.1097/01.brs.0000149074.21550.32] [PMID]

[4] Kratenová J, Zejglicová K, Malý M, Filipová V. Prevalence and risk factors of poor posture in school children in the Czech Republic. The Journal of School Health. 2007; 77(3):131-7. [DOI:10.1111/j.1746-1561.2007.00182.x] [PMID]

[5] Rajabi R, Seidi F, Mohamadi F. Which method is accurate when using the flexible ruler to measure the lumbar curvature angle"? deep point or mid-point of arch? World Applied Sciences Journal. 2008; 4(6):849-52. [Link]

[6] Balzini L, Vannucchi L, Benvenuti F, Benucci M, Monni M, Cappozzo A, et al. Clinical characteristics of flexed posture in elderly women. Journal of the American Geriatrics Society. 2003; 51(10):1419-26. [DOI:10.1046/j.1532-5415.2003.51460.x] [PMID]

[7] Ryan SD, Fried LP. The impact of kyphosis on daily functioning. Journal of the American Geriatrics Society. 1997; 45(12):1479-86. [DOI:10.1111/j.1532-5415.1997.tb03199.x] [PMID]

[8] Katz DE, Richards BS, Browne RH, Herring JA. A comparison between the Boston brace and the Charleston bending brace in adolescent idiopathic scoliosis. Spine. 1997; 22(12):1302-12. [DOI:10.1097/00007632-199706150-00005] [PMID]

[9] Lonstein JE, Winter RB. The Milwaukee brace for the treatment of adolescent idiopathic scoliosis. A review of one thousand and twenty patients. The Journal of Bone and Joint Surgery. 1994; 76(8):1207-21. [DOI:10.2106/00004623-199408000-00011] [PMID]

[10] Pfeifer M, Begerow B, Minne HW. Effects of a new spinal orthosis on posture, trunk strength, and quality of life in women with postmenopausal osteoporosis: A randomized trial. American Journal of Physical Medicine & Rehabilitation. 2004; 83(3):177-86. [DOI:10.1097/01.PHM.0000113403.16617.93] [PMID]

[11] Hamlabadi MP, Jafarnezhadgero A. The effect of 8 sessions of Thera-band exercises on the joint position sense of the knee and ankle in diabetic patients with osteoarthritis of the knee. Journal of Arak University of Medical Sciences. 2021; 12(1):31-43. [Link]

[12] Wild CY, Steele JR, Munro BJ. Insufficient hamstring strength compromises landing technique in adolescent girls. Medicine and Science in Sports and Exercise. 2013; 45(3):497-505. [DOI:10.1249/MSS.0b013e31827772f6] [PMID]

[13] Wild CY, Munro BJ, Steele JR. How young girls change their landing technique throughout the adolescent growth spurt. The American Journal of Sports Medicine. 2016; 44(5):1116-23. [DOI:10.1177/0363546516629419] [PMID]

[14] Sayer TA, Hinman RS, Paterson KL, Bennell KL, Hall M, Allison K, Bryant AL. Running-related muscle activation patterns and tibial acceleration across puberty. Journal of Electromyography and Kinesiology. 2020; 50:102381. [DOI:10.1016/j.jelekin.2019.102381] [PMID]

[15] Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N, et al. Enhancing a somatic maturity prediction model. Medicine and Science in Sports and Exercise. 2015; 47(8):1755-64. [DOI:10.1249/MSS.0000000000000588] [PMID]

[16] Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. Champaign: Human kinetics; 2004. [DOI:10.5040/9781492596837]

[17] Piran haml abadi M, Jafarnezhadgero A, Anoushirvani S. A preliminary design of new corrective and wireless thoracolumbar bracing for individuals with functional thoracolumbar kyphosis. Journal of Advanced Sport Technology. 2019; 3(1):33-6. [Link]

[18] Jafarnezhadgero AA, Hamlabadi MP, Sajedi H, Granacher U. Recreational runners who recovered from COVID-19 show different running kinetics and muscle activities compared with healthy controls. Gait & Posture. 2022; 91:260-5. [DOI:10.1016/j.gaitpost.2021.11.002] [PMID] [PMCID]

[19] Jafarnezhadgero A, Fatollahi A, Amirzadeh N, Siahkouhian M, Granacher U. Ground reaction forces and muscle activity while walking on sand versus stable ground in individuals with pronated feet compared with healthy controls. Plos One. 2019; 14(9):e0223219. [DOI:10.1371/journal.pone.0223219] [PMID] [PMCID]

[20] Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, Rau G, et al. European recommendations for surface electromyography. Roessingh Research and Development. 1999; 8(2):13-54. [Link]

[21] Jafarnezhadgero A, Ghorbanloo F, Fatollahi A, Dionisio VC, Granacher U. Effects of an elastic resistance band exercise program on kinetics and muscle activities during walking in young adults with genu valgus: A double-blinded randomized controlled trial. Clinical Biomechanics. 2021; 81:105215. [DOI:10.1016/j.clinbiomech.2020.105215] [PMID]

[22] Emami S, Jafarnezhadgero A, Piran Hamlabadi M. The effect of knee orthosis on co-contraction values of knee and ankle muscles during running in people with knee deformity in the frontal plane. Journal of Rehabilitation Research in Nursing. 2022; 8(4):76-87. [Link]

[23] Besomi M, Hodges PW, Clancy EA, Van Dieën J, Hug F, Lowery M, et al. Consensus for experimental design in electromyography (CEDE) project: Amplitude normalization matrix. Journal of Electromyography and Kinesiology. 2020; 53:102438. [DOI:10.1016/j.jelekin.2020.102438] [PMID]

[24] Farahpour N, Jafarnezhad A, Damavandi M, Bakhtiari A, Allard P. Gait ground reaction force characteristics of low back pain patients with pronated foot and able-bodied individuals with and without foot pronation. Journal of Biomechanics. 2016; 49(9):1705-10. [DOI:10.1016/j.jbiomech.2016.03.056] [PMID]

[25] Farahpour N, Jafarnezhadgero A, Allard P, Majlesi M. Muscle activity and kinetics of lower limbs during walking in pronated feet individuals with and without low back pain. Journal of Electromyography and Kinesiology. 2018; 39:35-41. [DOI:10.1016/j.jelekin.2018.01.006] [PMID]

[26] Sharma J, Heagerty R, Dalal S, Banerjee B, Booker T. Risk factors associated with musculoskeletal injury: A prospective study of british infantry recruits. Current Rheumatology Reviews. 2019; 15(1):50-8. [DOI:10.2174/1573397114666180430103855] [PMID]

[27] Hamlabadi MP, Jafarnezhadgero A, Anoushirvani S. [The effect of two types of thoracolumbosacral braces on electromyography activity and pain index in patients with low back pain during walking (Persian)]. Anesthesiology and Pain. 12(1):1-10. [Link]

[28] Hunt AE, Smith RM, Torode M. Extrinsic muscle activity, foot motion and ankle joint moments during the stance phase of walking. Foot & Ankle International. 2001; 22(1):31-41. [DOI:10.1177/107110070102200105] [PMID]

[29] Elliott BC, Blanksby BA. The synchronization of muscle activity and body segment movements during a running cycle. Medicine and Science in Sports. 1979; 11(4):322-7. [DOI:10.1249/00005768-197901140-00002] [PMID]

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