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脊柱矯具對於自發性脊柱側彎女性患者之動態表現

The Dynamic Effects of Custom-Made Spinal Orthoses on Females with Adolescent Idiopathic Scoliosis

蔡燕怡

Yen-Yi Tsai

指導教授：章良渭 博士

Advisor: Liang-Wey Chang, Ph.D.

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Abstract

Background. Few studies have discussed the dynamic effects of spinal orthotic intervention on patients with adolescent idiopathic scoliosis (AIS), nor have they investigated the motion adaptation on them.

Objectives. The objectives of this study is three-fold: 1) To evaluate dynamic and static balance between AIS patients and normal subjects; 2) to investigate the dynamic and static balance effects of spinal orthotic intervention in the AIS patients during investigative periods of immediate in-brace wearing and after four-month in-brace treatment; 3) to evaluate the motion adaptation after four-month brace treatment in the AIS patients.

Design. A prospective cohort study was performed for this investigation.

Participants. Fifteen adolescent females with AIS with Cobb angle of 20 to 50 degrees and fifteen age-matched healthy females participated in this study.

Interventions. The intervention treatment for the females with AIS was a custom-made total contact thoracolumbar spinal orthosis.

Methods. The gait kinematic data and the standing centre of pressure (COP) data were collected. For each AIS patient, data were collected for the following four conditions—pre-brace, immediate in-brace, after four-month of brace treatment data without the brace, and after four-month of brace treatment data in the brace. Normal subjects acted as the control and participated in gait analysis just one time.

Main outcome measures. The dynamic variables of temporal-distance parameters, walking smoothness with harmonic ratios, and torsional offset of central segments during gait were calculated. The static variables included COP sway, postural orientation and head decompensation in static standing were also calculated for all subjects and conditions.

Results. The walking smoothness measured by harmonic ratios was reduced in AIS patients compared with healthy teenagers, especially in the vertical direction on the head (p=.001), trunk (p=.001) and pelvis (p=.005) as well as the antero-posterior direction on the segments of the head on pelvis (p=.025) and the trunk on pelvis (p=.01). For the four-month effect of bracing, bracing negatively affected the smoothness in the medio-lateral direction on the head (p=.001), in the global reference, but the smoothness was not changed on the body reference in AIS patients. Moreover, the effect of bracing restricted the pelvis motion during gait in the frontal plane causing the limited motion on the trunk on pelvis. For the four-month motion adaptation, brace treatment promoted the walking rhythm and smoothness in the vertical direction on the segment of the head on pelvis (p=.026), but decreased in the medio-lateral direction on the head (p=.018).

Conclusion. AIS patients before the brace treatment exhibited significantly poor walking symmetry compared with age-matched girls. AIS patients had abnormal segmental offset during gait and abnormal segmental orientation in standing posture. Bracing stiffened the range of motion on the body but did not disturb walking rhythm in on the body reference in the four-month brace intervention. Brace treatment yielded motion adaptation for walking rhythm in the body reference in the four-month brace intervention.

Keywords: adolescent idiopathic scoliosis, spinal orthosis, brace, harmonic ratios, walking rhythm, balance, center of pressure, torsional offset

中文摘要

背景　少有研究探討背架對青春期自發性脊柱側彎女性病人動靜態的效應。

目的　1）比較青春期自發性脊柱側彎女性病人和健康人的動靜態表現差異； 2）研究背架治療對青春期自發性脊柱側彎女性病人在立即和四個月後，跟治療前比較，在動靜態表現差異； 3）探討背架治療對青春期自發性脊柱側彎女性病人是否帶來四個月的動作適應能力。

研究設計　前瞻性研究設計

受試者　15 位青春期自發性脊柱側彎女性病人，Cobb 角度介於 20 到 50 度，和健康女孩 15 位。

治療介入　為每位青春期自發性脊柱側彎女性病人量身訂製胸腰薦椎矯具

方法　測量走路時運動學資料及收集站姿時足底壓力軌跡。健康人僅測量一次，病人則測量四次，分別是 治療前、背架立即治療後、治療四個月後沒有穿背架，和治療四個月後有穿背架。

測量參數　動態參數包括：行走時的時空參數、行走韻律及流暢性(諧波比值)、行走身體旋轉偏置角度；靜態參數包含：站姿足底壓力軌跡分佈、站姿時身體旋轉偏置角度、頭部偏離身體中心線的距離。

結果 用諧波比值來測量行走時的韻律及流暢性，發現青春期自發性脊柱側彎女性病人的表現較健康人不好，以絕對空間來看，是發生在上下的運動方向，以相對空間來看，則是發生在前後的運動方向。四個月的背架效應，影響青春期自發性

脊柱側彎女性病人頭部的左右運動的流暢性有變差，但從相對空間來看，從骨盆看頭及從骨盆看肩膀的運動韻律，則是沒有影響。此外，背架限制了骨盆和從骨盆看肩膀，行走中在冠狀面的運動。在四個月動作適應上，從相對空間來看，背架治療有改善上下運動的走路流暢性，但從絕對空間看，頭部左右的行走韻律有變差。

總論　青春期自發性脊柱側彎女性病人在背架治療前的行走韻律及流暢性有比健康人差。病人在行走及站姿，身體存在旋轉偏置角度。背架治療四個月後，雖然背架限制了身體的活動角度，從相對空間來看，並不干擾走路時的韻律及流暢性。在背架治療4個月後，從相對空間來看，有發現動作的適應能力。

關鍵字: 青春期自發性脊柱側彎女性病人, 量身訂製胸腰薦椎矯具, 背架, 諧波比值, 行走韻律, 平衡, 足底壓力軌跡, 身體旋轉偏置角度

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Chapter I. Introduction

1.1 Foreword

Adolescent idiopathic scoliosis (AIS) is the three-dimensional deformation of the spine, notably a laterally deformed curve. Patients with AIS usually display trunk asymmetries, balance dysfunctions,[1,2,3,4] gait deviations[5,6] and neurological abnormalities.[7] In general medical practices, spinal orthotic treatment has been regarded as a valid way to reduce the spinal curve progression or the incidence of corrective surgery in individuals with idiopathic scoliosis.[8,9,10,11,12] However, the global function of the spinal orthotic treatment is still not clear except for the static correction of three-dimensional deformed spine. In clinical practice, orthotists design and modify spinal orthoses to improve static coronal deviations, i.e., the reduction of Cobb angle, the decrease of curve span, and the alignment of the inion or C7 positioned on the central sacral vertical line, according to the measurements of standing posterior-anterior roentgenogram.[13,14] However, in accessing the dynamic movement during activities, orthotic practitioners can only rely on their clinical observations to justify the functional improvements within the spinal orthosis. Until now, few studies discussed the static and dynamic effects of custom-made spinal orthotic interventions or investigated the motion adaptation induced by the sensory facilitation of custom-made spinal orthotic intervention and by the accommodation of biomechanical feature from the bracing. This research investigated the dynamic effects of the spinal orthotic intervention and the motion adaptation after four-month orthotic treatment in AIS patients.

1.2 Literatures Review

1.2.1 The Comparison between AIS Patients and Normal Subjects

1.2.1.1 Definition and Incidence of AIS

AIS is the three-dimensional lateral deformation of the spine that causes body-contour changes in the trunk and rib cage.[14] AIS is defined as a spine lateral deformity happening at age ten years old or later, generated during the growth spurt in the teenage years.[15] There is a high correspondence between AIS and gender. One literature related to the incidence of scoliosis in Canada reported that the girl-to-boy ratio is 1.25: 1 in general, but the ratio is larger as the deformed curve became more severe.[16] In lesser curves of 6 - 10 º, the girl to boy ratio is 1:1 but it is 5.4:1 for curves of more than 20 º.

1.2.1.2 Gait Asymmetry in the AIS Patients

There are a few gait studies related to idiopathic scoliosis (**Table 1.2.1.1**). Barrack et al.[17] compared the walking velocity, cadence, stride length and single limb support time of patients with AIS and healthy subjects and found that there were no significant differences in any of these parameters. Giakas et al.[5] revealed AIS patients have similar ground reaction forces (GRF) gait patterns in time domain compared with normal subjects, and Chen et al.[4] found the kinematic and temporal-spatial parameters are also similar compared with normal subjects. However, in the mean frequency characteristic of the GRF, patients with AIS emerged with asymmetries during the stance phase of gait in only the medio-lateral direction of GRF[5] (**Figure 1.2.1.1**). In Kramers' study,[18] the found the free moment in AIS patients was asymmetrical, and less symmetry of free moment is likely to be a result of the torsional deformity of the spine.

In the study of Lao et al .,[19] they used the test of posterior tibial nerve somatosensory cortical evoked potentials (PTN-SCEPs) to classify the AIS patients into subgroups of normal and abnormal, the abnormal PTN-SCEPs led to the impairment of the somatosensory pathways may cause poorer dynamic balance control in AIS patients.

In Lenke's reference study, [3] kinematics of the lower extremities are similar among AIS patients in pre-surgery, one year after spinal fusion, and two year post-surgery conditions. However, they found a decrease of the acromion–pelvis angle in the transverse plane and decompensation in coronal plane after spinal fusion surgery in the study's thirty AIS patients.

In studies to this date, the dynamic change after spinal orthotic intervention for AIS patients has been unclear. Because the few dynamic parameters might not be sufficient to differentiate the performance between the AIS patients and control group during gait, another variable used to evaluate the dynamic walking in AIS patients was needed.

Table 1.2.1.1 Studies related to Gait evaluation in the AIS Patients

	Participant count and grouping	Parameters	Results
Barrack et al., 1984 [17]	● 17 AIS (mean Cobb 27°) ● 12 normal	● Time-spatial parameters	● Similar gait pattern between AIS and normal groups
Giakas et al., 1996[5]	● 20 AIS (Cobb 25-62°) ● 20 normal	● to examine ground reaction forces (GRF) in the time domain and in the frequency domain ● absolute symmetry index	● This study showed that AIS patients have normal symmetric gait for GRF time domain parameters ● Significant bilateral asymmetry for AIS group was showed in the frequency domain of the medio-lateral of GRF
Chen et al.,1998 [4]	● 19 IS (King I & II, Cobb:22-67 deg) ● 15 normal	● Time-spatial parameters ● Sagittal kinematic	● Normal>IS: cadence ● Hip, knee, and ankle flexion during gait were similar between AIS and normal groups
Kramers et al., 2004[18]	10 AIS	● Free moment ● Segmental rotation in gait and standing	● Free moment was asymmetry ● The asymmetry of free moment is likely to be a result of the torsional deformity. ● The shoulder was more rotated to left relative to global parameter and to the pelvis during gait. ● The magnitude of the rotational offset during gait correlated to the standing posture.
Lenke et al., 2001 [3]	30 AIS	● Preoperative, 1-year, and 2-year post-op ● Kinematics of the lower limbs	● Kinematics of the lower limbs were not significantly different in the pre-surgery, 1 year after spinal fusion, and 2year post-surgery conditions.
Lao et al., 2008 [19]	● 8 AIS showed abnormal PTN-SCEPs* (Cobb 25±10°) ● 10 AIS showed normal PTN-SCEPs (Cobb 24±7°) ● 8 normal	● Kinematics symmetry	● Asymmetry in abnormal SCEPs AIS (R>L) 1. First peak of vertical ground reaction force 2. Second peak of vertical ground reaction force 3. Minimum hip joint moment 4. Maximum knee joint moment 5. Maximum ankle joint moment ● The AIS patients with abnormal PTN-SCEPs led to the impairment of the somatosensory pathways may cause poorer dynamic balance control.

*PTN-SCEPs: posterior tibial nerve somatosensory cortical evoked potentials

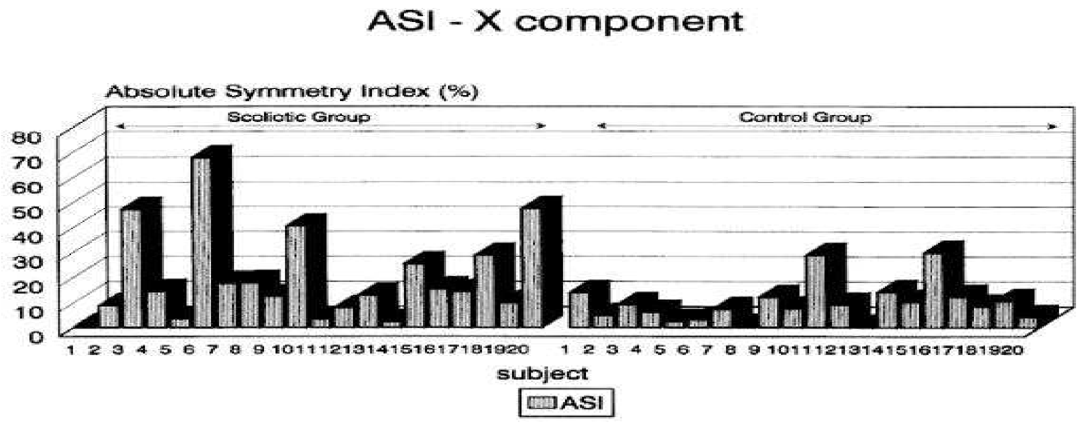
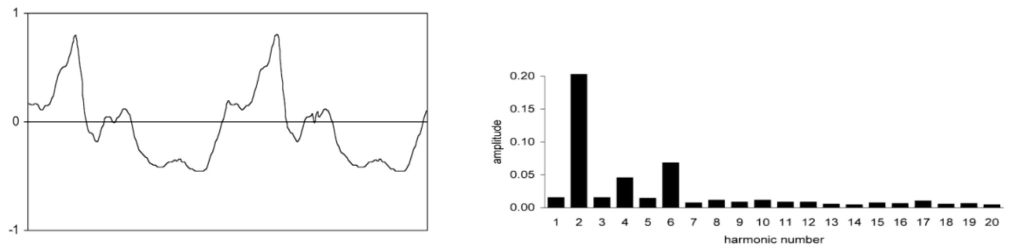


Figure 1.2.1.1 Asymmetry index (%) of the mean frequency feature in the medial-lateral direction of the ground reaction forces in stance phase of the gait for AIS patients (left) and control groups (right) (Cited from Giakas et al., 1996 [5]).

1.2.1.3 The Measurement of Smoothness on Head, Trunk & Pelvis

In many review articles, the harmonic ratio (HR) is an index of global walking stability that is measured based on the rhythm of accelerations of the body and can be examined in the vertical, anterior-posterior, and medio-lateral directions which lower HR is understood to indicate poorer stability.[20,21,22,23.24] A stable and rhythmic gait pattern should involve physical patterns [kinematic data], such as acceleration, velocity and motion etc., which are repeatable in each stride of gait. There was a method to decompose the initial physical data in the time series within one stride into individual harmonic numbers by using of a Fourier transform[21,25] (**Figure 1.2.1.2**). The HR is calculated by the sum of the amplitude values of the even harmonic numbers divided by those amplitude values of the odd harmonic numbers in the antero-posterior and the vertical directions. However, in the medio-lateral direction, HR was calculated by the sum of the amplitude values of the odd harmonic numbers divided by that of the even harmonic numbers.

Smoothness of walking has been used in a few studies on individuals. In Menz's study, smoothness was defined as walking on regular surfaces resulting in larger harmonic ratios measured at both the pelvis and head compared to the smaller harmonic ratios of irregular surface.[25] In other studies, elderly subjects with a high risk of falling show less rhythmic acceleration patterns of the pelvis, trunk and head compared with the elders with low risk of falling.[21,26] In addition, other studies showed that patients with Parkinson's disease,[20] and patients with diabetic peripheral neuropathy[27] are less rhythmic in acceleration patterns in walking than healthy older adults. Until now, there was no study using harmonic ratios to evaluate the walking smoothness in the AIS patients.



a. Vertical acceleration at the pelvis over the course of two steps (one stride). **b.** Amplitudes of the first twenty harmonics.

Figure 1.2.1.2 (a) the vertical acceleration of pelvis in one stride of the gait in time domain. (b) the vertical acceleration of pelvis in one stride of the gait in frequency domain. The sum of the amplitudes of the even harmonic numbers was larger than that of the odd harmonic numbers in the vertical acceleration of pelvis. (cited from Menz t al., 2003 [25])

1.2.1.4 Standing Balance Dysfunction and Malposture in the AIS Patients (Table1.2.1.2)

Various research had noted that AIS patients have poor balance control compared with normal subjects.[2,4,28,29] The sway areas of the center of pressure (COP), which is defined the COP excursion, are greater in values in the AIS patients compared with the control group in static standing. Last, the COP sway density curve[30] showed a longer distance between each stabilization zone and lesser time spent on each stabilization zone in AIS patients, owing to more frequent COP shifting compared with normal subjects.[29,31]

From a biomechanics perspective, standing postural balance is accomplished by maintaining the COP within the base of support. Thus, balance is carried out by the integration of the proprioceptive, visual and vestibular systems in the central nervous system and then through the alpha motor neurons to make the muscles perform the postural adjustments.[32] AIS patients could pass all the simple and static balance tests such as stable somatosensory input, with or without head turning, and with or without visual input.[33] When the somatosensory, visual, and vestibular systems are interfered simultaneously, AIS patients have higher failure rate, that is, an inability to maintain standing balance compared with the control subjects. Another study of Sahlstrand et al.[34] found the standing balance for the treatment group in AIS is insufficient compared with normal control in eyes closed condition. These researchers concluded that as AIS patients in the situation rely proprioception input, they display more imbalanced.

Still another study revealed that AIS patients show abnormal posture in which the scapular in the global coordinates rotates to right and the scapular in local pelvis coordinates rotates to right,[28] and the acromion rotates to right, the acromion on pelvis rotates to right.[2] Another study that noted spinal curve patterns, in AIS patients with thoracic curves, their thoracic kyphosis are lesser[35,36] and their lumbar lordosis are significantly smaller than those of the healthy subjects.[35] Allard hypothesized that poor standing balance in AIS patients was that of a sensory integration problem related to morphologic changes in the trunk and an abnormal perceptive reference body system.[37]

Allard et al.'s report demonstrated that the body's somatotype influences the standing posture equilibrium in adolescent healthy subjects.[38] Ectomorphic subjects, or the relative thinness and tallness of the body in persons, display 72% more COP sway than endomorphic subjects (the relative fattiness of the body). Allard et al. also found the endomorphic AIS girls have a larger COP sway area than their able-bodied counterparts, and this was explainable for the greater stability in the healthy subjects rather than for greater imbalance in the AIS patients.[37]

Owing to the unclear effect of spinal bracing on standing balance, our study investigated the subgrouping of different somatotypes in AIS patients after brace treatment by administering a standing balance task with the sensory interference to get insight into the standing balance effects of the spinal orthotic treatment.

Table 1.2.1.2 Studies related to Standing Balance Dysfunction and Posture in the AIS Patients

	Participant count and grouping	**Parameters**	**Results**
Chen et al. 1998 [4]	● 30 IS, Cobb angle of 22-67 deg ● 15 normal	● COP parameters	● Scoliotic patients has poor standing balance: 2. Increased sway area, radius, medial lateral and anterior posterior areas ML, AP
Zabjek et al., 2005 [28]	● 22 AIS (Cobb 21° ±14°) ● 18 normal	● T1 & S1 sway [what is this?] ● angular and linear position of global and relative body segment parameters	● AIS > normal: 4. increased range of T1 & S1 sway in A/P anterior posterior direction 5. scapulars rotated to right 6. scapular on pelvis rotated to right
Nault et al., 2002 [2]	● 43 AIS, mean Cobb 30 deg ● 38 normal	● COP parameters ● COM ● The head, trunk, and pelvis orientations	● AIS > normal: 6. Sway area COP & COM 7. COP_AP mean position 1.2 cm posterior 8. COP – COM_AP(mm) 9. in Frontal plane: Acromions SB to left 10. in Horizontal plane: Acromions Rot. right, Acromion/pelvis Rot. right ● Standing imbalance was related to altered body posture parameters measured in the frontal and horizontal planes ● A larger COP–COM difference was attributed to a greater neuromuscular demand to maintain standing balance in AIS.
Beaulieu et al., 2009 [29]	● Observation group: 23 AIS (Cobb 18±7°) ● Pre-brace group: 26 AIS (27 ±16°) ● Normal: 53	● COP ● sway density plot	● Scoliotic patients of pre-brace group has poor standing balance: 2. Increased Sway area , mean distance, mean peak ● Pre- brace> normal & observation > normal 2. Increased COP_ML & AP ??? ● Pre-brace scoliotic patients might be related to the sensory integration disorder as showed by an increase of mean distance and a decrease of mean peak of the COP trajectory which meant the poor balance.
Simoneau et al., 2006 [31]	● 8 AIS (mean Cobb 45.6°) ● 9 normal	● COP ● sway density plot	● poor balance in AIS 2. greater COP range, COP RMS velocity, MD [what is RMS and MD?]
Byl et al., 1997 [33]	● 24 IS (Cobb 10~60°) ● 24 normal	● Falling rate in balance test	● When the somatosensory, visual, and vestibular systems were challenged, subjects with idiopathic scoliosis had more proportion to fail.
Sahlstrand et al.,1978 [34]	● 57AIS: 48 single + 9 double curves ● 32 normal ● AIS subgroup: observation (Cobb<20°) & brace treatment groups	● COP parameters ● Eyes open and eyes closed	● AIS > normal: 2. COP_AP & ML ● AIS_treatment > normal 3. eyes open: none 4. eyes closed : COP_AP, ML, area ● AIS_observation > normal 3. eyes open: COP_ML 4. eyes closed : COP_AP, ML, area
Allard et al.,2004 [37]	● Normal:36 Endomorphs/ Mesomorphs/ Ectomorphs= 12:8:16 ● AIS:38 Endomorphs/ Mesomorphs/ Ectomorphs= 11:8:19	● COP	● Endomorphic AIS patients had a larger sway area than healthy counterparts

1.2.2 The Effects of Spinal Orthotic Treatment in the AIS Patients

The custom-made, total contact thoraco-lumbo-sacral orthosis (TLSO) was used on patients with adolescent idiopathic scoliosis who had curve apex below T8 by Watts's team.[39] This orthosis was fabricated from thermoplastic material wrapped and positioned over the trunk and pelvis. The orthosis corrected the deformed spine by directing forces on the apex of the curve.[39] To this day, spinal orthoses are still the primary non-surgical intervention of decreasing a scoliosis deformity and decreasing its progression. As recommended by Scoliosis Research Society, spinal orthoses are generally suggested to the AIS patients with a Cobb angle between 25 and 45 degrees. Their primary function is to prevent the scoliosis curve from continuing its progression and also to allow some curve correction. Spinal orthotic treatment had been shown to reduce the incidence of surgery.[8,9]

Two hundred eighty six girls with a thoracic or thoracolumbar curve of 25 to 35º were followed 4 years to determine the treatment effects of the spinal orthotic intervention, electrical stimulation or just observation in a study by the Scoliosis Research Society.[10] Treatment of the spinal orthotic intervention was successful, defined as avoiding 6 degrees of progression or more until the patients were 16 years old, in 74 percent of the cases after four years compared to observation only and electrical stimulation which had a successful rate of 34 percent and 33 percent, respectively. Gabos et al.[11] found that of the 55 AIS patients who completed a course of orthotic treatment, and followed up by a mean time of 14.6 years, only seven patients (13 percent) had a curve progression more than 5 degrees. In this curve progression group, no one had curve more than 17 degrees of progression when compared to the initial deformity. The authors concluded that most AIS patients with a curve of 20–45°, who successfully complete a course of orthotic treatment, can be expected their curves to maintain stable into adulthood.

Some researchers suggest the overall spinal balance in the orthotic management in AIS patients was also an influence on spine stability. The coronal plane deviation needs to be addressed too, such as head decompensation[13] (**Figure 1.2.2.1**). Winter and Carlson[40] indicated that, if the decompensation happened, the use of a trochanteric extension and add pads until the orthosis tilts and corrects the head to the central sacral line.

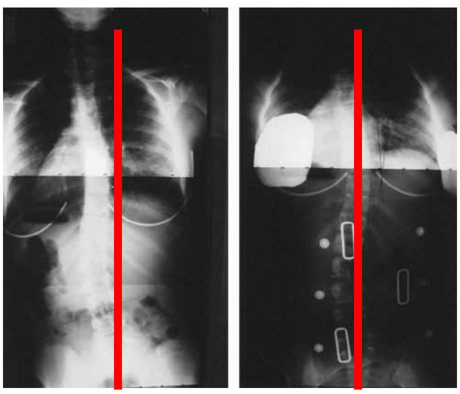


Figure 1.2.2.1 Out-of-orthosis and in-orthosis posterior-anterior radiographs. The vertical line was the central sacrum line. (Cite from Smith, 2004[13])

In Chow's study,[41] they found when AIS patients closed eyes to stand on the solid base, there was no significant difference in the balance function between the in-brace and without-brace conditions (**Figure 1.2.2.2**). Their results were an immediate effect of spinal orthotic intervention on the balance performance in the AIS patients. It is still unclear about the spinal orthotic effects on the balance performance when the effect of pre-brace condition is compared with that of long-term in-brace condition. In Sadeghi's study,[12] after four months of spinal orthotic treatment in AIS patients, spinal deformity was found to be reduced from an average of 31 degrees to 9 degrees in the orthosis. In their study, there was similar in the sway area, medio-lateral, and anterior-posterior of COP displacement between the in-brace and out-of-brace condition in AIS patients after four months of orthotic intervention. The authors thought that the spinal orthosis restrained the lateral deviation of the spine without disturbing the standing balance of AIS patients. It is important to note that these researchers just used the four-month in-brace condition compared with the condition of four-month bracing without brace. After four-months of spinal orthotic treatment, one can reason that patients could have the motion adaptation leading to no significant differences in COP parameters in that study. It is doubted that the performance in the condition of four-month bracing without brace is similar with that in the pre-brace condition.

Therefore, in this study, time factors including zero-month and four-month in- and out-brace conditions will be utilized to confirm the spinal orthotic effect in AIS patients.

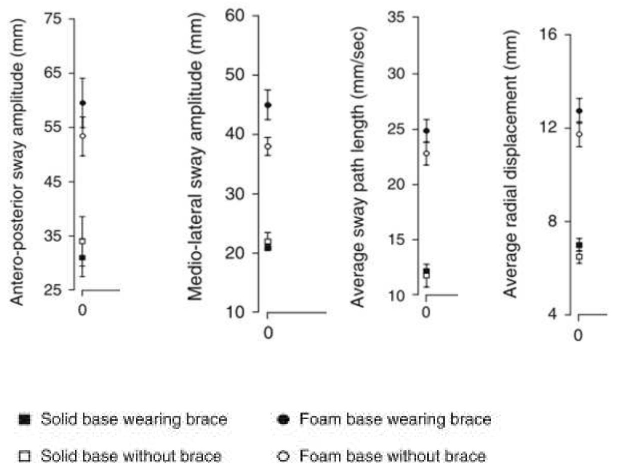


Figure 1.2.2.2 (Left) To compare the medial-lateral sway in AIS patients standing on solid base and foam base combined with in-brace and out-of-brace while loading different backpack weights. (Cited from Chow et al., 2007 [41])

1.2.3 Motion Adaptation after bracing in AIS patients

Whatever the causes of AIS could be, it is of interest if treatments based on biomechanics or neural control are interrelated and if one or both could have a major role in rehabilitation of postural deviations in the AIS patients. According to Ridding and Rothwell,[42] motion adaptation of the trunk posture requires afferent input to the central nervous system. They believed that following, a yet identify-able neurologic dysfunction in the AIS patients, the ‘intrinsic’ afferent input feedback could be decreased resulting in poor proprioception or somatic sensation. In Lao’s study, they concluded that the impairment of the somatosensory pathways may cause poor dynamic balance control.[19] Other researchers also concluded that the trunk configuration is perceived predominantly by somatic sensation.[43] For human beings, the arms are under the visual control, but the posterior trunk is a hidden from our visual view. Therefore, most people do not have a clear understanding of their back posture. However, when humans see their back posture in a mirror, they can identify body deviations which are not usually perceived in their daily life.

Researchers proposed that spinal orthoses may offer afferent stimulation of the somatic sensation causing augmented sensory feedback to the trunk.[44] To attain automatic self-correction of scoliotic curves, the augmented sensory feedback might be important in the rehabilitative treatment of AIS. Therefore, spinal orthoses could have different roles, as a biomechanical device to correct the spinal curve and also as an instrument to offer continuous somatic sensory stimulation and to improve the perception of abnormal body postures in the rehabilitative program. Motion adaptation can be evaluated by assessing the AIS patients' performance of a movement to define the integration within the nervous system after spinal orthotic intervention.[45] However, there has been no study to date to confirm the motion adaptation effects on spinal orthotic treatment in the AIS patients.

1.2.4 Purposes and Hypotheses

Since few studies have addressed brace effect on dynamic and static balance for AIS patients, the purpose of this study was threefold: 1) to evaluate dynamic and static balance between AIS patients and normal subjects. The dynamic variables included the walking rhythm and rotational offset, and static variables consisted of COP excursions, the segmental orientation, and head decompensation; 2) to investigate the dynamic and static balance effects of spinal orthotic intervention in the AIS patients in the conditions of the immediate, four-month in-brace conditions; 3) to evaluate the four-month motion adaptation with the brace treatment in the AIS patients (**Figure 1.2.4.1**). In this study, it is expected to discover that a non-smooth walking pattern might exist in AIS patients. In addition, it is possible to find the global perspective of the functional effects of spinal orthotic treatment in the AIS patients in addition to eliminating the Cobb angle.

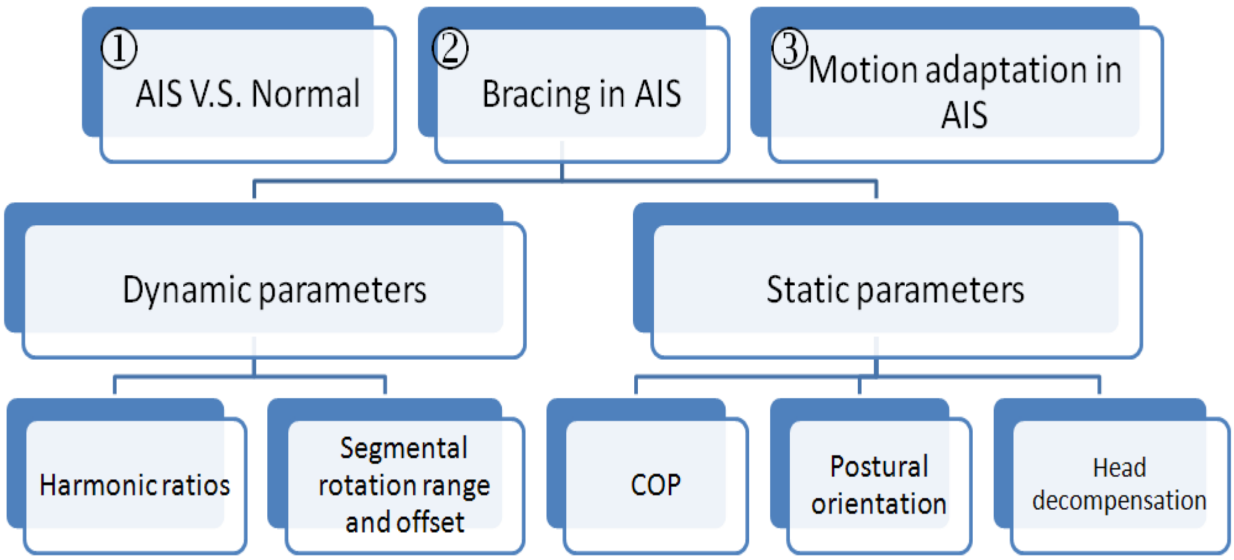


Figure 1.2.4.1 A diagram describes the study purposes

Our hypotheses were 1) the walking smoothness and rhythm as well as standing balance would be disturbed in AIS patients. 2) bracing might improve the walking smoothness and rhythm as well as standing balance in AIS patients in the post four-month brace intervention. 3) motion adaptation could be yielded to promote the walking rhythm and standing balance without brace after four-month brace intervention.

Measurements such as the level of deformity, gait, and posture analysis are important parameters to assess outcome of management. However, in the clinical practice, only static radiographic measurement of the degree of curvature, such as Cobb angle, is used to evaluate and re-evaluate the AIS patients before and after treatments. It is anticipated that other dynamic parameters could display the dysfunction in AIS patients and can be used in the clinical evaluation and treatment of patients with AIS.

Chapter II Materials and Methods

2.1 Subjects

The two subject groups were the AIS and control groups respectively. The AIS subject group were 15 females with Cobb angle of 20 to 50 degrees, without other spinal deformities, unsteadiness, numbness or weakness of limbs, tinnitus, headache, vomiting dysfunctions or surgeries of the spine or lower extremities that could disturb their gait. In addition, orthopedic or rehabilitation doctors had recommended the spinal orthotic intervention to these female subjects to halt the progression of their scoliosis. They had not received orthotic treatment before, and were the ages between 10 to 16 years old. These AIS patients were recruited in this study for more comprehensive understanding of the dynamic postural effects of spinal orthotic intervention (**Table 2.1.1**). Control subjects were fifteen age-matched adolescent girls without any known disorders and injuries that could disturb their gait.

Ethical assent for this study was awarded by the Human Research Ethics Committee in the Mennonite Christian Hospital in Hualien, Taiwan. The research procedures were clearly explained to each case and their guardian, and a written informed consent was received from each subject and her guardian prior to participating in the experiment.

Table 2.1.1 Details of the anthropometry and curvature patterns in AIS patients

No.	Age (years)	Height (cm)	Weight (kg)	AIS curve pattern	Cobb angle Pre-brace (degrees)	Apex level	Cobb angle with brace immed. (degrees)
1	10.5	152.5	39	R thoracic/L lumbar	45/27	T8-T9/L2	35/21
2	13.5	162	50	R thoracic/L lumbar	35/40	T8/L2	24/28
3	14.8	167	50	L thoracic/R lumbar	35/26	T7/L1	27/22
4	14.1	153.5	45	R thoracic	24.5	T9	20
5	11.9	156	46	R thoracic	30	T7-T8	20
6	13.2	155	46	R thoracic/L lumbar	38/37	T8/L1	33/34
7	12.3	142	29	R thoracic	24	T9	14
8	12.3	150.4	39.8	R lumbar	24.5	L2	18.6
9	12.8	160	56	R thoracic/L lumbar	37.6/36	T8/L2	26.5/24
10	12.7	157	49	R thoracic/L lumbar	30/37	T8/L1	23.6/30
11	11.3	158	41	R thoracic/L lumbar	32/27	T8/L1	26/22
12	12	147	38	L lumbar	22	T12-L1	7
13	11.6	146	35	R thoracic/L lumbar	48/39	T8/L1-L2	30/30
14	14.4	155	45	L lumbar	48	L1	40
15	13.2	167	48.7	R thoracic/L lumbar	31.5/36	T8/L2	21/31

2.2 Study design

2.2.1 Experiment procedures

Each normal subject was evaluated by the gait motion analysis and the standing balance tasks. The AIS subjects were instructed to make three visits to experiment sites and research procedures were described as follows. (**Figure 2.2.1**)

(1) The first visit:

a) The degree of their deformity (Cobb angle) was measured by the experienced orthotist. Maturity (age, Risser's sign and menarche), body height and weight of each patient were also recorded.

b) Then plaster impression of each AIS patient was taken by the experienced orthotist for the modification and fabrication of an custom-made, vacuum formed high temperature thermoplastic, total contact thoraco-lumbar-sacral orthosis (TLSO) (**Figure 2.2.2**).

c) Each AIS patient was evaluated by the gait motion analysis and the standing balance tasks without TLSO (1st Gait analysis).

(2) The second visit:

a) Appromiately two weeks after cast impressions were taken, the custom-made TLSO was delivered to each patient and whole spine posterior-anterior radiographies of each patient while standing with wearing spinal orthosis were taken. The static Cobb angles, vertebral rotations and decompensation from the vertical central sacral line were measured and recorded [13] (**Figure 2.2.3**).

b) Each AIS patient was evaluated for the immediate effects of the TLSO intervention using the gait motion analysis and performing the standing balance tasks with TLSO (2nd Gait analysis).

The AIS patients were instructed to get accustomed to the spinal orthosis within the first month, and had to wear the spinal brace about 23 hours a day, taking rest for one hour only for bathing and/or physical exercises.

(3) The third visit: (remove TLSO 24 hours before this evaluation)

a) After four months intervention of the TLSO, each AIS patient was evaluated the four-month motion adaptation without the orthosis using gait motion analysis while performing standing balance tasks (3rd Gait analysis). Next, the subject wore their orthosis for one-hour, and then tested for the four-month effect of the brace using gait motion analysis while performing the standing balance tasks (4th Gait analysis).

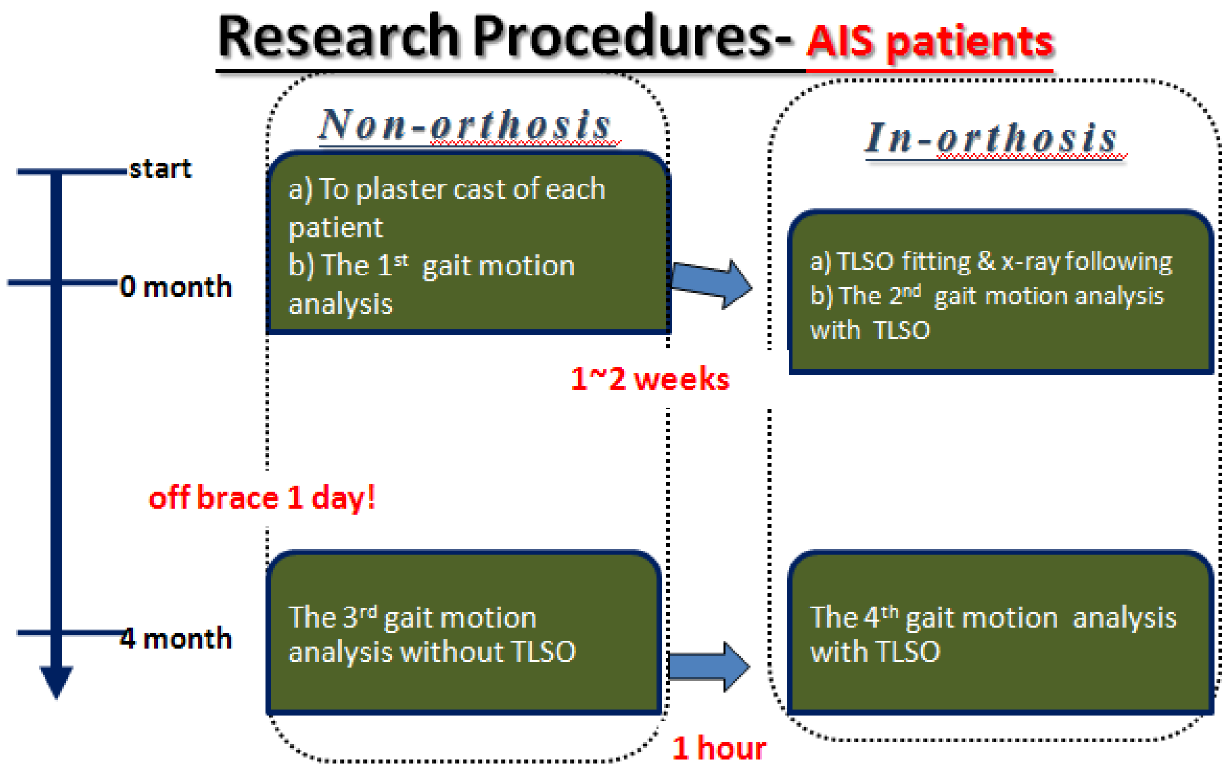


Figure 2.2.1 Research procedures for AIS patients

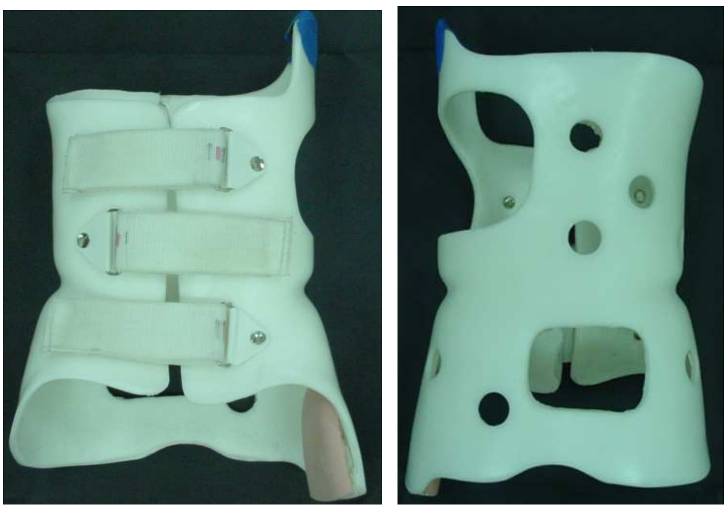
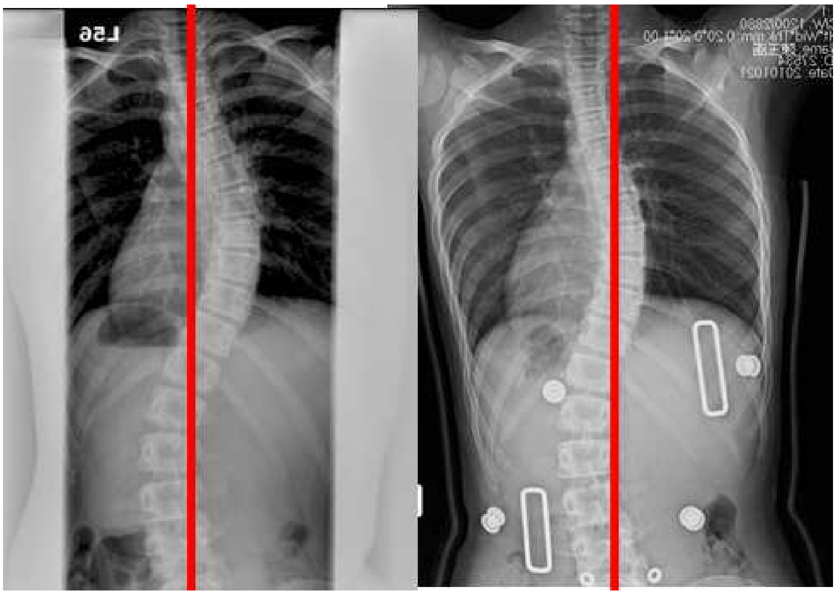


Figure 2.2.2 (left) The thoraco-lumbar-sacral orthosis (TLSO) was custom-made by orthotists of Rehabilitation Department, Mennonite Hospital, Hualien, Taiwan and of Rehabilitation Engineering Research Center, National Taiwan University. Left photo is an anterior view, and right is a posterior view.



(a) Without TLSO (b) With TLSO

Figure 2.2.3 Standing radiographies of a eleven-year-old female patient (No. 13) with adolescent idiopathic scoliosis showed (a) a 48 degree main thoracic curve with apex on right T8, and a 39 degree lumbar curve with apex on left L1-2 before orthotic treatment and showed (b) a 30 degree main thoracic curve, and a 30 degree lumbar curve within a custom-made thoraco-lumbar-sacral orthosis (TLSO)

2.2.2 Instrument

An AMTI force platform was used to measure the COP traces with sampling rate at 200 Hz (AMTI, Newton, MA,USA) (**Figure 2.2.4**). Three-dimension motion was captured using Optotrak® Certus™ capture system with sampling rate at 50 Hz from Northern Digital Inc., Canada (**Figure 2.2.5**). Each position sensor was embedded with three cameras to sense three-dimensional positions of LED markers. Five rigid bodies (**Figure 2.2.6**) each of which had three LED built-in markers were placed at selected locations on both feet, the pelvis, the upper trunk and the head of each subject. Note that each rigid body had three LED markers on it so that a local coordinate system of one segment can be generated. The digitized landmarks were as follow: bilateral calcaneous, which defined the phase of the gait cycle; the bilateral ASIS and right PSIS, which defined the orientation of the pelvis; the bilateral acromions and spinal process of the first thoracic vertebrae (T1) which defined the orientation of the upper trunk; and the bilateral tragus of the ear and the inion which defined the orientation of the head. The digitization method was designed to use the stylus (**Figure 2.2.7**) to locate the desired anatomic landmarks relative to the rigid body of sensor.

Figure 2.2.4 One AMTI force platform (AMTI, Newton, MA,USA)

Figure 2.2.5 The position sensor used in this experiment was OPTOTRAK CERTUS from Northern Digital Inc., Canada. Each position sensor was embedded with three cameras to sense three-dimensional positions of LED markers.

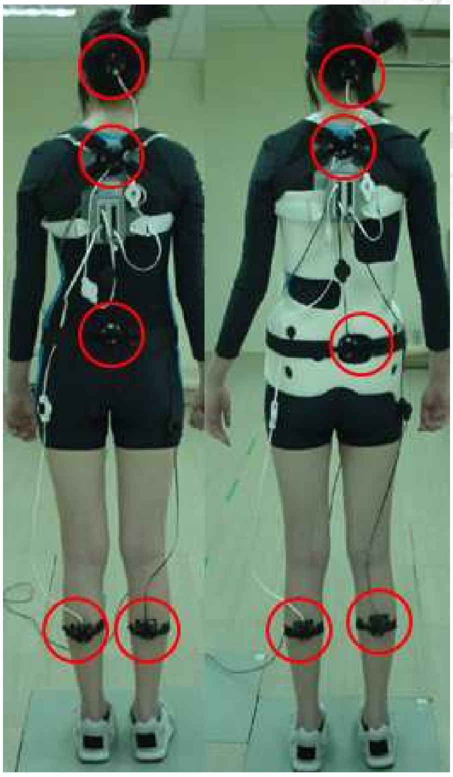


Figure 2.2.6 Five rigid bodies were placed at selected locations. Each rigid body with three LED markers on it generated a local coordinate system of each segment.

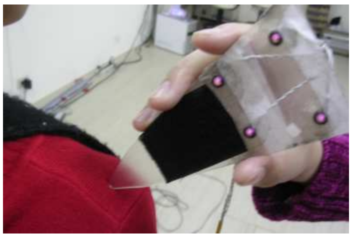


Figure 2.2.7 Using the stylus to locate and digitize the desired anatomic landmarks relative to the rigid body of sensor.

2.2.3 Protocol design

2.2.3.1 Gait motion task

Gait data was collected by each subject walking with shoes along a 6-m walkway at their self-selected walking speed (**Figure 2.2.8**). The results of five trials were averaged for each subject.

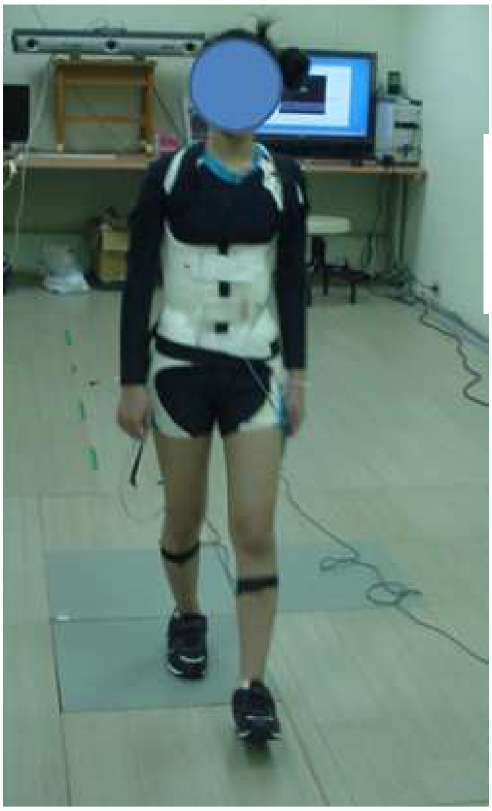


Figure 2.2.8 (Left) Walking task with shoes along a 6-m walkway at their self-selected walking speed.

2.2.3.2 Standing balance task

Standing postural balance was tested using an AMTI force platform (AMTI, Newton, MA, USA) with eyes open and closed. Each subject was instructed to stand quietly on the force plate with Romber standing (**Figure 2.2.9**). They were asked to keep their vision on a target placed at eye level, 3 m ahead with their arms relaxed by their sides. Each subject completed three trials of 60 seconds each. Prior to the start of the experiment trials, several initial tasks were performed which allows subjects to become familiar with the study procedures.

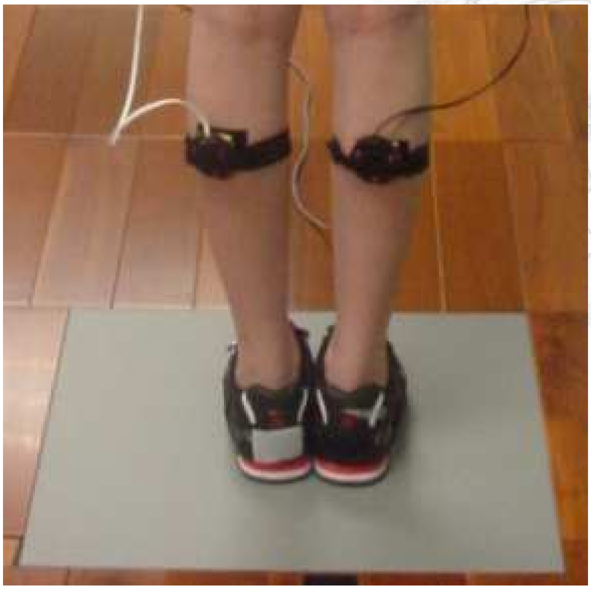


Figure 2.2.9 Romber standing on force plate.

2.2.4 Data analysis

2.2.4.1 Gait analysis

The vertical (Z), anterior-posterior (X), and medial-lateral (Y) motion data of the head, the trunk and the pelvis were collected from one stride of each walking trial. The raw motion data was filtered by a fourth-order, zero-lag, low-pass Butterworth filter with a cutoff frequency of 25 Hz prior to further analysis. The gait cycle was defined by the heel sampling data from motion capture system. The parameters were calculated as followed:

A) Locomotion Parameters. Velocity (m/s), duration of the stride (ms), stride length (m) and step width (m) were measured during the gait trials.

B) Harmonic ratio (HR): Harmonic ratios were computed by the decomposition of the velocity values in the frequency domain via Fourier Transformation (**Figure 2.2.10**).

$$F(t) = b_0 + \sum_{n=1}^{N/2} \left[a_n \sin\left(n \frac{2\pi}{T} t\right) + b_n \cos\left(n \frac{2\pi}{T} t\right)\right]$$

Where N equals the numbers of frames

(Cited from Giakas et al., 1996 [5])

In this transformation, $F(t)$ represents the function of velocity of the body with time. $a_1, a_2, a_3, a_4, \ldots, a_{N/2}$ and $b_0, b_1, b_2, b_3, b_4, \ldots, b_{N/2}$ are harmonic coefficients, n was the harmonic number, T was the periodic time of the stride duration and t is time.

The amplitude (P_n) of each harmonic number was the root of the sum of harmonic coefficients' squared.

$$P_n = \sqrt{a_n^2 + b_n^2}$$

For the vertical (VT) and antero-posterior directions (AP), the harmonic ratio (HR) was defined by the summation of the first 10 even harmonic amplitudes divided by the summation of the first 10 odd harmonic amplitudes[25]. For the medio-lateral(ML) direction, the harmonic ratio was defined by the summation of the odd harmonic amplitudes were divided by the summation of even harmonic amplitudes. Higher harmonic ratio values were representative of increased smoothness in the walking pattern and for this study defined "smoothness".[23]

For the VT and AP directions $$HR = \frac{\sum \text{Amplitudes of even harmonics}}{\sum \text{Amplitudes of odd harmonics}}$$

For the ML direction $$HR = \frac{\sum \text{Amplitudes of odd harmonics}}{\sum \text{Amplitudes of even harmonics}}$$

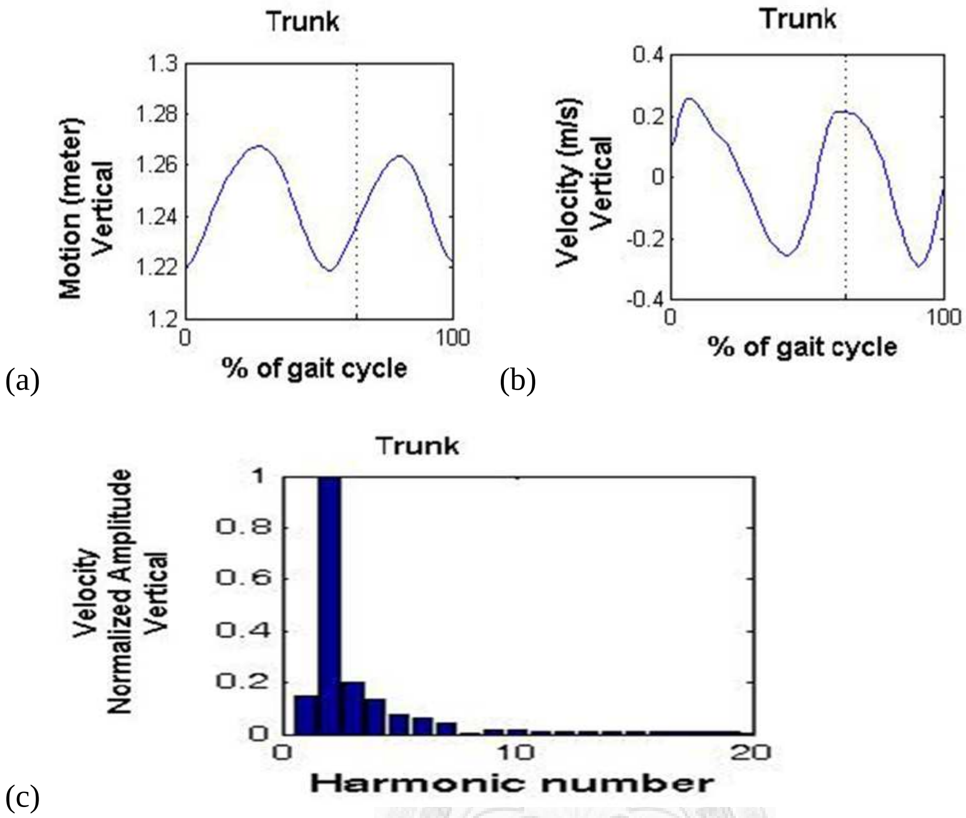


Figure 2.2.10 (a) The vertical displacement of the trunk with time domain in one stride. (b) The vertical velocity of the trunk with time domain in one stride. (c) The vertical velocity of the trunk in the frequency domain in one stride.

As authors from the review articles described collecting HR data from an accelerometer instrument in the frequency domain via Fourier Transformation, they used the acceleration of the body segment to describe the rhythm of body and to provide a view of global walking stability. [20,21,25] Instead of using the accelerator, this study's equipment was able to capture the motion data directly. In this perspective, all the motion, velocity and acceleration of the body could be used to demonstrate the characteristics of subject's gait pattern. It is understood that these parameters are periodic functions in each stride, except the anterio-posterior motion of body, which is a linear motion and must be processed before using Fourier Transformation. Note that in this study we chose velocity signal to calculate the harmonic ratio. In fact, our study had also considered the acceleration data which was calculated by twice the differentiation of the raw data of motion, but they were not used because the acceleration data in frequency domain exhibited many noise interferences in the larger harmonic numbers.

C) the peak-to-peak ranges and offset of segmental obliquity and rotation during walking. To measure the peak-to-peak ranges and offset of the head, trunk, pelvis, segment of the head on pelvis, and segment of the trunk on pelvis obliquity and rotation during walking, the following formulas were used:

Peak-to-peak range=maximal. rotational angle – minimal rotational angle

Offset= (maximal angle + minimal. angle) /2

Positive offset value in the frontal plane was defined as an obliquity to right side and negative value was to the left. On the other hand, positive offset values in the transverse plane were defined as the rotation to left, and negative values were to the right.

2.2.4.2 Standing balance tasks

The center of pressure (COP) describes the point of the resultant vertical forces of the body mass applied on the forceplate. The excursions of the COP defined subject's stability,[4] which was also thought of as the neuromuscular control of the COM.[46] The raw data from the force plate was filtered by fourth-order Butterworth low-pass filters with the cut-off frequencies of 2.5 Hz.[41,31]

A) Global posturographic parameters, which estimate the overall "size" of the sway patterns. The calculations of parameters were as follow.

a) The COP excursion: it was measured from the ground reaction forces and moments collected from the force plate in the stance balance task. The formulas are as followed:

$$COP_{AP} = (-M_{ML} + F_{AP}d)/F_V$$

$$COP_{ML} = (M_{AP} + F_{ML}d)/F_V$$

where F was force, M was moment, $_{ML}$ was medio-lateral direction, $_{AP}$ was anterior-posterior direction, $_{v}$ was vertical direction and d was the height of force plate from origin.

b) The mean antero-posterior position of the center of pressure (x_c): The mean COP_{AP} displayed the magnitude of the subjects' forward leaning in the sagittal plane, the anterior direction was defined as a positive value. The x_c equation is

$$x_c = \frac{1}{N}\sum_{i=1}^{N} x_i \quad ,$$

where x_i was the position of the i-th COP in the anterior-posterior direction, and N was the total number of data points.

c) The mean medio-lateral position (y_c): The mean COP_{ML} displayed the magnitude of the lateral leaning of subjects where the left side was defined as a positive value as collected by the force-plate coordination system. The y_c equation is

$$y_c = \frac{1}{N}\sum_{i=1}^{N} y_i,$$

where y_i as position of the i-th COP in the medio-latera1 direction, and N was the total number of data points.

d) Path length per second (Pace): This parameter was a measurement of velocity.[47,48] It was the average distance traveled per second during the time period of one sample and was defined as

$$P = \frac{f}{N-1}\sum_{i=1}^{N-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2} \quad ,$$

where f was the sampling frequency per second, N the total number of data points, x_i was the position of the i-th COP in the anterior-posterior direction, y_i was position of the i-th COP in the medio-latera1 direction.

e) The sway area per second: This parameter is defined as the integrated area within two continuous immediate COP and the points (x_c and y_c). (**Figure 2.2.11**) The equation is given as

$$\Delta A = \frac{1}{2}\sum_{i=1}^{N-1}|(x_i\, y_{i+1} + x_{i+1}y_c + x_c y_i) - (x_{i+1}\, y_i + x_c y_{i+1} + x_i y_c)| \;/\; 60$$

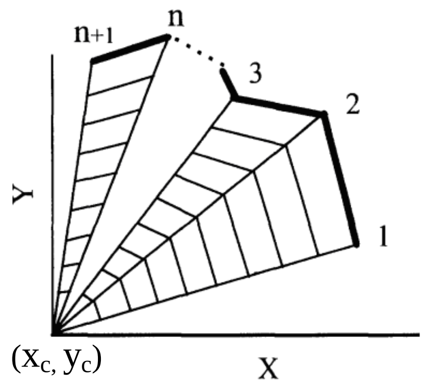


Figure 2.2.11 The sway area was the summation of the triangle area within two continuous instant center of pressure and origin during the span of the task. (Cited from Chen et al., 1998[4])

B) Structural posturographic parameters, which attempted to decompose the sway patterns into individual elements. The formulation of parameters were as follows.

The sway density plot was measured by calculating the number of continuous samples, for each time instant, falling inside a circle with a radius R and the instant COP as the circle center [30,49,31,29](**Figure 2.2.12**). The sway density curve was filtered with a fourth-order Butterworth filter. The sample number was divided by the sampling rate producing a time unit (second) for the ordinate axis. The sway density curve (SDC) was a time-versus-time curve to display the time of the COP trajectory inside a moving circle of radius R, which we chose as 2.5 mm.[30,29] The "peaks" of the sway density curve represent the time instants at which the COPs are relatively steady and "valleys" are instants at which the COPs are relatively unsteady.

(a) Mean peak (MP): The mean value of all peaks was defined as the mean peak.

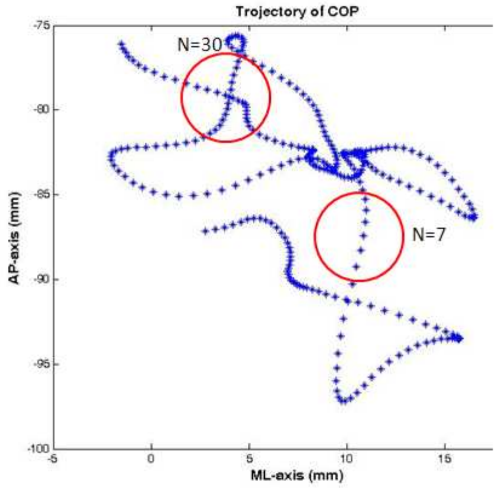
MP represents the average sway density at all relatively steady instants and estimates the degree of steadiness and balance control commands variability.

(b) Mean distance (MD): It is the mean value of all distances between the consequent two peaks. The MD represents the average amplitude of COP trajectory from one relatively steady instant to another and is expressed as balance control commands amplitude.

An increase of mean distance and a decrease of mean peak were representative of insufficient postural balance control because the COP sways larger and stayed less time in each center of stabilization in the COP trajectory.[30]

C) Postural orientations in static standing: Postural orientations were obtained by the segmental obliquity (in the coronal plane) and rotation (in the transverse plane) of the head, trunk, pelvis, segment of the head on pelvis, and segment of the trunk on pelvis in the static standing position. Segmental obliquity (in the coronal plane) to right side was defined as a positive value, and segmental rotation (in the transverse plane) to left side was defined as a positive value (**Figure 2.2.13**).

D) Head decompensation: This parameter was defined as the maximal perpendicular distance from the vertical line passed through the center of ears to the vertical line, which was passed through the center of bilateral ASIS, in static standing (**Figure 2.2.14**).

(a) 

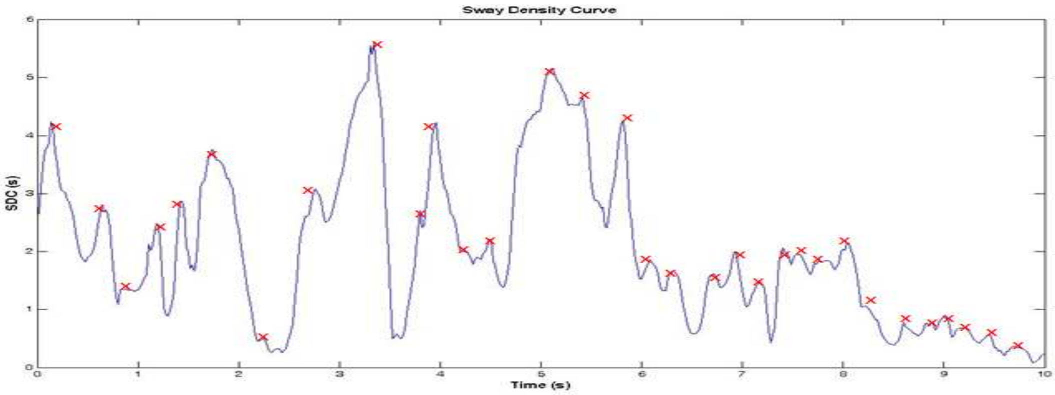
(b) 

Figure 2.2.12 (a)COP trajectory, dotted with sampling rate (50 Hz). "N" meant the numbers of dots within a circle of 2.5mm radius in that instant of time. (b) sway density cure with 10 seconds period and peak points with 'x' markings.

(a) 

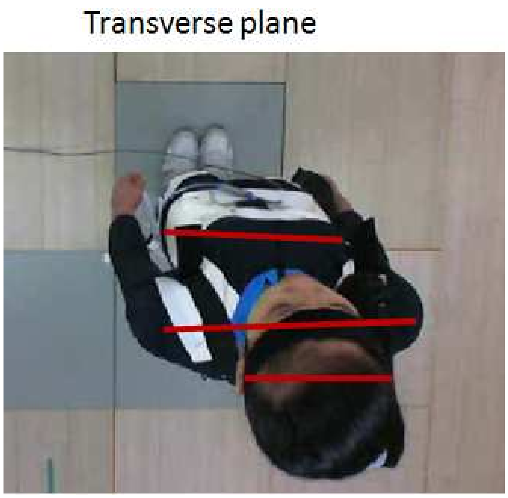
(b) 

Figure 2.2.13 Postural orientation (a) the value of the orientation in the frontal plane on the pelvis is negative, which means tilting to left side (b) the value of the orientation in the transverse plane on the pelvis is negative, which means rotation to right side

Figure 2.2.14 Head decompensation to left.

2.2.5 Analysis design

If the walking rhythm was different between AIS patients and the control, the different curve patterns of AIS patients could be categorized into subgroups to compared with the control.

The standing balance could be influenced by the body somatotype in adolescents.[38] In our study, each participant was subdivided by a height-weight index [height (cm)/cube root of weight (kg)][38] to determine their thinness. Although the more commonly used classification of somatotype uses the skinfold thickness of particular body, the breadth of particular bone, and the girth of limbs, this study opted to the more simplified height-weight index. Based on the raw anthropometric data from Allard's anthropometric data[38] and Dupertuis 's report,[50] this study used the score of 44 of height-weight ratios as the cut point and classified the thin group as height-weight ratios less than or equal to 44 and the non-thin group as height-weight ratios greater than 44.

In addition, the postural orientation in standing and segmental offset during gait could be related to the curve pattern in AIS patients. The AIS patients were sorted to three groups--double curve of right thorax and left lumbar, single curve of right thorax, and single curve of left lumbar. Each subgroup of AIS patients was compared with the healthy teenagers for the postural orientation and segmental offset. If harmonic ratios were different between AIS patients and control, AIS patients were classified in the same way to compare with the healthy teenagers.

2.3 Definition of special terms

Bracing immediately causes the body to have an immediate reflex and biomechanical response from the orthosis. As the performance of in-brace immediate conditions was different with that of pre-brace condition, this study particularly noted this condition and defined it as **the immediate effect of bracing**. On the other hand, four months of bracing with a spinal orthosis causes motion adaptation on the body due to the orthotic biomechanics. This ability to change and adapt in four-month in-brace condition compared with pre-brace condition, and this condition was defined as **the four-month effect of bracing**. Four-month bracing without brace brought the body the motion adaptation. This condition was defined as **the four-month motion adaptation** if the ability was changed in the condition of four-month bracing without brace compared with the pre-brace condition (**Figure 2.3.1**).

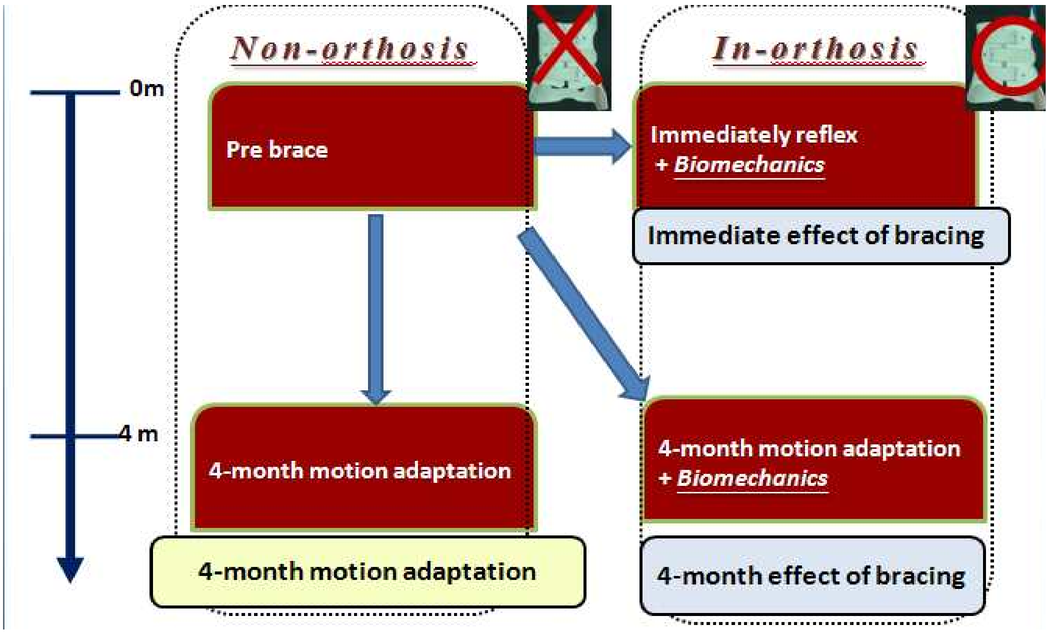


Figure 2.3.1 Definition of special terms

2.4 Statistical Analysis

All the variables were tested by the normality distribution priority. The value of Shapiro-Wilk normality test was greater than .05. Time-spatial parameters and harmonic ratios in both control and experiment groups were passed the normality tests. Therefore, independent t test was chose to compare the healthy teenagers and AIS patients. A 2 time x 2 brace two-way repeated Analysis of Variance (ANOVA) was used to compare among 0-month and four-month in-brace and out-brace conditions. The planned comparisons used paired-t test as follows. The **immediate effect of bracing** was compared pre-brace and in-brace immediate conditions. The **four-month effect of bracing** was compared pre-brace and four-month in-brace conditions. Lastly, the **four-month motion adaptation** was compared pre-brace and four-month out-brace conditions.

Because the harmonic ratios, the range and offset of segmental obliquity and rotation during gait, postural orientation in standing and head decompensation in each subgroup (double, thorax and lumbar) do not fit the normality distribution, Mann-Whitney U test was used to compare the healthy teenagers and each subgroup of AIS patients. Friedman test was used to compare among zero-month and four-month in-brace and out-brace conditions just in AIS patients with double curve due to few sample size in groups of single thorax and single lumbar curve. Wilcoxon test also was used to compare the planned comparisons in AIS patients of double curve.

A two group (AIS vs normal) versus two subgroup (thin vs non-thin) two-way Analysis of Variance (ANOVA) was chosen for the COP global and structural parameters to compare the healthy teenagers and AIS patients. However, Friedman test was used to compare among zero-month and four-month in-brace and out-brace conditions in AIS patients by the subgroup due to the few sample size. Wilcoxon test was used to compare the planned comparisons in AIS patients.

Using the pearson correlation coefficient to test the correlation between the segmental offset during gait and the postural orientation in standing. A significant level is set 0.05 with two-tail.

Chapter III Results

3.1 Dysfunction and impairment in AIS patients

3.1.1 Anthropometric data and spatial-temporal gait parameters

Comparison of the anthropometric data results showed that the height (healthy: 1.56 ± 0.05 m; AIS: 1.55 ± 0.07 m), mass (healthy: 48.8 ± 7.5 kg; AIS: 43.8 ± 6.9 kg), or age (healthy: 13.5 ± 0.85 years; AIS: 12.8 ± 1.19 years) were similar between healthy teenagers and AIS patients (**Table 3.1.1)**. The anthropometric data of each subgroup (double, R't thorax and Lumbar) of AIS patients and healthy teenagers were also similar (**Table 3.1.2)**. In the thin or non-thin group, the anthropometric data was similar between AIS patients and healthy teenagers. The weight in the thin group was lighter than the non-thin group (p=.04) and the height in the thin group was taller than the non-thin group (p=.03) (**Table 3.1.3**).

Spatial-temporal gait parameters containing walking velocity (healthy: 1.03 ± 0.14 m/s; AIS: 1.08 ± 0.15 m/s), walking period (healthy: 1.14 ± 0.8 s; AIS: 1.10 ± 0.1 s), stride length (healthy: 1.22 ± 0.14 m; AIS: 1.20 ± 0.14 m), or step width (healthy: 0.06 ± 0.3 m; AIS: 0.04 ± 0.12 m) were similar in healthy teenagers and AIS patients (**Table 3.1.4**).

Table 3.1.1 Data of the anthropometry between healthy teenagers and AIS patients (Mean ± SD)

	AIS (All)	Healthy teenager	Sig.
Numbers	15	15	
Age (year)	12.75 ± 1.5	13.51 ± 1.16	p= .054
Height (cm)	155.23 ± 7.1	156.6 ± 5.1	p= .547
Weight (kg)	43.8 ± 6.9	48.8 ± 7.5	p= .069
Cobb angle in major curve(°)	34.9 ± 8.5	--	
In-brace correction percentage (%)	27.5 ± 14	--	

Table 3.1.2 Data of the anthropometry among the subgroups of AIS patients-I
Median ± (upper/lower quarter)

	AIS (Double)	AIS (R't thorax)	AIS (Lumbar)
Numbers	9	3	3
Age (year)	12.2 ± (0.5/ 1.3)	12.3 ± (1.8/ 0.4)	12.3 ± (2/ 0.3)
Height (cm)	158 ± (6/4)	153 ± (2/11)	150 ± (4/3)
Weight (kg)	48.7± (1/8)	45± (1/16)	39.8± (5/1)
Cobb angle in major curve(°)	37.6± (4/1)	25± (5/1)	24.5± (23/2)
In-brace correction percentage (%)	22.2± (7/4)	33± (8/13)	20± (44/7)

Table 3.1.3 Data of the anthropometry among the subgroups of AIS patients-II
Median ± (upper/lower quarter)

	Thin group		Non-thin group	
	AIS	healthy teenager	AIS	healthy teenager
Numbers	4	6	7	9
Age (year)	12.4 ± (2/ 1)	13.4 ± (1/ 0.3)	12.8 ± (1.3/ 0.8)	13.1 ± (0.7/ 0.4)
Height (cm) *	162 ± (4/13)	159 ± (5/4)	155 ± (2/1.5)	155 ± (3/4)
Weight (kg) *	44.8± (4/8)	45.5± (1/5)	46± (3/1)	53.5± (3/10)
Cobb angle in major curve(°)	36± (9/3)	--	37± (1/12)	--
In-brace correction percentage (%)	20.8± (13/4)	--	20± (13/3)	--

***: The comparison was significantly different between thin group and non-thin group, p<.05**

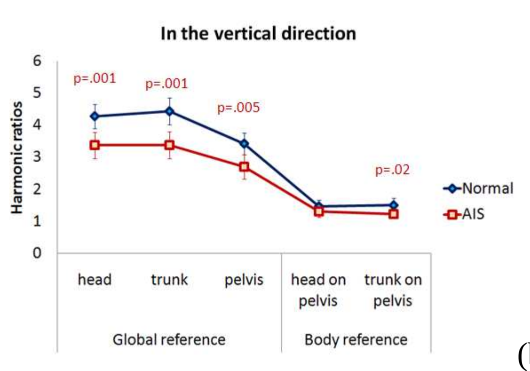
Table 3.1.4 Spatial-temporal gait parameters (Mean ± SD)

	AIS	Healthy teenagers	Sig.
Period (sec)	1.10 ± .1	1.14 ± .08	p= .22
Stride length (m)	1.20 ± .14	1.22 ± .14	p= .77
Velocity (m/s)	1.09 ± .15	1.03 ± .14	p= .31
Step width (m)	.04 ± .03	.06 ± .03	p= .46

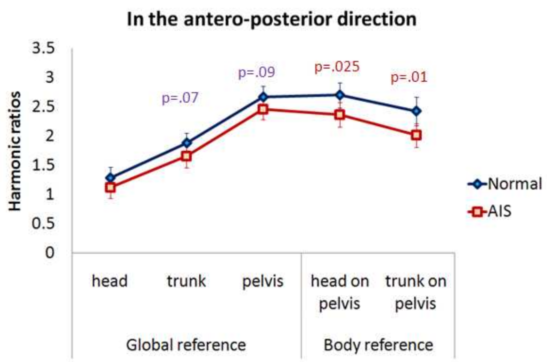
3.1.2 Harmonic ratios on the head, trunk and pelvis during gait

In the vertical direction, AIS patients exhibited significantly smaller harmonic ratio compared with age-matched girls on all segments of the head (p=.001), trunk (p=.001) and pelvis (p=.005) in the global reference, and on the segment of trunk on pelvis (p=.02) in the body reference (**Figure 3.1.1(a)**). In the antero-posterior direction, harmonic ratios were significantly smaller on segments of the head on pelvis (p=.025) and the trunk on pelvis (p=.01) in the body reference in AIS patients than the healthy teenagers (**Figure 3.1.1(b)**). There were similarities in the medio-lateral directions of harmonic ratios at all segments both in the global and in the body references in AIS patients and the healthy teenagers (**Figure 3.1.1(c)**).

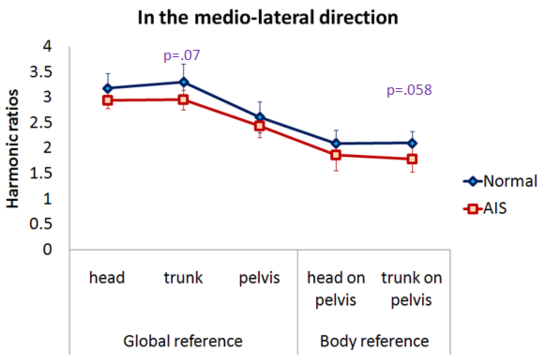
In AIS patients with double curve, harmonic ratios were significantly smaller in the vertical direction on head (p=.007), trunk (p=.005), and pelvis (p=.005) in the global reference view. The harmonic ratio was also significantly smaller in the antero-posterior direction on the segment of the trunk on pelvis (p=.02) in AIS patients with double curve (**Table 3.1.5**).



(a)



(b)



(c)

Figure 3.1.1 Harmonic ratios (HR) between AIS patients (pre-brace) and healthy teenagers on the head, the trunk and the pelvis in the global reference and on segments of the head and the trunk in the pelvis body reference during gait. (a) HR in the vertical direction; (b) HR in the antero-posterior direction; (c) HR in the medio-lateral direction. The error bars represent 95% confidence interval.

In AIS patients with right thoracic curve, harmonic ratios were significantly smaller in the antero-posterior direction on segments of the head on pelvis (p=.002) and the trunk on pelvis (p=.01) in the body reference view. The harmonic ratio was also significantly smaller in the medio-lateral direction on segment of the trunk on pelvis (p=.03) in AIS patients with right thoracic curve (**Table 3.1.5**).

In AIS patients with lumbar curve, harmonic ratios were significantly smaller in the vertical direction on head (p=.028) and trunk (p=.02) in the global reference view. Harmonic ratios was significantly smaller in the medio-lateral direction on segments of the head on pelvis (p=.02) and the trunk on pelvis (p=.02) in the body reference in AIS patients with lumbar curve (**Table 3.1.5**).

Table 3.1.5 Harmonic ratios (HR) between each subgroup of AIS patients (pre-brace) and healthy teenagers on segments both in the global reference and in the body reference during gait

			Healthy teenagers N=15	AIS (Double) N=9		AIS (R't thorax) N=3		AIS (Lumbar) N=3	
			Median	Median	p	Median	p	Median	p
AP	Global reference	Head	1.2	.8	.1	1.4	.2	.9	.051
		Trunk	1.8	1.5	.1	1.9	.9	1.6	.06
		Pelvis	2.7	2.6	.3	2.3	.1	2.4	.2
	Body reference	Head on pelvis	2.7	2.4	.1	2	.002*	2.2	.5
		Trunk on pelvis	2.5	2.1	.02*	1.6	.01*	2.3	.4
ML	Global reference	Head	3.1	2.7	.07	3	.9	2.8	.08
		Trunk	3.1	2.8	.06	3	.4	3	.1
		Pelvis	4.4	2.5	.8	2.7	.3	2.2	.1
	Body reference	Head on pelvis	2.1	1.8	.9	1.8	.4	1.2	.02*
		Trunk on pelvis	2.1	2	.2	1.5	.03*	1.2	.02*
V	Global reference	Head	4.2	3	.007*	3.5	.2	3.3	.028*
		Trunk	4.4	3	.005*	3.6	.2	3.1	.02*
		Pelvis	3.3	2.4	.005*	3.2	.9	2.9	.1
	Body reference	Head on pelvis	1.3	1.2	.3	1.1	.07	1.5	.8
		Trunk on pelvis	1.5	1.2	.08	1.1	.1	1.4	.5

1. *: meant p< .05 between the subgroup of AIS patients and healthy teenagers.
2. AP: HR in the antero-posterior direction; ML: HR in the medio-lateral direction; V: HR in the vertical direction.

3.1.3 Peak-to-peak range and offset of all segmental obliquities and rotations during gait

There was similar on the peak-to-peak range for segmental obliquities and rotations during walking between AIS patients and healthy teenagers (**Table 3.1.6**).

Table 3.1.6 Peak-to-peak range (°) of all segmental obliquity and rotation during walking between AIS patients and healthy teenagers

	Healthy teenagers N=15	AIS (Double) N=8		AIS (R't thorax) N=3		AIS (L't lumbar) N=2	
	Median	Median	p	Median	p	Median	p
Obliquity							
Head	3.2	3.9	.4	2.8	.6	4.5	.3
Trunk	3.1	3.4	.7	2.7	.6	3.1	1
Pelvis	8	7.5	.7	6.3	.3	8.3	.8
Head on pelvis	8.5	10	.7	7.8	.4	11.4	.2
Trunk on pelvis	9.1	9.6	.4	8.2	.3	10.9	.2
Rotation							
Head	4.8	5.1	.7	5.3	.6	4.3	.9
Trunk	6.7	7	.8	7.9	.4	5.8	.4
Pelvis	8.1	6.9	.3	8.6	.6	10.3	.7
Head on pelvis	11.7	8.6	.2	9.8	.6	11	.9
Trunk on pelvis	9.9	8.9	.5	9.5	1	10	1

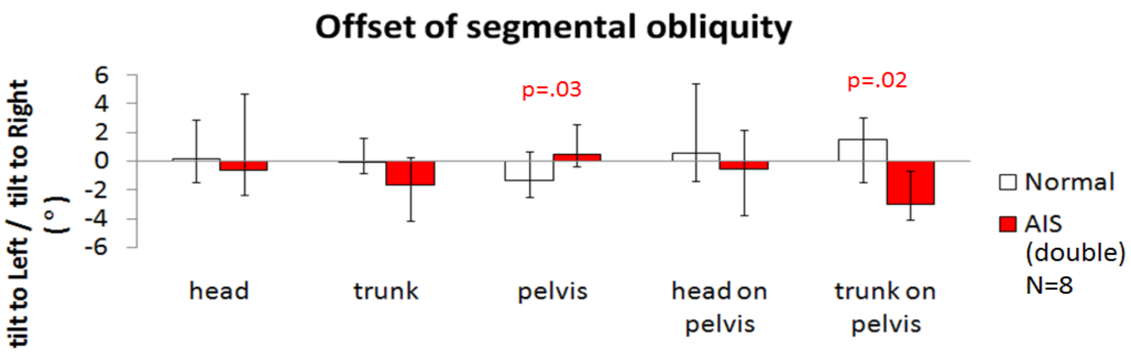
p value shows the comparison of healthy teenagers and subgroup of AIS patients

In AIS patients with double curve of right thorax and left lumbar, offsets of the trunk on pelvis was significantly oblique to left (p=.02), and trunk offsets showed a trend of rotating to left side (p=.056) during gait (**Figure 3.1.2).**

In AIS patients with single curve of right thorax, offset of the trunk was significantly both oblique (p=.03) and rotated (p=.02) to left side during gait. The trunk on pelvis was with a trend of tilting to left (p=.07) during gait (**Figure 3.1.3).**

In AIS patients with single left lumbar, offsets of the trunk on pelvis showed a trend

(a)



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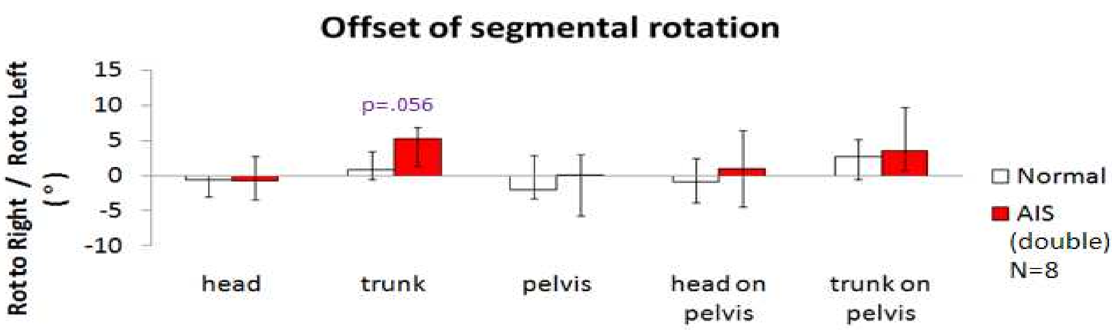
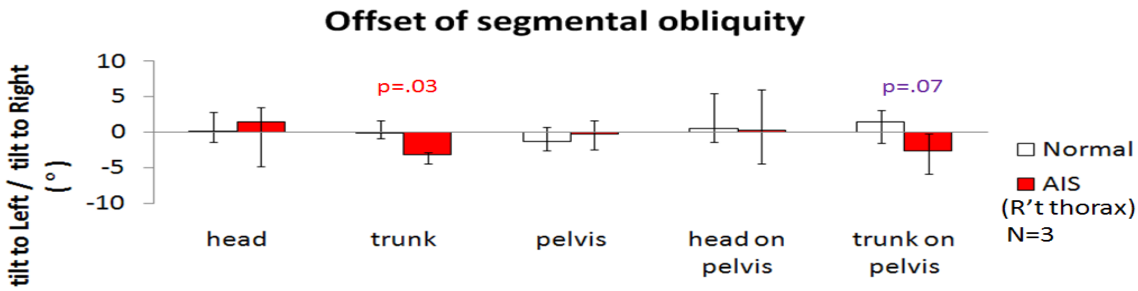
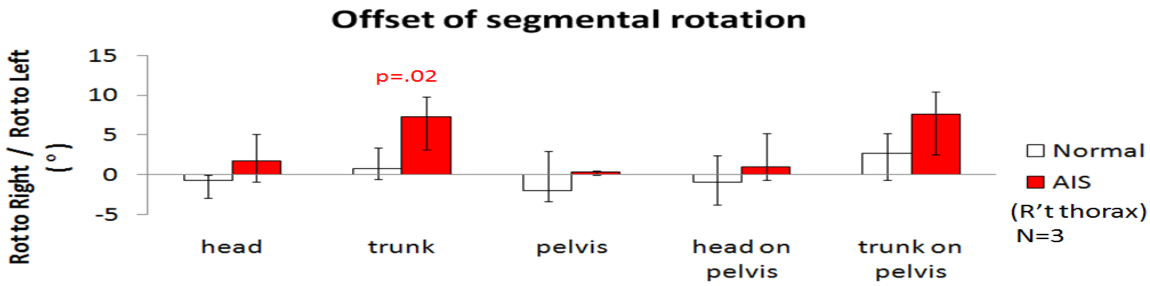


Figure 3.1.2 The offset (degree) of all segmental obliquity and rotation during walking between healthy teenagers and AIS patients with the double curve of right thorax and left lumbar. (a) Offsets of segmental obliquity. Positive value was meant the orientation tilted to right side; negative value was meant the orientation tilted to left side. (b) Offsets of segmental rotation. Positive value was meant the orientation rotated to left side; negative value was meant the orientation rotated to right side. The value was presented by median ± upper/lower quarter.

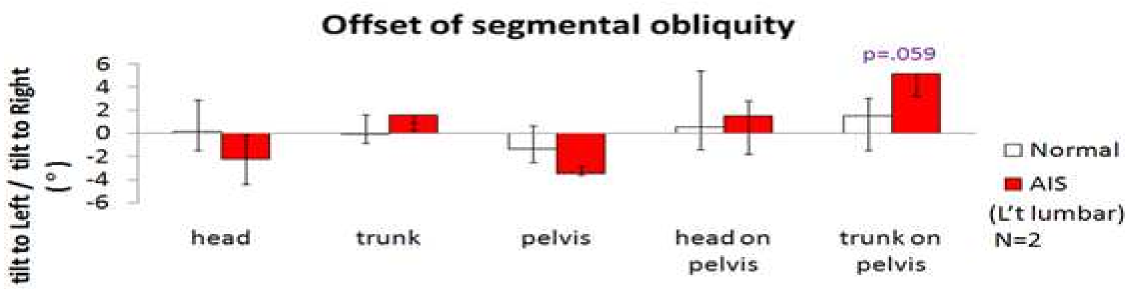


(a)

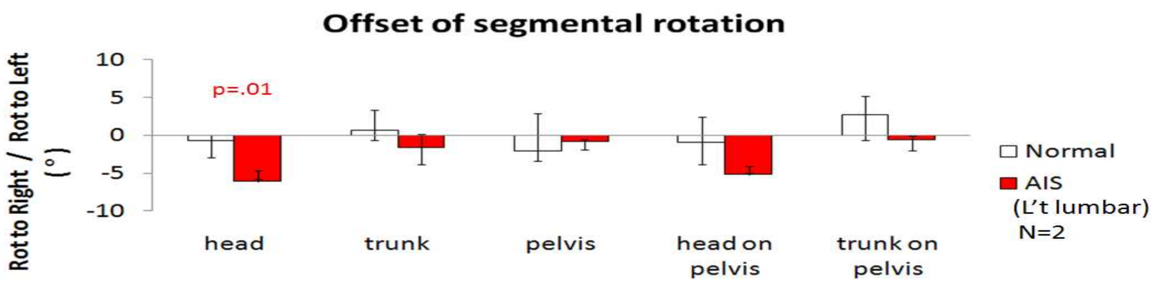


(b)

Figure 3.1.3 The offset (degree) of all segmental obliquity and rotation during walking between healthy teenagers and AIS patients with the single curve of right thorax. (a) Offsets of segmental obliquity. Positive value was meant the orientation tilted to right side; negative value was meant the orientation tilted to left side. (b) Offsets of segmental rotation. Positive value was meant the orientation rotated to left side; negative value was meant the orientation rotated to right side. The value was presented by median ± upper/lower quarter.



(a)



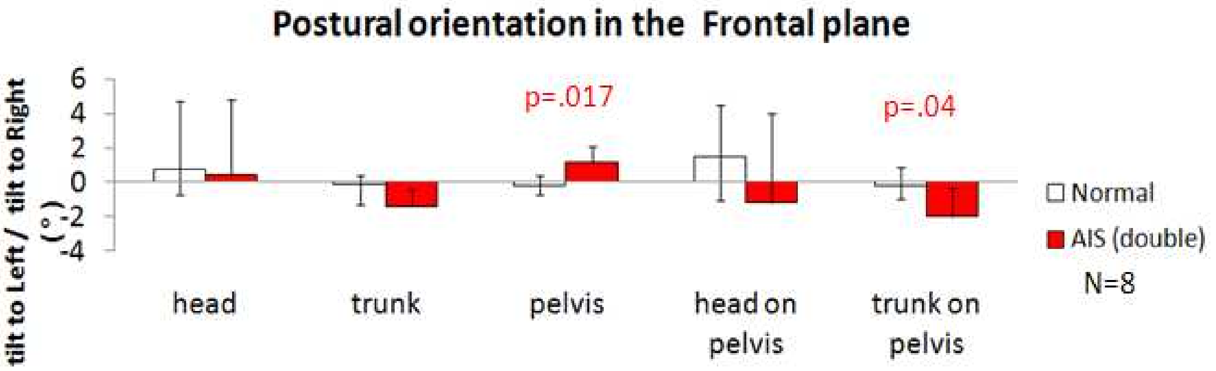
(b)

Figure 3.1.4 The offset (degree) of all segmental obliquity and rotation during walking between healthy teenagers and AIS patients with the single curve of left lumbar. (a) Offsets of segmental obliquity. Positive value was meant the orientation tilted to right side; negative value was meant the orientation tilted to left side. (b) Offsets of segmental rotation. Positive value was meant the orientation rotated to left side; negative value was meant the orientation rotated to right side. The value was presented by median ± upper/lower quarter.

3.1.4 Postural orientation in static standing

AIS patients with double curve of right thorax and left lumbar displayed statistically significant pelvis tilted to right side (p=.017) and the trunk on pelvis tilted to left side (p=.04) in the frontal plane for the static standing posture (**Figure 3.1.5 (a)**). This subgroup AIS patients also had pelvic deviation of rotation to the right (p=.007), and the trunk on pelvis deviation of rotation to left (p=.001) in the transverse plane when compared to healthy teenagers (**Figure 3.1.5 (b)**).

(a)



(b)

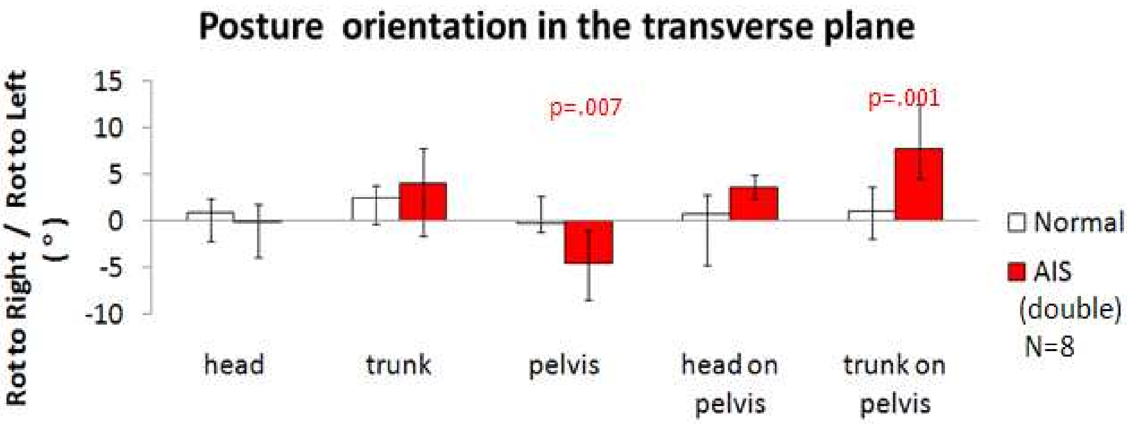
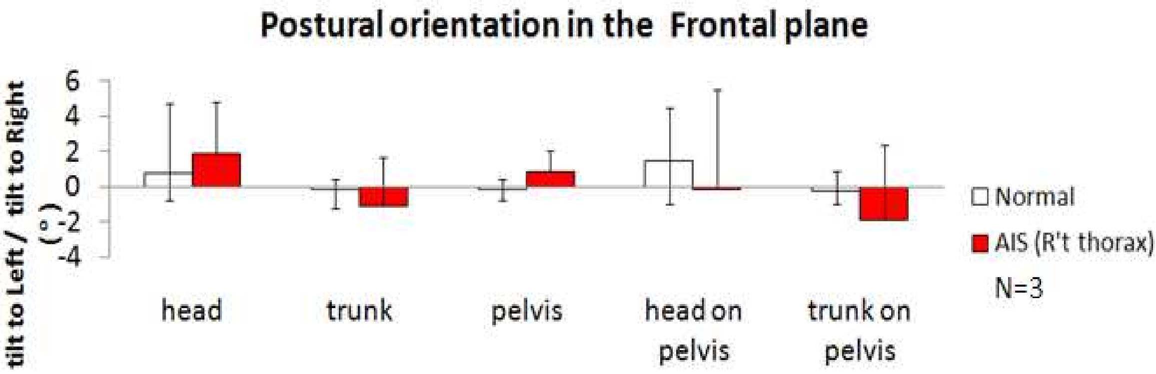
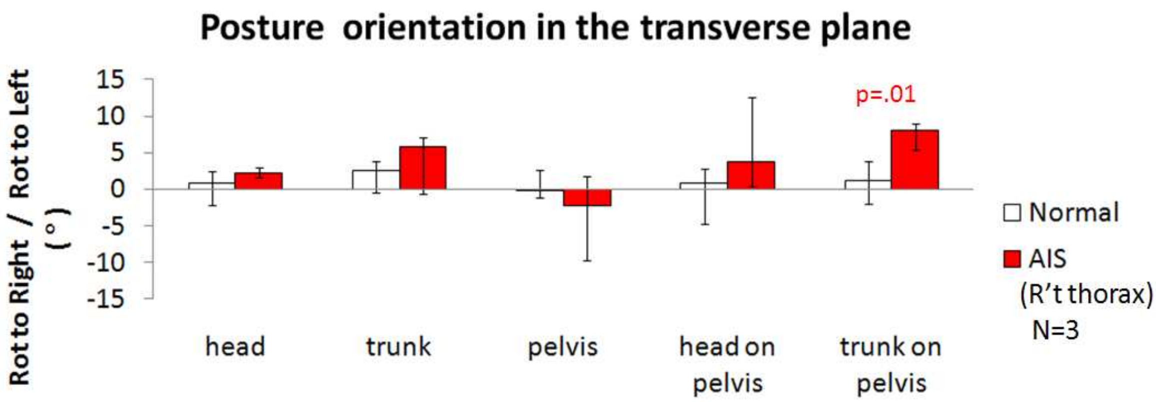


Figure 3.1.5 The postural orientation between AIS patients and healthy teenagers in the AIS patients with the double curve of right thorax and left lumbar. (a) The orientation in the frontal plane. Positive value was meant the orientation tilted to the right; negative value was meant the orientation tilted to the left. (b) The orientation in the transverse plane. Positive value was meant the orientation rotated to the left; negative value was meant the orientation rotated to the right. The value was presented by median ± upper/lower quarter.

AIS patients with single curve of right thorax displayed statistically significant the trunk on pelvis deviation of rotation to the left (p=.01) in transverse plane when compared with healthy teenagers (**Figure 3.1.6**).



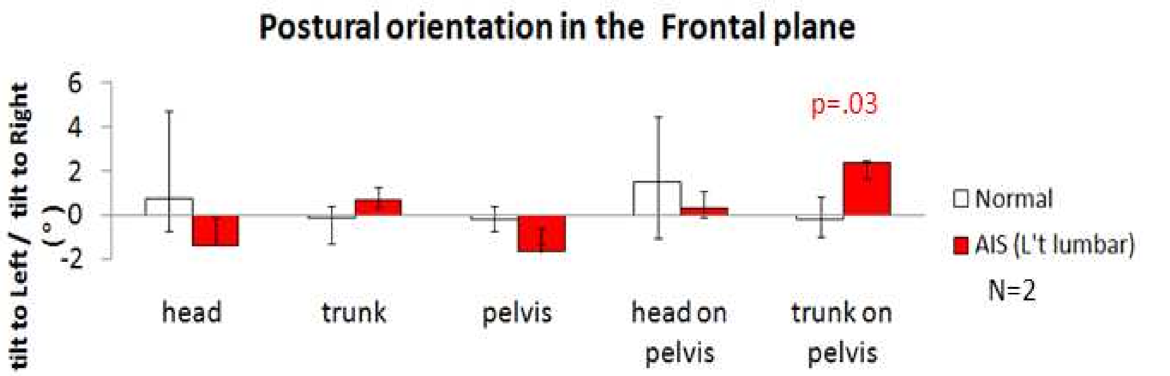
(a)



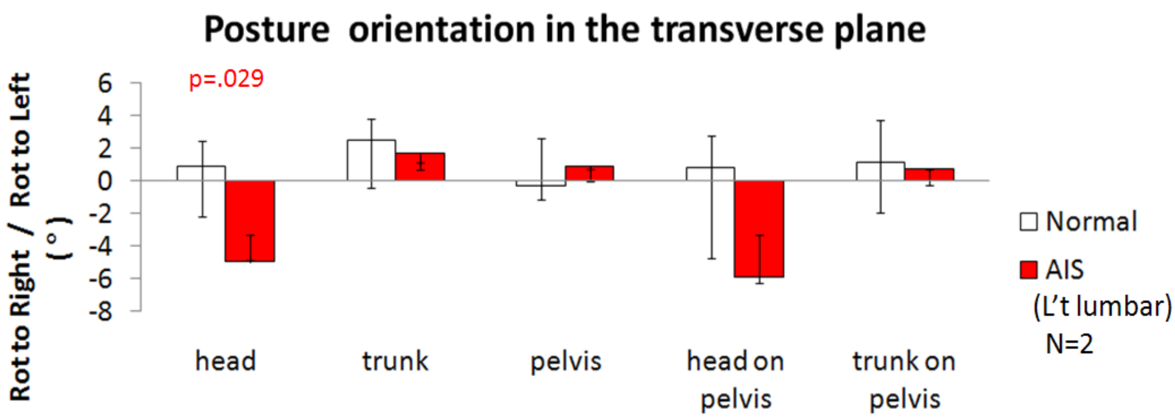
(b)

Figure 3.1.6 The postural orientation between AIS patients and healthy teenagers in the AIS patients with the single curve of right thorax. (a) The orientation in the frontal plane. Positive value was meant the orientation tilted to the right; negative value was meant the orientation tilted to the left. (b) The orientation in the transverse plane. Positive value was meant the orientation rotated to the left; negative value was meant the orientation rotated to the right. The value was presented by median ± upper/lower quarter.

AIS patients with single curve of left lumbar displayed statistically significant the trunk on pelvis tilt to right side (p=.03) in the frontal plane and the head deviation of rotation to right side (p=.029) in the transverse plane when compared with healthy teenagers for static standing posture (**Figure 3.1.7**).



(a)



(b)

Figure 3.1.7 The postural orientation between AIS patients and healthy teenagers in the AIS patients with the single curve of left lumbar. (a) The orientation in the frontal plane. Positive value was meant the orientation tilted to the right; negative value was meant the orientation tilted to the left. (b) The orientation in the transverse plane. Positive value was meant the orientation rotated to the left; negative value was meant the orientation rotated to the right. The value was presented by median ± upper/lower quarter.

3.1.5 Correlation between the segmental offset during gait and the postural orientation in standing in AIS patients

The following figures show the offset of trunk rotation during gait correlated to the trunk rotation (r^2=.48, p=.009) and trunk-pelvis rotation (r^2=.45, p=.01) in the standing posture (**Figure 3.1.8**).

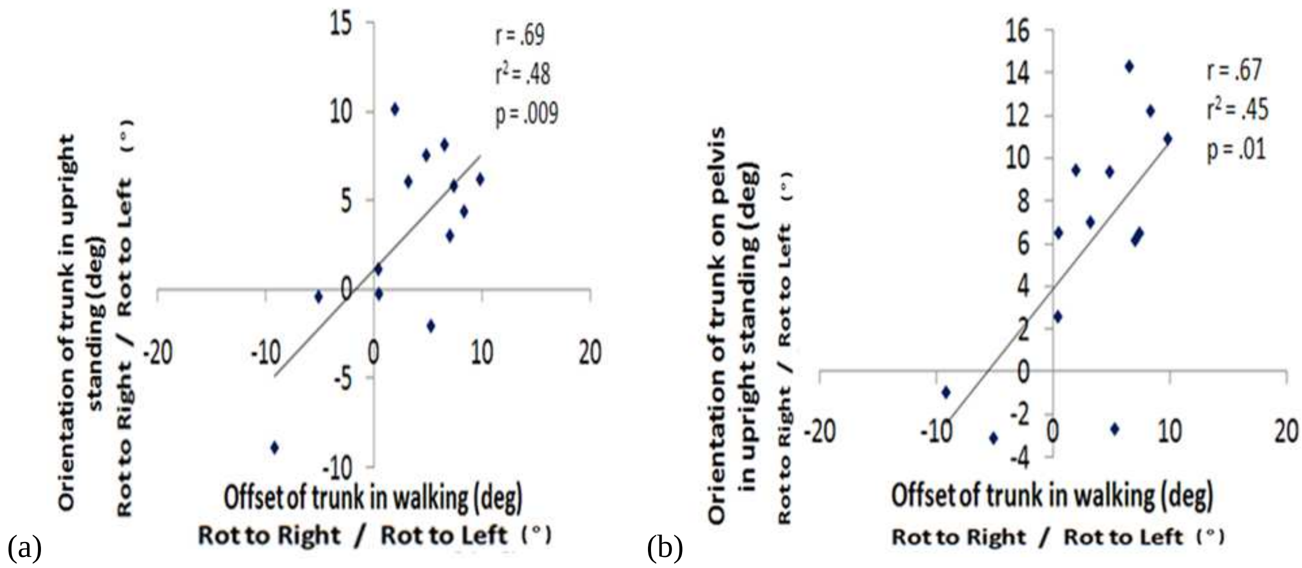


Figure 3.1.8 (a) Correlation between the offset of the segment of trunk rotation (°) during walking and the trunk rotation (°) in static upright standing (°). (b) Correlation between the offset of the segment of trunk rotation (°) during walking and the segment of the trunk on pelvis rotation (°) in static upright standing (°). Positive value was meant the orientation rotated to left side; negative value was meant the orientation rotated to right side.

3.1.6 Head decompensation in standing position

AIS patients, who had the double curve with right thorax and left lumbar, showed significantly larger head decompensation to left side (p=.04). AIS patients with single curve of right thorax showed significantly larger head decompensation to right side (p=.03) (**Figure 3.1.9**)

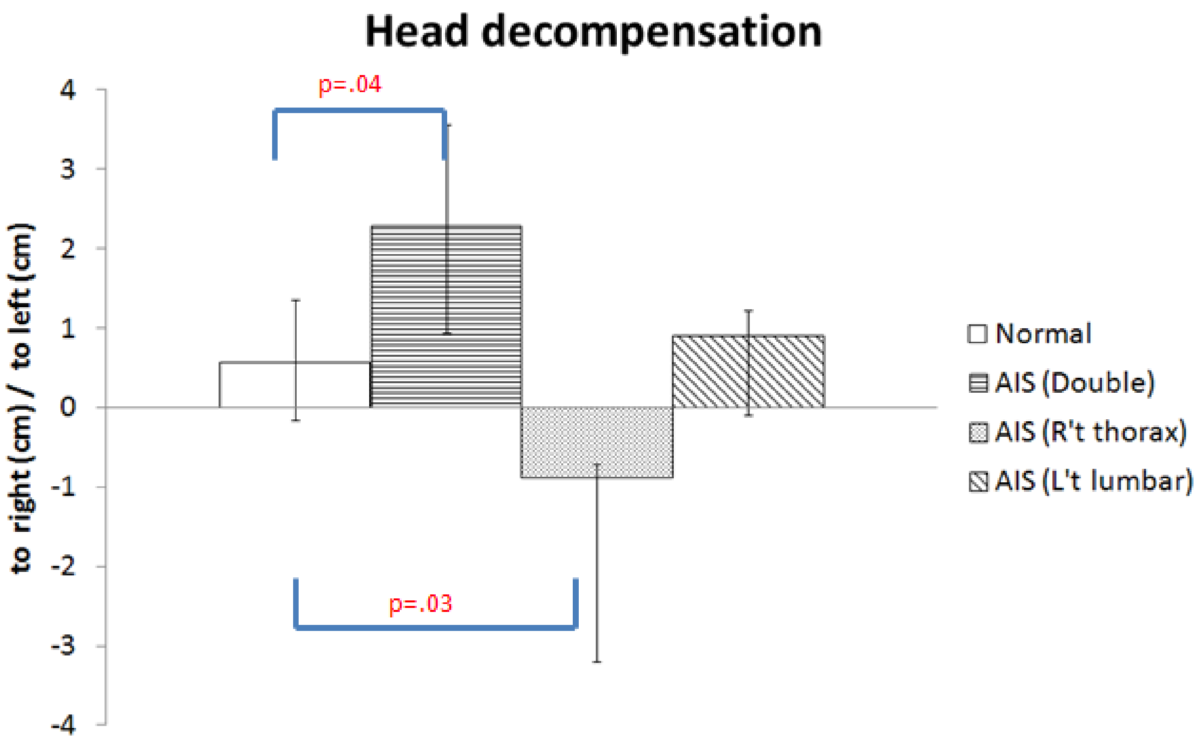


Figure 3.1.9 Head decompensation. The figure shows head decompensation from left to right in the sequence of healthy teenagers, AIS patients with double curve of right thorax and left lumbar, AIS patients with single curve of right thorax, and AIS patients with single curve of left lumbar. The value was presented by median ± upper/lower quarter.

3.1.7 COP parameters in standing

For the non-thin group, AIS patients had a tendency to show a "poor" standing balance control compared with the same somatotype healthy teenagers in eyes closed position. There was a trend of larger values for COP parameters for mean distance in open eyes condition, and for COP pace, sway area, and mean distance in eyes closed condition in AIS patients compared with healthy subjects in the non-thin group (height-weight ratios < 44) (**Figure 3.1.10**).

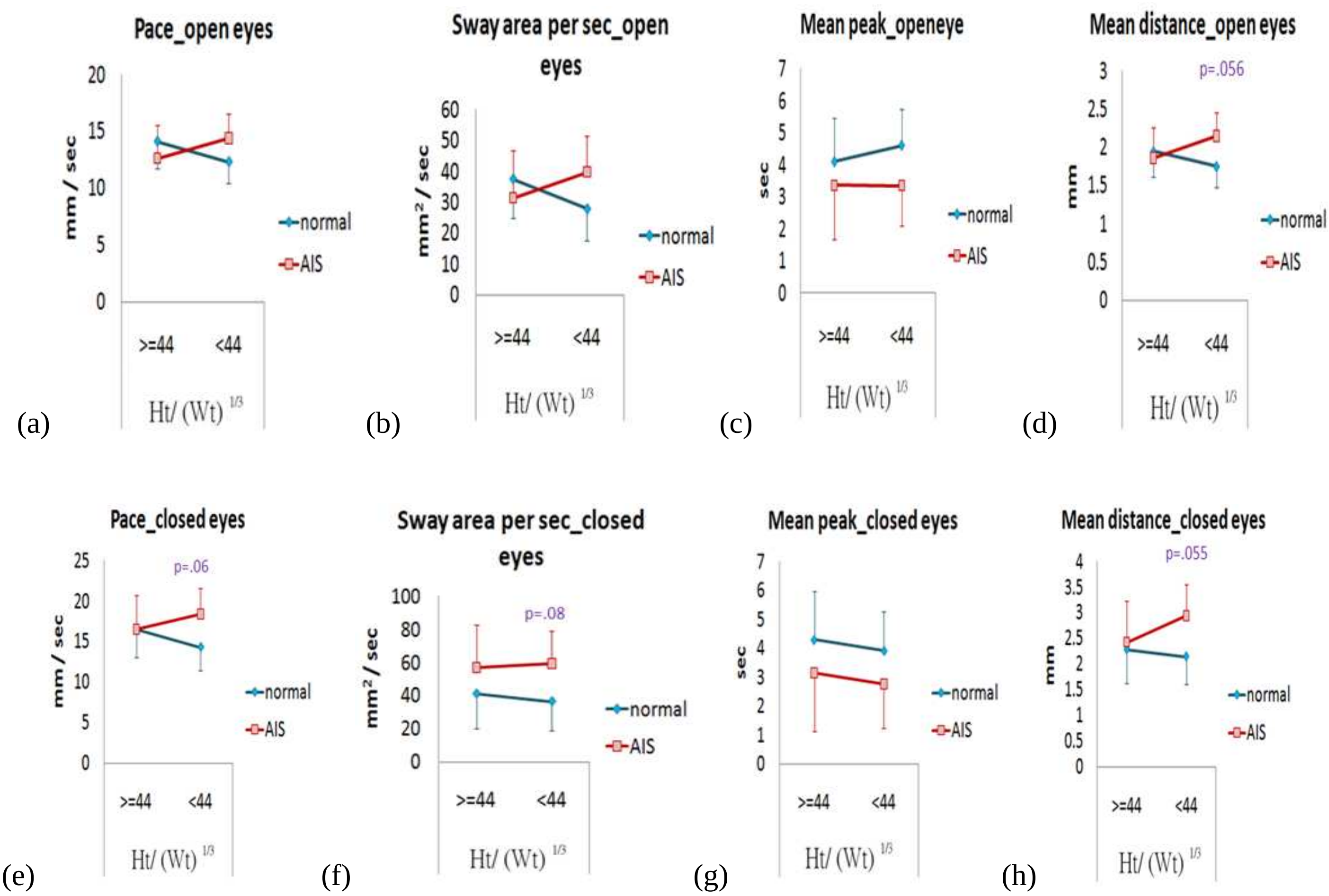


Figure 3.1.10 The standing balance between AIS patients and normal subjects. Using height-weight ratios (=44) to separate thin group (height-weight ratios≥44) and non-thin group (height-weight ratios<44) in AIS patients and normal subjects. From (a) to (d) were in open eyes conditions, and from (e) to (h) were in closed eyes conditions. Error bars were represented half of 95% confidence interval.

3.1.8 Summary

Table 3.1.7 shows a summary for harmonic ratios during gait in AIS patients compared with normal subjects.

Table 3.1.7 The summary of harmonic ratios (HR) during gait in AIS patients

			AIS compared with normal subjects				
			H	**T**	**P**	**H/P**	**T/P**
Dynamic parameters	**HR (All)**	**AP**		⬇	⬇	⇩	⇩
		ML		⬇			⬇
		V	⇩	⇩	⇩		⇩
	HR (Double)	**AP**					⇩
		ML	⬇	⬇			
		V	⇩	⇩	⇩		⬇
	HR (R't Thorax)	**AP**				⇩	⇩
		ML					⇩
		V				⬇	
	HR (Lumbar)	**AP**	⬇	⬇			
		ML	⬇			⇩	⇩
		V	⇩	⇩			

- ⇩: smaller values of HR in AIS patients compared with control (p<.05);
- ⬇: smaller values of HR in AIS patients compared with control (a trend);
- H: head; T: trunk; P:pelvis; H/P: head on pelvis; T/P: trunk on pelvis

Table 3.1.8 presents a summary of the offset during gait and standing orientation in AIS patients. A summary of the head deconpensation in static standing in AIS patients is also included in **Table 3.1.8**. Sample size in the comparisons on each parameter was showed on **Table 3.1.9.**

Table 3.1.8 The summary of dynamic and static parameters in AIS patients

				AIS compared with normal subjects				
				H	T	P	H/P	T/P
Dynamic parameters	Offset	Obliquity	Double					Tilt to left
			R't Thorax		Tilt to left			
			L't Lumbar					
		Rotation	Double					
			R't Thorax		Rot o left			
			L't Lumbar	Rot to right				
Static parameter	Posture orientation	Obliquity	Double					Tilt to left
			R't Thorax					
			L't Lumbar					Tilt to right
		Rotation	Double			Rot to right		Rot to left
			R't Thorax					Rot to left
			L't Lumbar	Rot to right				
	Decompensation		Double	Decompensatied to left side				
			R't Thorax	Decompensatied to right side				
			L't Lumbar					
	COP		Thin					
			Non-thin	A trend of large values for COP parameters				

H: head; T: trunk; P:pelvis; H/P: head on pelvis; T/P: trunk on pelvis

Table 3.1.9 Sample size of AIS patients and normal subjects for various studies

Sample size			AIS	Normal
Dynamic parameters	Harmonic ratios	All	15	15
		Double	9	
		R't thorax	3	
		Lumbar	3	
	Range & Offset	Double	8	15
		R't thorax	3	
		L't lumbar	2	
Static parameters	Decompensation & Posture	Double	8	15
		R't thorax	3	
		L't lumbar	2	
	COP	Thin	4	6
		Non-thin	7	9

3.2 The effect of bracing and motion adaptation in AIS patients

3.2.1 The walking rhythm for AIS patients

Analysis of the variance (ANOVA) of the harmonic ratio showed no significant interaction of time (0 month and 4month) x brace (in brace and out brace) in three directions (antero-posterior, medio-lateral and vertical) on all segments (the head, trunk and pelvis in the global reference view; the head on pelvis and the trunk on pelvis on the body reference view).

3.2.1.1 In the Antero-Posterior Direction

The effect of bracing

Analysis of the variance of the harmonic ratio showed a main effect of brace on the head (f[1,8]=9.8, p=.014) displaying larger harmonic ratio on the head in the in-brace condition than in the out-brace condition (**Figure 3.2.1 (a)**).

Analysis of the variance of the harmonic ratio showed a main effect of brace on segments of the head on pelvis (f[1,8]=9.4, p=.015) (**Figure 3.2.1 (d)**)and of the trunk on pelvis (f[1,8]=19.5, p=.002) (**Figure 3.2.1 (e)**), yielding smaller harmonic ratio on segments of the head on pelvis and of the trunk on pelvis in in-brace condition than in out-brace condition. In the paired-t test, the harmonic ratio was decreasing on the segment of the trunk on pelvis in 0-month in-brace condition compared with 0-month out-brace condition (p=.018), which was defined as the immediate effect of bracing. However, the harmonic ratio was similar on the segment of the trunk on pelvis in 4-month in-brace condition compared with 0-month out-brace condition, which was defined as the 4-month effect of bracing.

Motion adaptation

Analysis of the variance of the harmonic ratio showed a main effect of time on the segments of the head on pelvis (f[1,8]=16.5, p=.004) (**Figure 3.2.1 (d)**)and of the trunk on pelvis (f[1,8]=7.6, p=.025) (**Figure 3.2.1 (e)**), yielding larger harmonic ratio on segments of the head on pelvis and of the trunk on pelvis in 4-month condition than in 0-month condition. In the paired-t test, the harmonic ratio showed no significant difference but had a trend of increasing harmonic ratio on the segment of the head on pelvis in 4-month out-brace condition compared with 0-month out-brace condition (p=.08), which was defined as 4-month motion adaptation.

3.2.1.2 In the Medio-Lateral Direction

The effect of bracing

Analysis of the variance of the harmonic ratio showed a main effect of brace on the head (f[1,8]=9.4, p=.016), appearing smaller harmonic ratio on the head in the in-brace condition than in the out-brace condition(**Figure 3.2.2 (a)**). In the paired-t test, the harmonic ratio was decreasing with a trend on the head in 0-month in-brace condition compared with 0-month out-brace condition (p=.059), which was defined as the immediate effect of bracing. The harmonic ratio was significantly decreasing on the head in 4-month in-brace condition compared with 0-month out-brace condition (p=.001), which was defined as the 4-month effect of bracing.

Analysis of the variance of the harmonic ratio showed a main effect of brace on the segment of the trunk on pelvis (f[1,9]=6.4, p=.036), yielding larger harmonic ratio on the segment of the trunk on pelvis in the in-brace condition than in the out-brace condition(**Figure 3.2.2 (e)**).

Motion adaptation

Analysis of the variance of the harmonic ratio showed a main effect of time on the head (f[1,8]=6.2, p=.03), displaying smaller harmonic ratio on the head in the 4-month condition than in the 0-month condition(**Figure 3.2.2 (a)**). In the paired-t test, the harmonic ratio was significantly decreasing on the head in 4-month out-brace condition compared with 0-month out-brace condition (p=.018), which was defined as 4-month motion adaptation.

3.2.1.3 In the Vertical Direction

The effect of bracing

Analysis of the variance of the harmonic ratio showed a main effect of brace on the trunk (f[1,8]=7.1, p=.028), yielding smaller harmonic ratio on the trunk in the in-brace condition than in the out-brace condition(**Figure 3.2.3 (b)**).

Motion adaptation

Analysis of the variance of the harmonic ratio showed a main effect of time on the head (f[1,8]=6.6, p=.03), displaying larger harmonic ratio on the head in the 4-month condition than in the 0-month condition(**Figure 3.2.3 (a)**).

Analysis of the variance of the harmonic ratio showed a main effect of time on the segment of the head on pelvis (f[1,8]=6.5, p=.03), displaying larger harmonic ratio on the segment of the head on pelvis in the 4-month condition than in the 0-month condition(**Figure 3.2.3 (d)**). In the paired-t test, the harmonic ratio was significantly increasing on the segment of the head on pelvis in 4-month out-brace condition compared with 0-month out-brace condition (p=.026), which was defined as 4-month motion adaptation.

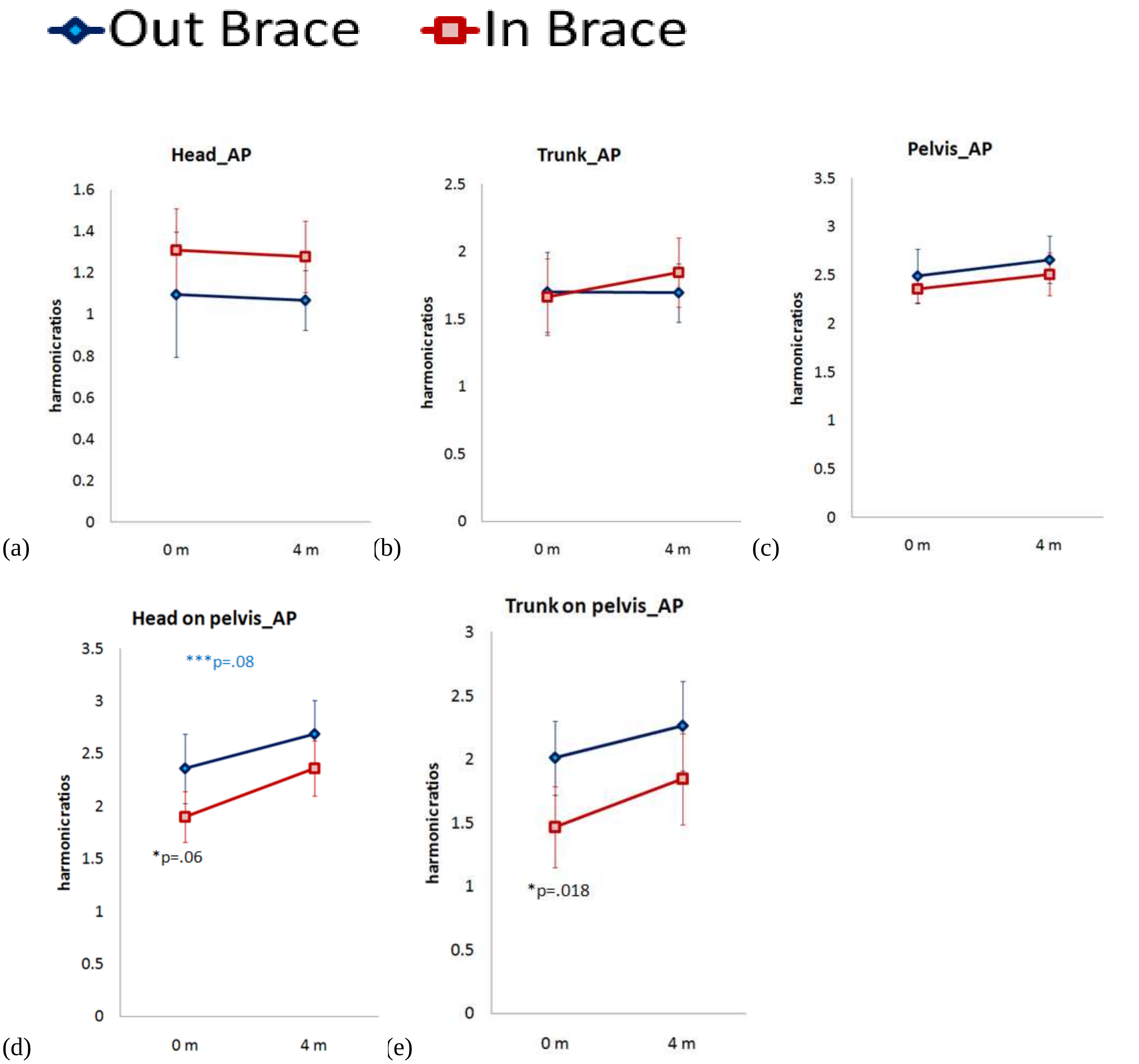


Figure 3.2.1 Harmonic ratios (HR) during gait in the antero-posterior (AP) direction in two time of 0-month and 4-month, and the two conditions of out brace and in brace. (a) HR on the head; (b) HR on the trunk; (c) HR on the pelvis; (d) HR on the segment of the head on pelvis; (e) HR on the segment of the trunk on pelvis. The error bars represent 95% confidence interval

***: meant the comparison of 0-month out-brace condition and 0-month in-brace condition (immediate effect of bracing)**

****: meant the comparison of 0-month out-brace condition and 4-month in the in-brace condition (4-month effect of bracing)**

*****: meant the comparison of 0-month and 4-month in the out-brace condition (4-month motion adaptation)**

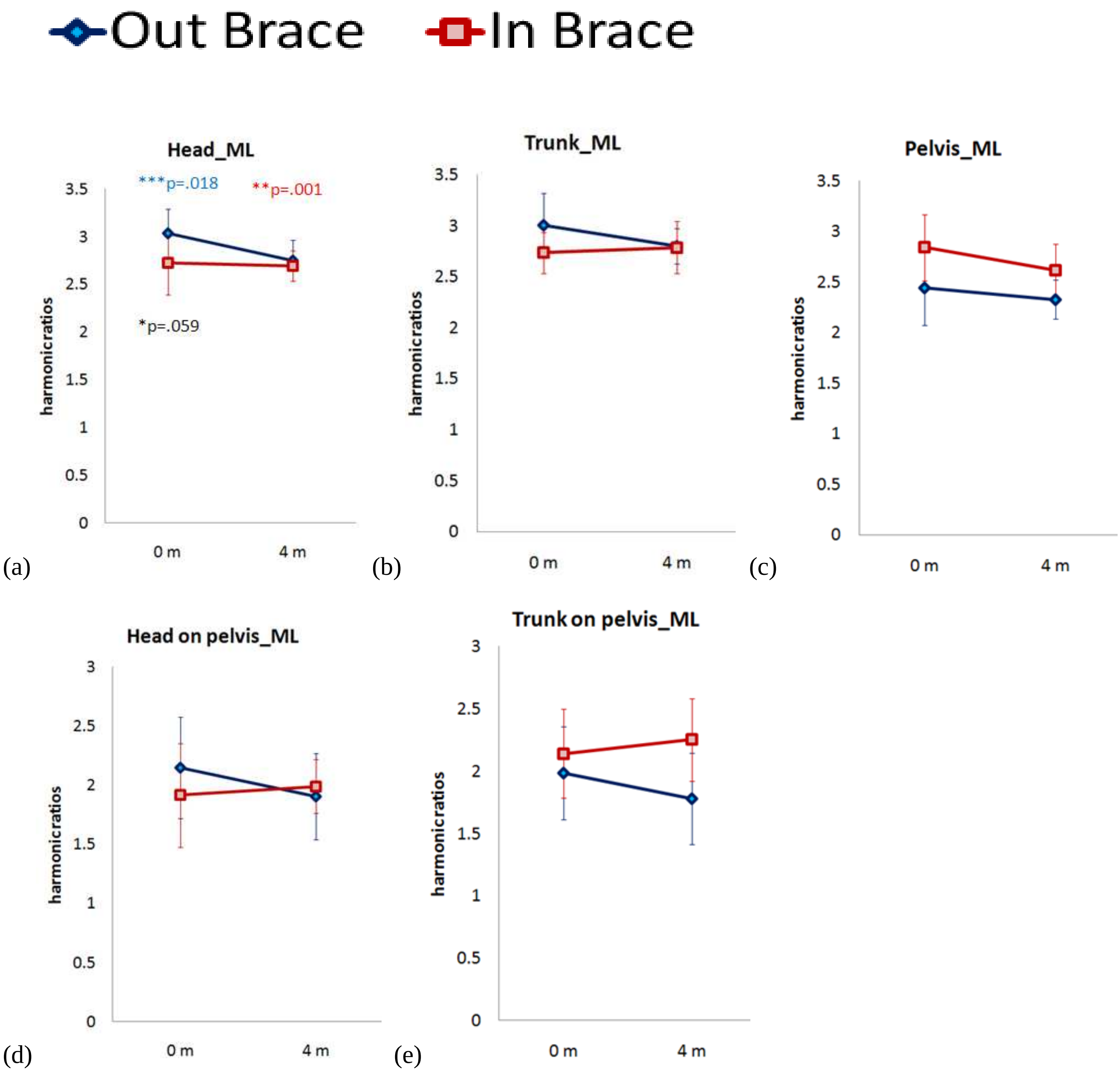


Figure 3.2.2 Harmonic ratios (HR) during gait in the medio-lateral (ML) direction in two time of 0-month and 4-month, and the two conditions of out brace and in brace. (a) HR on the head; (b) HR on the trunk; (c) HR on the pelvis; (d) HR on the segment of the head on pelvis; (e) HR on the segment of the trunk on pelvis. The error bars represent 95% confidence interval

***: meant the comparison of 0-month out-brace condition and 0-month in-brace condition (immediate effect of bracing)**

****: meant the comparison of 0-month out-brace condition and 4-month in the in-brace condition (4-month effect of bracing)**

*****: meant the comparison of 0-month and 4-month in the out-brace condition (4-month motion adaptation)**

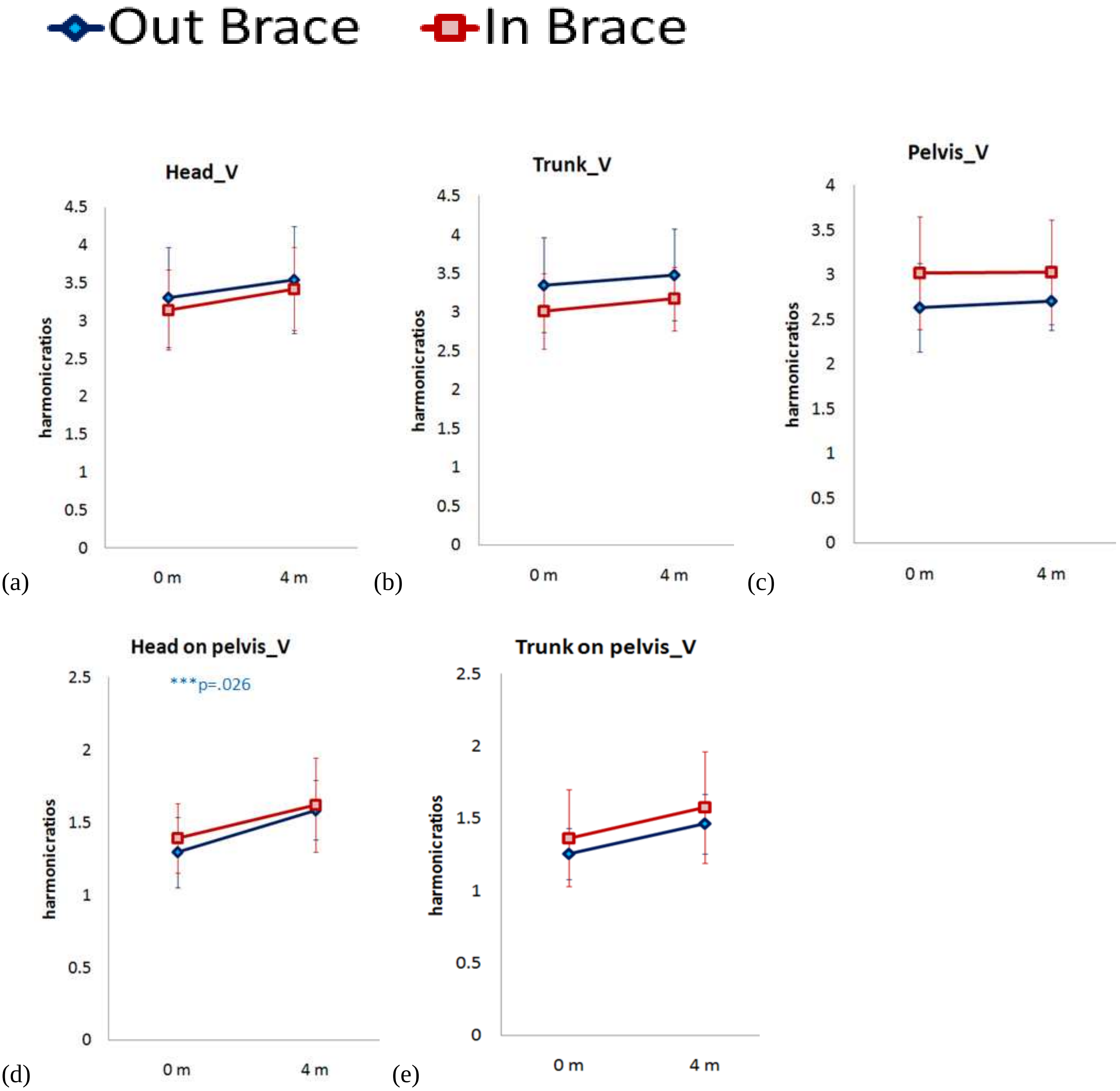


Figure 3.2.3 Harmonic ratios (HR) during gait in the vertical (V) direction in two time of 0-month and 4-month, and the two conditions of out brace and in brace. (a) HR on the head; (b) HR on the trunk; (c) HR on the pelvis; (d) HR on the segment of the head on pelvis; (e) HR on the segment of the trunk on pelvis. The error bars represent 95% confidence interval

***: meant the comparison of 0-month out-brace condition and 0-month in-brace condition (immediate effect of bracing)**

****: meant the comparison of 0-month out-brace condition and 4-month in the in-brace condition (4-month effect of bracing)**

*****: meant the comparison of 0-month and 4-month in the out-brace condition (4-month motion adaptation)**

3.2.2 The peak-to-peak range of segmental obliquity and rotation during gait for AIS patients with double curve

3.2.2.1 In the Frontal Plane

Nonparametric analysis of the peak-to-peak range during gait, among four conditions of 0-month out-brace, 0-month in-brace, 4-month out-brace, and 4-month in-brace, showed significant differences on the head (p=.02), the pelvis (p=.002), and the segment of the trunk on pelvis (p=.001) in the frontal plane in AIS patients with double curve of right thorax and left lumbar (**Table 3.2.1)**.

The effect of bracing

In the pairwise comparison, the peak-to-peak range in the frontal plane was increasing on the head in 0-month in-brace condition compared with 0-month out-brace condition (p=.028), which was defined as the immediate effect of bracing (**Figure 3.2.4(a))**. The peak-to-peak ranges in the frontal plane were decreasing on the pelvis (p=.028) and the segment of the trunk on pelvis (p=.028) in 0-month in-brace condition compared with 0-month out-brace condition, which was defined as the immediate effect of bracing (**Figure 3.2.4(b)&(c))**. In addition, the peak-to-peak ranges in the frontal plane were decreasing on the pelvis (p=.028) and the segment of the trunk on pelvis (p=.028) in 4-month in-brace condition compared with 0-month out-brace condition, which was defined as the 4-month effect of bracing (**Figure 3.2.4(b)&(c))**.

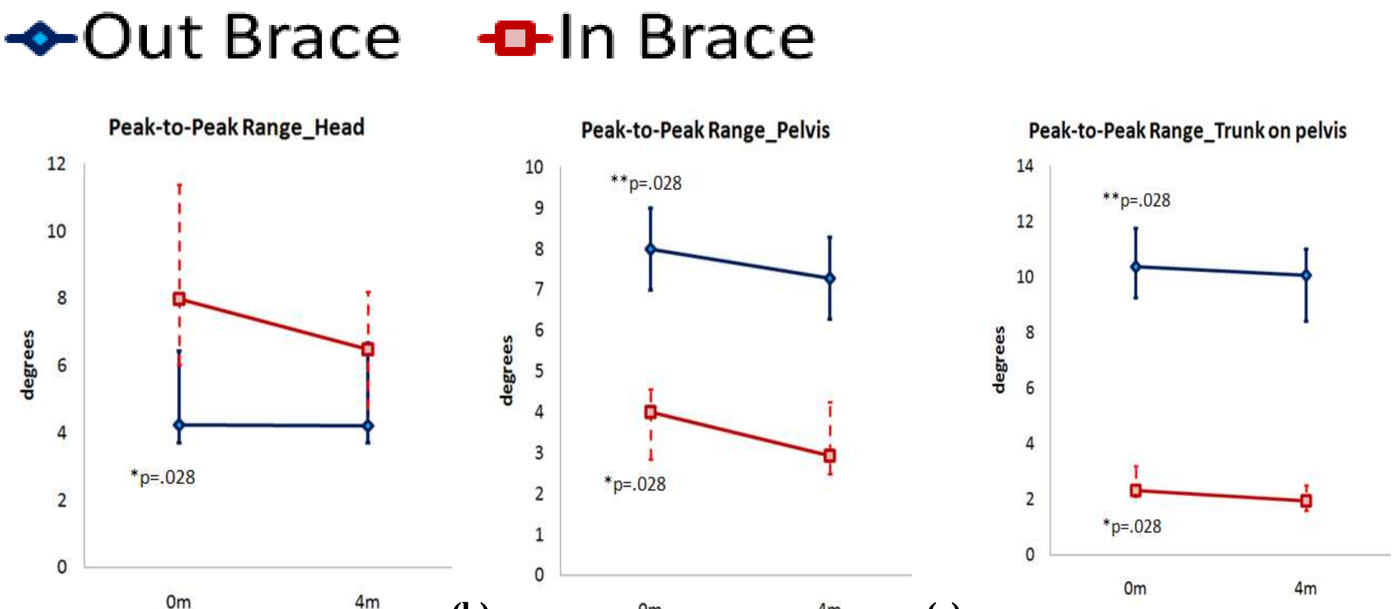
Motion adaptation

There was no motion adaptation, which was defined the difference in the comparison of in 4-month out-brace condition with 0-month out-brace condition, for the peak-to-peak range in the frontal plane during gait.

Table 3.2.1 Peak-to-peak range (°) in the frontal plane in AIS patients with double curve of right thorax and left lumbar

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Head	4.2	1.6	7.9	3.8	4.2	2	6.4	2.5	χ^2[6,3]=9.8	.02*
Trunk	3.6	3	3.8	3	3.6	2.1	2.7	1.8	χ^2[6,3]=3.8	.2
Pelvis	7.9	3.8	4	1.6	7.2	3.1	2.9	1.3	χ^2[6,3]=15.4	.002*
Head on pelvis	10.7	2.6	11	3.3	10.3	2.3	8.4	1.6	χ^2[6,3]=5.2	.1
Trunk on pelvis	10.3	3.8	2.3	1.8	10	3.1	1.9	1.1	χ^2[6,3]=16	.001*

***: meant p< .05 among the 4 conditions (2 time x 2 brace) of the brace treatment in AIS patients with double curve**



(a) (b) (c)

Figure 3.2.4 The peak-to-peak range in the frontal plane on the head (a), on the pelvis (b), and on the segment of the trunk on pelvis (c), during gait in two time of 0-month and 4-month, and the two conditions of out brace and in brace for AIS patients with double curve. The value was presented by median ± upper/lower quarter.

***: meant the comparison of 0-month out-brace condition and 0-month in-brace condition (immediate effect of bracing)**

****: meant the comparison of 0-month out-brace condition and 4-month in the in-brace condition (4-month effect of bracing)**

*****: meant the comparison of 0-month and 4-month in the out-brace condition (4-month motion adaptation)**

3.2.2.2 In the Transverse Plane

Nonparametric analysis of the peak-to-peak range in the transverse plane during gait showed significant differences on the trunk (p=.05) and the segment of the trunk on pelvis (p=.001) among the four conditions (2 time x 2 brace) of the brace treatment in AIS patients with double curve of right thorax and left lumbar (**Table 3.2.2**).

The effect of bracing

The peak-to-peak range in the transverse plane was decreasing on the segment of the trunk on pelvis (p=.028) in 0-month in-brace condition compared with 0-month out-brace condition, which was defined as the immediate effect of bracing (**Figure 3.2.5(b))**. In addition, the peak-to-peak range in the transverse plane was decreasing on the segment of the trunk on pelvis (p=.028) in 4-month in-brace condition compared with 0-month out-brace condition, which was defined as the 4-month effect of bracing (**Figure 3.2.5(b))**.

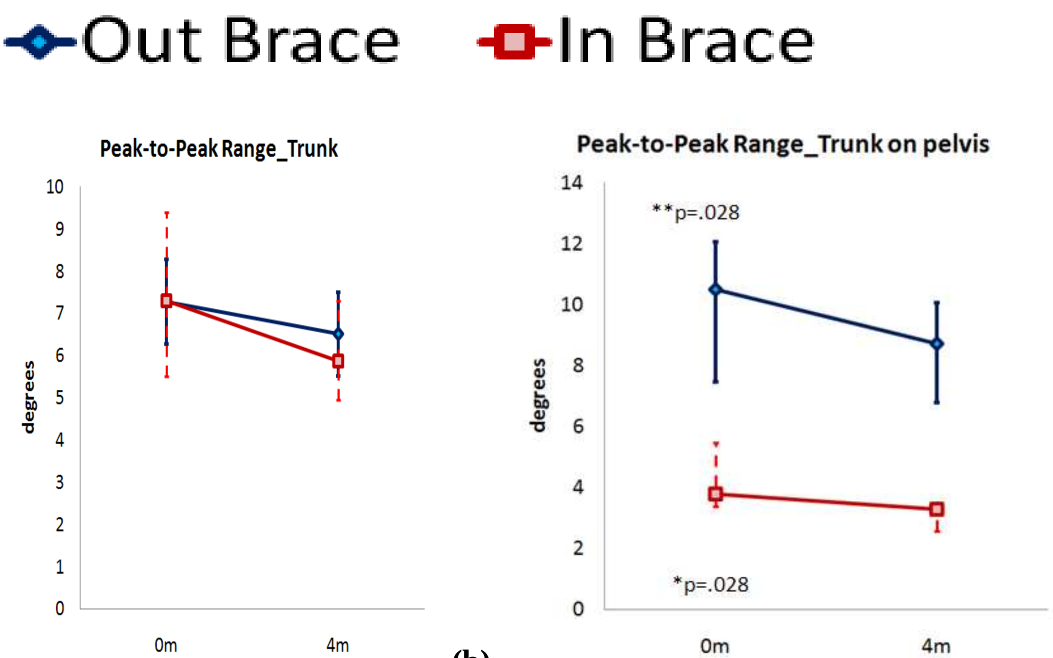
Motion adaptation

There was no motion adaptation, which was defined the difference in the comparison of in 4-month out-brace condition with 0-month out-brace condition, for the peak-to-peak range in the transverse plane during gait.

Table 3.2.2 **Peak-to-peak range (°) in the transverse plane in AIS patients with double curve of right thorax and left lumbar**

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Head	5.2	3.1	5.6	3.1	4.2	1.6	4.7	2	$\chi^2[6,3]=6.6$	.08
Trunk	7.2	3.3	7.3	2.8	6.5	2.5	5.8	1.3	$\chi^2[6,3]=7.8$	.05*
Pelvis	7.8	2.6	7.4	2.5	7.2	3.3	5.7	1.5	$\chi^2[6,3]=6.2$	.1
Head on pelvis	9.4	3.3	8.6	2.3	8.6	2.5	7.1	1.8	$\chi^2[6,3]=4.2$	.2
Trunk on pelvis	10.5	3.8	3.7	2	8.7	3.1	3.2	1	$\chi^2[6,3]=17$	.001*

***: meant p< .05 among the 4 conditions (2 time x 2 brace) of the brace treatment in AIS patients with double curve**



(a) **(b)**

Figure 3.2.5 The peak-to-peak range in the transverse plane on the trunk (a), and on the segment of the trunk on pelvis (b), during gait in two time of 0-month and 4-month, and the two conditions of out brace and in brace for AIS patients with double curve. The value was presented by median ± upper/lower quarter.

***: meant the comparison of 0-month out-brace condition and 0-month in-brace condition (immediate effect of bracing)**

****: meant the comparison of 0-month out-brace condition and 4-month in the in-brace condition (4-month effect of bracing)**

*****: meant the comparison of 0-month and 4-month in the out-brace condition (4-month motion adaptation)**

3.2.3 Other parameters

Due to the few sample size or the no significant result of nonparametric analysis among the four conditions (2 time x 2 brace) of the brace treatment in AIS patients, the results of parameters of segmental offset during gait, COP parameters in standing, postural orientation, and head decompensation were placed in **Appendix C**.

3.2.4 Summary

AIS patients had smaller harmonic ratios than normal subjects in the antero-posterior direction on the body reference view during gait. Among the four conditions (2 time x 2 brace) for AIS patients, the main effect of brace was showed the attenuation on the symmetry in the antero-posterior direction, but the main effect of the treatment time was showed the improvement on the symmetry in the antero-posterior direction on the body reference view during gait **(Table 3.2.3 & Table 3.2.4)**. In the antero-posterior direction on the body reference view, the immediate effect of bracing was found the walking symmetry decreased, but the four-month effect of bracing was observed the walking symmetry unchanged. In addition, the four-month motion adaption was showed the walking symmetry improved with a trend.

The bracing attenuated the walking symmetry on the head in the medio-lateral direction happened on the four-month effect of bracing and four-month motion adaptation **(Table 3.2.3 & Table 3.2.4)**. However, the bracing improved the walking symmetry happened on the four-month motion adaptation in the vertical direction on the body reference view during gait **(Table 3.2.4)**.

Sample size in the comparisons on each parameter was showed on **Table 3.2.6.**

Table 3.2.3 The summary of harmonic ratios in main effect of the brace, immediate effect of bracing, and four-month effect of bracing in all AIS patients

		Main effect of the brace in AIS patients					Immed. effect of bracing					Four-month effect of bracing				
		H	T	P	H/P	T/P	H	T	P	H/P	T/P	H	T	P	H/P	T/P
HR (All)	AP	↑			⇩	⇩					⇩					
	ML	⇩				↑	(↓)					⇩				
	V		⇩													

↑: Improvement (p<.05); ⇩: Degeneration (p<.05); (↓): Degeneration (a trend)

H: head; T: trunk; P:pelvis; H/P: head on pelvis; T/P: trunk on pelvis

Table 3.2.4 The summary of harmonic ratios in main effect of the treatment time and four-month motion adaptation in all AIS patients

		Main effect of treatment time in AIS patients					Four-month motion adaptation				
		H	T	P	H/P	T/P	H	T	P	H/P	T/P
HR (All)	AP				↑	↑				(↑)	
	ML	⇩					⇩				
	V	↑			↑					↑	

↑: Improvement (p<.05); ⇩: Degeneration (p<.05); (↑): Improvement (a trend)

H: head; T: trunk; P:pelvis; H/P: head on pelvis; T/P: trunk on pelvis

In-brace condition decreased the peak-to-peak range on the pelvis and the trunk on pelvis in the frontal plane during gait, and decreased the peak-to-peak range on the trunk on pelvis in the transverse plane during gait (**Table 3.2.5**).

Table 3.2.5 The summary of peak-to-peak ranges during gait in the immediate effect of bracing, four-month effect of bracing and four-month motion adaptation in AIS patients with double curve

		Immed. effect of bracing					Four-month effect of bracing					Four-month motion adaptation				
		H	T	P	H/P	T/P	H	T	P	H/P	T/P	H	T	P	H/P	T/P
Peak-to-peak range	Frontal	↑		⇩		⇩			⇩		⇩					
	Transverse					⇩					⇩					

↑: Increased (p<.05); ⇩: Decreased (p<.05);

H: head; T: trunk; P:pelvis; H/P: head on pelvis; T/P: trunk on pelvis

Table 3.2.6 Sample size (numbers) for each parameter on three comparisons

Sample size			Immediate effect of bracing	Four-month effect of bracing	Four-month motion adaptation
			AIS	AIS	AIS
Dynamic parameters	HR (All)		15	9	9
	HR (Double)		9	7	7
	HR (R't thorax)				
	HR (L't lumbar)				
	Range & Offset	Double	8	6	6
		R't thorax			
		L't lumbar			
Static parameters	COP	Thin	4	2	2
		Non-thin	7	4	4
	Decompensation & Posture	Double	8	6	6
		R't thorax			
		L't lumbar			

Chapter IV Discussion

4.1 Dysfunction and impairment in AIS patients

4.1.1 Smoothness of walking

In our study, the smoothness of walking significantly decreased in AIS female patients compared with the healthy female teenagers, specifically in the vertical direction in the global reference view, and in the antero-posterior and the vertical direction in the body reference view. The vertical direction in the global reference view was sensitive to distinguish the walking smoothness between female AIS patients and their healthy teenager counterparts. This distinction also happened on the segment of the trunk on pelvis in the body reference view. The musculoskeletal system is understood to be the main role at attenuating high frequency oscillations prior to reaching the head as shock transmission throughout the body during gait.[51] The spinal column attenuated the higher frequencies, generally above 20 Hz. The force attenuation in the vertical direction was primarily dependent on the shock absorption characteristics of the spine, associated soft tissues and lower legs. Kavanagh et al. argued that the trunk segment acts as a low-pass filter during walking.[23] Applying their theory, thus, any abnormality in the stability of the trunk and pelvis, the deformed neuromuscular structure, or the non-rhythmic movements of the legs would display the abnormal rhythmic velocity patterns at the head, trunk and pelvis.

This study showed that the antero-posterior direction in the body reference view was sensitive enough to distinguish the walking smoothness between AIS patients and healthy teenagers. Mac-Thiong et al. [35] and O hlen et al. [36] found that thoracic kyphosis in AIS patients with thoracic scoliotic curves is less than the normal kyphosis. Their study showed that the lumbar lordosis in the patients with thoracic scoliosis curves is significantly smaller than that of the healthy subjects.[36] In addition, the adjustment of the sagittal balance also involves active compensation from the lower extremities and the cervical spine. In AIS patients, there is significant correlation between the trunk hypokyphosis and the development of cervical kyphosis.[52] The abnomality in the spinal sagittal balance could affect the walking rhythm in the antero-posterior direction on segments of the head on pelvis and the trunk on pelvis, in the body reference perspective. However, as this study results showed, there are no significant influences for the walking smoothness on the antero-posterior direction in the global reference view. It might be a strategy of dominant stability in the global reference.

Menz et al.[25] and Brach et al.[24] found that walking speed affects smoothness of walking and furthermore, self-selected walking speed has the smoothest gait. In our study, we did not adjust the harmonic ratios for the value of walking speed owing to the results showed no velocity difference between the groups.

4.1.2 The peak-to-peak range and offset during walking and the postural orientation in standing for segmental obliquity and rotation

This study found no difference in the range of segmental obliquity and rotation during walking between the AIS patients and healthy teenagers. This finding is contrary to some studies that showed the range of pelvic rotation on transverse plane was smaller in the IS patients.[4,53] Still, there was another finding in the report of Mahaudens et al..[6] They found that the ranges of shoulders and pelvis obliquities are smaller in AIS patients compared to normal, but they did not find a difference in ranges in the transverse plane. And all of them[4,6,53] explained this may be the reason that the AIS patients need to limit body segments to keep the asymmetry upper body in balance.

This study showed that for both subgroups of AIS patients with the double curve of right thorax and left lumbar [18] and the single right thoracic curve, the offset of the trunk during gait is rotated to left, and the standing orientation of the trunk on pelvis is rotated to left.[28] In addition, just for AIS patients with the double curve of right thorax and left lumbar, the offset during gait and standing orientation of the trunk on pelvis are tilted to left, and the standing orientation of the pelvis is rotated to right.

In our study, we found the offset of trunk rotation during gait is positively correlated to the standing orientation of the trunk rotation and trunk-pelvis rotation. In the study of Kramer et al.,[18] they discovered that the magnitude of the offset of the trunk-pelvis rotation during walking is correlated to the orientation of the trunk-pelvis rotation in standing. Even though our finding is not totally agreeable with results of Kramer et al, the same inference showed the magnitude of the offset during gait is correlated to the standing postural orientation. The offset during walking is likely caused by the abnormal postural orientation, resulting from the deformed spine. AIS patients seemly had an abnormal body perception in the global reference view and on the body reference view.

4.1.3 Head decompensation in standing

AIS patients exist more head decompensation in static standing compared with healthy teenagers.[1] In our study, AIS patients with double curve of right thorax and left lumbar has head decompensation to left side, and patients with single curve of right thorax appear head decompensation to right side.

4.1.4 The static standing balance

The results showed that non-thin group of AIS patients is with a trend of poor static standing balance control compared with non-thin group of healthy teenagers for COP parameters of sway pace, sway area, and mean distance in the closed eyes condition. However, in the past research reports, they found a significant deficit in standing balance exists in AIS patients.[4, 29,31,34,37] In global posturographic parameters (sway area and displacement)[4, 34,37] and structural posturographic parameters (mean distance and mean peak),[29,31] significant differences are also found between AIS with the pre-brace and able-bodied groups.

The reason why our study did not show the significant difference between AIS patients and healthy teenagers could be as follows. Firstly, the small sample size resulted from the subgroup of different somatotype could have rendered our data as insignificant. Secondly, we used a method to distinguish the somatotype, the height-weight ratios, which has never been proven to be valid classification system. In future study, other body anthropometry data should have been collected to make classification of the body somatotype. Lastly, Guo et al.[54] displayed the association between abnormal somatosensory evoked potentials (SSEPs) and AIS patients. Abnormal SSEP was showed in 14.3% of AIS patients, and AIS patients with abnormal SSEPs has significant insufficient standing balance in an eyes closed condition compared to AIS patients with normal SSEPs or normal subjects. In their study, the balance performance was not different between AIS patients with normal SSEPs and healthy subjects in an eyes closed condition. They theorized that proprioception derived from the body motions and force between the support surface and feet is a superior sensory input for balance control under solid surface conditions. The AIS patients with abnormal SSEPs has the interfered standing balance performance when the subject needs relying on the proprioceptive sensory in the eyes closed condition. In our study, the results of the tibial nerve evoked SSEPs test in our AIS patients were unknown. Future study of the SSEPs could be used to evaluate the balance performance in AIS patients.

4.1.5 Brief summary

The deformed spine seemly interfered AIS patients' walking rhythm, segmental symmetry, postural orientation including the head decompensation, and the standing balance control. However, it is not clear the body performance resulted from the biomechanical distortion, abnormal sensory integration, or the defective perception and motor control in the brain. It needs further study to confirm the cause and effect.

4.2 The influence of the immediate effect and four-month effect of bracing in AIS patients

4.2.1 Walking rhythm and smoothness

This study found that in the intervention of spinal orthosis, harmonic ratio of the head decreased in the medio-lateral direction in immediately and four-month in-brace conditions in the global reference view for the AIS patients. In the medio-lateral direction, the trunk segment plays a main role in regulating gait-related oscillations.[23] However, the spine column, in in-brace condition, has a high tension on soft tissues around the concave side of the spine, which are the results of the corrective force applied by spinal orthosis. It may lead to more attenuation on the shock absorption properties and then influence the smoothness in the medio-lateral direction in brace condition. In Lowry's study,[20] although they measured the walking characteristics in patients with Parkinson's disease, they showed the presence of axial body rigidity could have led to the smaller harmonic ratios. In our study, in-brace condition also stiffened the body, contributing less adaptive movements in the pelvis and trunk and secondarily influenced the head movement.

For the immediate effect of bracing, the walking smoothness on segment of the trunk on pelvis, in the body reference view, was significantly decreased in immediate in-brace condition compared with the smoothness of the pre-brace condition in the antero-posterior direction in AIS patients. The custom-made TLSO is designed with a reduction of lumbar lordosis applied during the casting process. In Hubert's study, he found that after Boston brace intervention, a significant reduction of thoracic kyphosis formed, 38° ± 16 to 25°± 14.[55] Therefore, it may be the TLSO that causes the thoracic hypokyphosis and lumbar hypolordosis may destroy the walking rhythm in the antero-posterior direction on segment the trunk on pelvis, in the body reference view.

However, as time went by, for the four-month effect of bracing, we found the walking smoothness did not changed compared with the pre-brace condition in the antero-posterior direction on the segment of the trunk on pelvis in AIS patients. It meant that the walking smoothness on the segment of the trunk on pelvis improved from the immediate in the brace to the four-month in-brace conditions. We suppose that the compensation mechanism in the antero-posterior direction happened on the segment of the trunk on pelvis to overcome the restriction of movements in the sagittal plane from the brace.

4.2.2 Segmental peak-to-peak range and offset during walking

Other studies noted, the spinal orthoses stiffen the trunk and pelvic movements in the frontal and the transverse planes.[56,57] Our finding was showed the brace constrained the pelvic motion in the frontal plane and stiffened the motion of the trunk on pelvis in both the frontal and the transverse planes during gait. In addition, in the transverse plane, the brace did not stiffen the peak-to-peak motion on the trunk and the pelvis. The decreasing peak-to-peak range on the trunk on pelvis was the result of the reciprocal pattern on both the trunk and the pelvis breaking into a block.

In the in-brace condition, the peak-to-peak range of the head obliquity increased during walking. One plausible explanation is that the body used a compensatory strategy to overcome the restricted characteristics of the orthosis.

4.2.3 Standing balance

Owing to the few sample size in both AIS subgroups of thin and non-thin somatotype, the result of the standing balance after brace treatment in AIS patients was not presented in this study. In Chen's study,[4] they showed bracing may influence the balance function in AIS patients, but only when the proprioceptive and visual systems are simultaneously disturbed. In their study, the standing balance is the same between the pre brace and the in-brace immediate condition with the subjects' eyes closed. For about the study of Sadeghi et al.,[12] they thought after four months brace treatment, the standing balance is similar between the four-month in-brace and the four-month out-brace conditions in AIS patients. It still needs the future study to make sure the 4-month effect of bracing for standing balance.

4.2.4 Brief summary

The immediate and 4-month effects of bracing in the global reference were degenerated the walking rhythm on the head in the medio-lateral direction, but in the body reference, no attenuation of walking rhythm was happened in the 4-month effect of bracing. Moreover, the effect of bracing restricted the pelvis motion during gait in the frontal plane causing the limited motion on the trunk on pelvis. However, the effect of bracing did not stiffen the motion on the trunk and the pelvis in the transverse plane during gait, the motion on the trunk on pelvis was limited resulted from the de-reciprocal movement between the trunk and the pelvis.

4.3 The four-month motion adaptation of brace treatment in AIS patients

4.3.1 Walking rhythm and smoothness

For the four-month motion adaptation, the harmonic ratio of the head in the global reference view decreased significantly in the medio-lateral direction from the pre-brace condition to the four-month brace use, out-brace testing condition in AIS patients. This decrease in smoothness is likely the effect of the brace biomechanics which influenced the dynamic control in the medio-lateral direction in the global reference view. As we note that the most limiting movement from the spinal orthosis is in the frontal plane and transverse plane, movements in the frontal plane involve medio-lateral and vertical directions, and motions in the transverse plane involve the medio-lateral and antero-posterior directions. Therefore, the most restrictive movement from the spinal orthosis happens in the medio-lateral direction and leads to a negative motion adaptation.

For the positive values in four-month motion adaptation, the walking rhythm increased on the segment of the head on pelvis, in the body reference view, in the vertical direction in the four-month use, testing out-of-brace condition compared with pre-brace condition in AIS patients. Before ontogenesis of idiopathic scoliosis, the 'normal' children learn to adapt their postural orientation and movement using the strategy of stabilization in the global reference view and the strategy of stabilization in the body reference view.[58] The restrained construction of the rigid orthosis, which fixed the trunk and the pelvis as one unit, strengthens the strategy of stabilization on the body which may change the dominant strategy of stabilization to the body reference framework. Even though the disturbance arising from the brace, AIS patients tried to adapt and overcome it to acquire a familiar walking rhythm. In our study, these patients had successfully adapted on their walking smoothness and rhythm in the vertical direction in the body reference view in the out-brace condition after four-month brace treatment.

Moreover, the compensation mechanism in the antero-posterior direction, which happened on the segment of the head on pelvis to overcome the restrictions of movements in sagittal plane from the orthosis, had a trend to promote the motion adaptation after the 4-month brace treatment.

4.3.2 Standing balance

Owing to the few sample size in both AIS subgroups of thin and non-thin somatotype, the result of the standing balance for motion adaptation after brace treatment in AIS patients was not presented in this study. It needs the future study to understand the 4-month motion adaptation for standing balance.

4.3.3 Brief summary

After brace intervention, in the body reference, the positive motion adaptation was happened on the walking rhythm and symmetry, but in the global reference, the negative motion adaptation was showed on the walking rhythm.

Chapter V Conclusion

AIS patients exhibited significantly poor walking rhythm compared with age-matched girls. AIS patients had abnormal segmental offset during gait and abnormal segmental orientation in standing posture. This study showed that the static malposture has a correlation to the dynamic segmental offset. Although bracing which stiffens the trunk is the temporary treatment for AIS patients to stop the curve continual progression in their growth period, four-month bracing did not disturb interfere the walking rhythm, except for head medio-lateral smoothness. In addition, orthotic treatment allows motion adaptation for walking rhythm in the body reference perspective.

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Appendix A

財團法人臺灣基督教門諾會醫院受試者同意書

計畫名稱：量身訂製的胸腰薦椎矯具對於青春期自發性脊柱側彎女性病人在動態表現的影響
執行單位： 門諾醫院復健科物理治療組 **電話**：03-8241190 台灣大學醫工所 **電話**：02-33663297 **計畫主持人**：蔣博文 **職稱**：復健科醫師 **電話**：03-8241190 **協同主持人**：章良渭 **職稱**：台灣大學醫工所教授 **電話**：02-33663298 **研究人員**：蔡燕怡 **職稱**：物理治療師/台大醫工所學生 **電話**：0938-571330 **※二十四小時緊急聯絡人**：蔡燕怡 **電話**：0938-571330
受試者姓名： **性別**： **出生日期**： **病歷號碼**： **通訊地址**： **聯絡電話**： **法定代理人姓名/有同意權人姓名**： **與受試者關係**： **性別**： **出生日期**： **身份證字號**：

通訊地址：

聯絡電話：

一、 計畫簡述

當自發性脊柱側彎的孩子，側彎角度介於 20-45 度時，量身訂製之「背架」是目前的治療方法。背架治療已經過許多研究支持，被確定是可以防止側彎繼續惡化的方法。事實上部分有脊柱側彎的小孩被發現有平衡上的問題，特別是當視覺和本體覺被干擾時，不穩定會更加明顯。我們希望透過這個研究，來確定脊柱側彎孩子，在經過背架治療後，平衡表現會不會改善?同時透過走路的檢查分析，找出背架治療前後的行走特徵與沒有脊柱側彎的小孩比較，有沒有變化或不同的地方。另外這個實驗會追蹤約六個月的時間，想觀察背架治療有沒有幫助脊柱側彎孩子的自主姿勢動作改善。

這項研究預計實施期間(99 年 01 月 05 日~100 年 01 月 05 日)。

這項研究經費預期向門諾醫院院內計畫申請之。

二、研究目的

①想瞭解對於青春期自發性脊柱側彎之女孩，在背架介入前、介入後和一般沒有側彎的孩子，在動態及靜態姿勢中平衡控制的表現。

②想瞭解對於青春期自發性脊柱側彎之女孩，經過 6 個月的背架治療後，對姿勢是否有提供自主姿勢動作的改善。

三、試驗對象之條件

①控制組: 15 位健康的孩子，年齡介於 10 歲至 16 歲，沒有以下疾病或症狀，可能干擾到步態及姿勢控制，如輕微脊椎側彎、其他形式之脊柱變形、走路不穩、長短腳、下肢麻或無力、頭痛、頭暈、嘔吐、、、等。

②實驗組: 15 位青春期自發性脊柱側彎之女孩，年齡介於 10 歲至 16 歲，由復健科或骨科醫師診斷，其脊柱側彎角度介於 20-45 度，側彎分類為右側胸椎型。 沒有其他疾病或症狀，可能干擾到步態及姿勢控制，如其他形式之脊柱變形、走路不穩、下肢麻或無力、頭痛、頭暈、嘔吐、、、等。

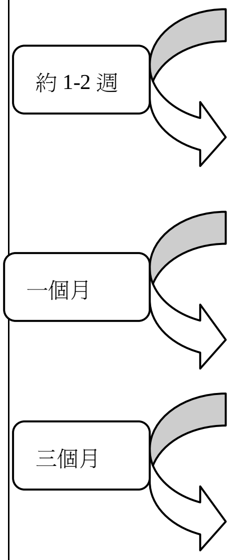
四、試驗方法、程序及相關檢驗

①針對健康受試者: 向受試者解釋研究計畫及流程並取得同意書；

-1 足底壓力點軌跡分析: 安靜站著維持 60 秒，眼睛張開及閉眼，站立在測力板(the force plate)上，各測試 3 次；一腳前一腳後站姿，眼睛張開及閉眼，站立在測力板上，維持安靜站立 10 秒，各測試 3 次。

-2 步態動作分析: 身上會貼上遠紅外線發射器，分別貼在頭後面、骨盆後面，及雙側的腳跟，用一般速度行走約 6 公尺的走道，測試 5 次。

②針對脊柱側彎的孩子:



	原本的醫療過程	該研究計畫需要您協助的部分
第一次訪視	當您向醫院或輔研中心尋求背架治療時，當天我們會幫您打石膏取身體的模型。	這項研究計畫需要您做第一次的足底壓力點軌跡分析，及步態動作分析(如”①針對健康受試者”中的敘述) (一個小時)
第二次訪視	醫院或輔研中心會幫您試穿背架，並需安排全脊柱 x 光的拍攝，確定脊柱矯正的角度改善	這項研究計畫需要您做第二次的足底壓力點軌跡分析，及步態動作分析(如”①針對健康受試者”中的敘述) (一個小時)
第三次訪視		這項研究計畫需要您做第三次的足底壓力點軌跡分析，及步態動作分析(如”①針對健康受試者”中的敘述) (三個小時)
第四次訪視	背架治療 6 個月後，需回醫院追蹤脊椎側彎的角度	這項研究計畫需要您做第四次的足底壓力點軌跡分析，及步態動作分析(如”①針對健康受試者”中的敘述) (三個小時)

五、可能產生之副作用、危險、不適、發生率及處理方法

剛開始接受背架治療時，需要約 1-2 週的適應期，穿戴背架的治療時間是希望可以每天穿足 23 小時的時間。在適應期當中，若有皮膚的不適應（當您發現脫下背架 15-20 分鐘後，身上有紅印仍沒有退去)，請立即與我們連絡，先停止穿戴訓練，並預約背架修改的時間，在尚未修改前，請先不要穿戴背架，避免皮膚破皮感染的發生。

六、其他可能之治療方式及說明

對於 20-45 度自發性脊柱側彎病人，目前有效阻止脊柱側彎退步的醫學治療常規是使用背架治療，比較能有效阻止側彎惡化。有部分的人，會使用背架同時接受復健運動或是接受整脊治療。

七、試驗預期效益

這項研究想進一步了解背架的治療，除了可以阻止側彎角度退步之外，是否可以改善自發性脊柱側彎孩子的姿勢平衡和改變情形，也可以瞭解背架穿戴後對姿勢改變的影響、背架治療半年後對姿勢改變的影響、和半年後不穿背架對姿勢改變的影響。從臨床觀察，可以發現脊柱側彎的孩子在穿上背架後，走路及站立姿勢確實被改變，但尚未被科學方法量化。因此希望這個研究可以協助臨床醫療人員及病人對背架治療的效益能有更清楚的認識。

八、試驗進行中受試者之禁忌、限制與應配合之事項

①因該研究是探討背架的長期對姿勢控制的影響，所以需請患者要確實在 2-4 週的適應期內漸漸增加背架穿戴時數，最後達到 23 小時/天的背架穿戴時數。

②需先穿上吸汗的棉質內衣，在穿上背架，可以減少皮膚摩擦或皮膚不適等問題。

③背架在穿戴時，應確實將綁帶拉緊至標記線上，完成正確背架穿戴。

④在適應期內若在使用背架時，有發現皮膚發紅或摩擦，在脫下背架 15-20 分鐘後，紅印人未消去，請與我們連絡並約時間修改背架，在尚未修改完之前，請先不穿戴背架，以免造成皮膚更大的傷害。

⑤背架的清潔也需要維護，用冷清水清洗，並擦乾，以保持皮膚衛生。

九、受試者權益

（一）參加試驗之獎勵

①針對脊柱側彎的孩子:

-您因有背架製作的醫療需求，由該研究計畫支付醫院或輔研中心，矯具製作費 4600 元，這項費用做為您的矯具醫療折扣，酬謝您四次到院的辛勞。(備註:門諾醫院的背架製作費 NT.15500 元;台北輔研中心的背架製作費 NT.19000~23000 元)

②針對健康受試者: 贈送一份禮品(市價約 250 元)，以答謝您的撥空參加。

(二) 參加試驗之收穫

①針對脊柱側彎的孩子:

-常規的背架治療只透過 x 光片提供病人靜態姿勢的效益，但該實驗的分析可以同時提供您姿勢平衡表現的改變。

-經過半年的追蹤，可以了解背架治療有無提供脊柱側彎孩子在自主姿勢動作的改善。

（三）損害賠償

- 如依本研究所訂臨床試驗計畫，在接受實驗過程中若有造成損害，由計畫主持人、協同主持人及研究人員負損害賠償責任。但本受試者同意書上所記載之可預期不良反應，不予補償。
- 如依本研究所訂臨床試驗計畫，背架治療期間若遇到問題時，應找原製作單位尋求醫療照顧及醫療諮詢。
- 除前二項補償及醫療照顧外，本研究不提供其他形式之補償。若您不願意接受這樣的風險，請勿參加試驗。
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試驗所得資料可能發表於學術雜誌，但不會公佈您的姓名，同時計畫主持人將謹慎維護

您的隱私權，如果發表試驗結果，受試者之身份仍將保密。衛生署主管機關、試驗委託者與本院人體試驗審議委員會在不危害您的隱私情況下，依法有權檢視您的資料。

（五）試驗過程中如有新資訊可能影響您繼續參與臨床試驗的意願的任何重大發現，都將即時提供給您。

（六）當您參加完此研究計畫時(約半年的時間)，背架仍應繼續穿戴，因為背架的治療時間需要持續穿戴到青春期過後(身高不再長高時)，且需要每半年到醫院追蹤全脊柱的 x 光片，評估脊柱角度有否退步，當背架長度不夠時，就需再製作新的，以防止脊柱角度惡化而需要手術的介入。

（七）若您對研究有疑問時，您可以和計畫主持人聯絡，計畫主持人 蔣博文 ，電話：03-8241190 手機：0932-653191 ；對個人權益有疑慮，可和本院人體試驗委員會聯絡，電話：03-8241457、傳真：03-8241603、E-mail：emtchris@mch.org.tw 或郵寄地址：970 花蓮市民權路 44 號財團法人臺灣基督教門諾會醫院人體試驗委員會收。

十、試驗之退出與中止

您可自由決定是否參加本試驗。試驗過程中，您不須任何理由，可隨時撤銷同意，退出試驗，且不會引起任何不愉快或影響日後的醫療照顧。此外，您已充份了解必要時，試驗主持人或臨床試驗委託者亦可能中止該試驗之進行。

十一、簽章

（一）取得同意書人（本計畫中擔任之職稱：研究人員 ）

本人已詳細解釋本計畫中上述研究方法的性質與目的，及可能產生的危險與利益，並已回答受試者之疑問。

取得同意書人簽名： 年 月 日

（二）受試者

經由說明後本人已詳細瞭解上述研究方法及可能產生的危險與利益，有關本試驗計畫的疑問，亦獲得詳細解釋。本人同意並自願參與本研究，且將持有同意書副本。

受試者簽名： 年 月 日

身份證字號： 聯絡電話：

通訊地址：

法定代理人簽名： 年 月 日

身份證字號： 聯絡電話：

通訊地址：

Appendix B

The original design of the study contained an one-month in-brace and out-brace testing analysis for the AIS patients. Because of the similar test results of the in-brace immediate and the pre-brace condition, the study methods were altered. See the initial data of one-month in-brace and one-month out-brace conditions as showed below.

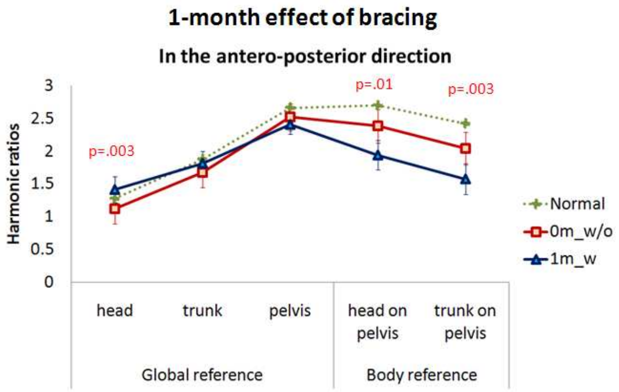
If the data was significantly different in one-month in-brace condition when compared to pre-brace condition, the study would have continued. This data was to be defined as **the one-month effect of bracing**. In addition, if the out-brace condition after one-month brace treatment brought the body into motion adaptation, the study would have continued and used this data. This motion adaptation in the out-brace condition after one month of brace treatment was defined as **the one-month motion adaptation.**

1 One-month effect of bracing

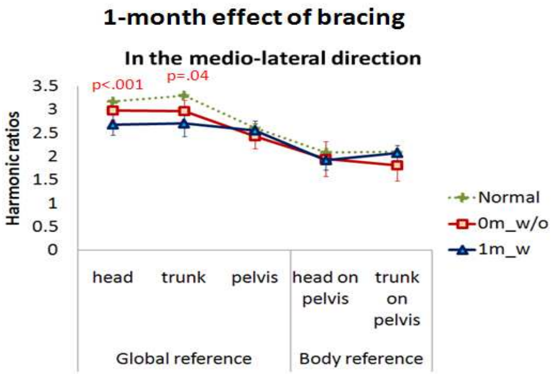
1.1 One-month effect of bracing on the walking rhythm for AIS patients

In the antero-posterior direction, harmonic ratios were significantly increased on the head (p=.003), and decreased on segments of the head on pelvis (p=.003) and the trunk on pelvis (p<.001) in one-month in-brace condition compared with the pre brace condition (**Figure 1**).

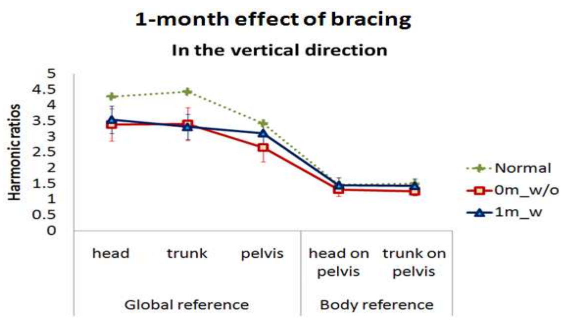
In the medio-lateral direction, harmonic ratios were significantly decreased on the head (p<.001) and trunk (p=.042) in one-month in-brace condition compared with the pre brace condition (**Figure 1**).



(a)



(b)



(c)

Figure 1 One-month effect of bracing on the walking rhythm on the head, trunk and pelvis in the global reference view and on segments of head on pelvis and the trunk on pelvis in the body reference view for AIS patients. (a) HR in the antero-posterior direction. (b) HR in the medio-lateral direction. (c) HR in the vertical direction. The error bars represent 95% confidence interval.

1.2 One-month effect of bracing in segmental rotations and obliquities during walking for AIS patients

The peak-to-peak ranges of pelvis obliquity (p<0.001) and rotation (p=0.04), the segment of the trunk on pelvis obliquity (p<0.001) and rotation (p<0.001) decreased, and head obliquity (p=0.007) increased in one-month in-brace condition compared with the condition of pre brace during walking in AIS patients (**Figure 2)**.

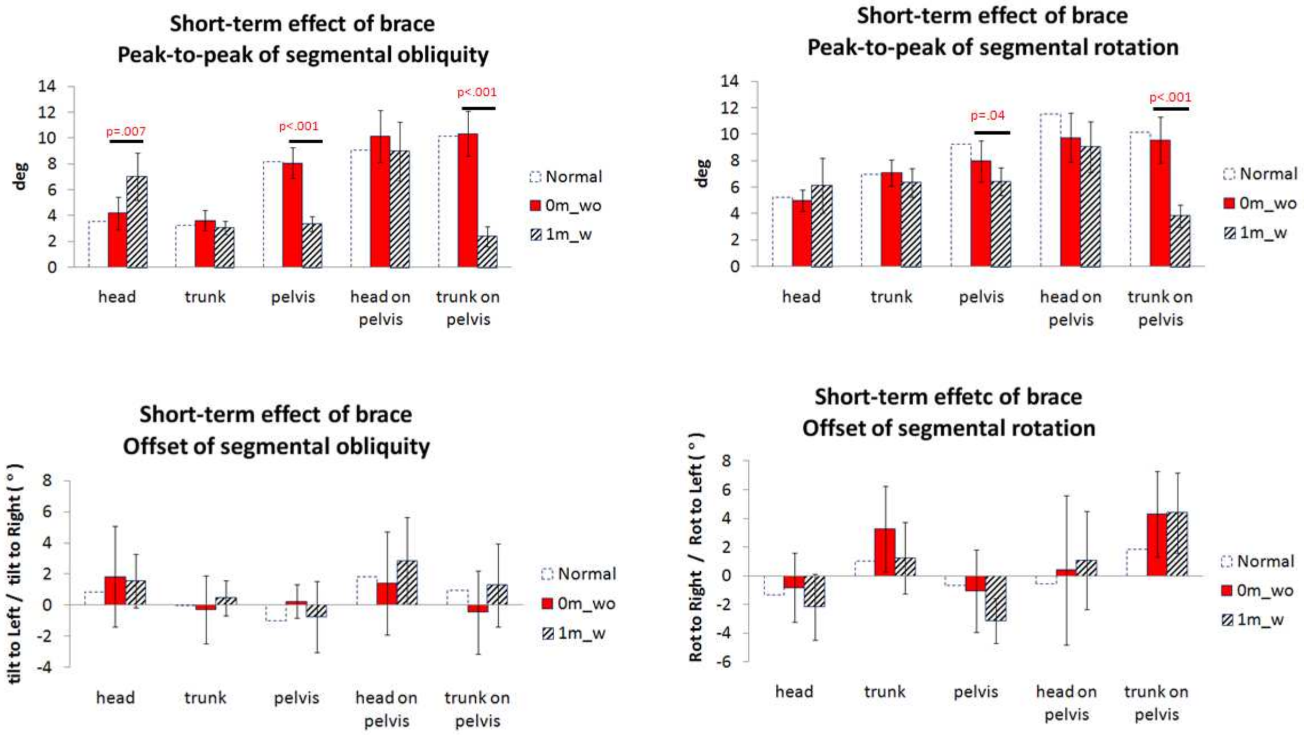


Figure 2　One-month effect of bracing in segmental ranges of obliquity(up-left) and rotation(up-right), and offsets of obliquity(down-left) and rotation(down-right) during walking for AIS patients.　The error bars represent 95% confidence interval.

1.3 One-month effect of bracing in standing balance for AIS patients

In one-month in-brace condition compared with the condition of pre brace, the COP parameters were significantly increased for sway area (p=.017) and for COP maximal medio-lateral sway (p=.03) in static standing balance with eyes open.　Similarly, COP parameters were significantly increased for COP pace (p=.03), for sway area (p=.03), and for maximal AP sway (p=.02) in static standing balance with eyes closed for AIS patients.　Therefore, the on-month effect of bracing did not change significantly enough in the standing balance performance in AIS patients in the open eyes and the closed eyes.

2 One-month motion adaptation

2.1 One-month motion adaptation on the walking rhythm for AIS patients

In all three directions, there were similar for the harmonic ratio on the head, trunk and pelvis, and segments of head on trunk and trunk on pelvis in one-month out-brace condition compared with the condition of the pre brace **(Figure 3)**.

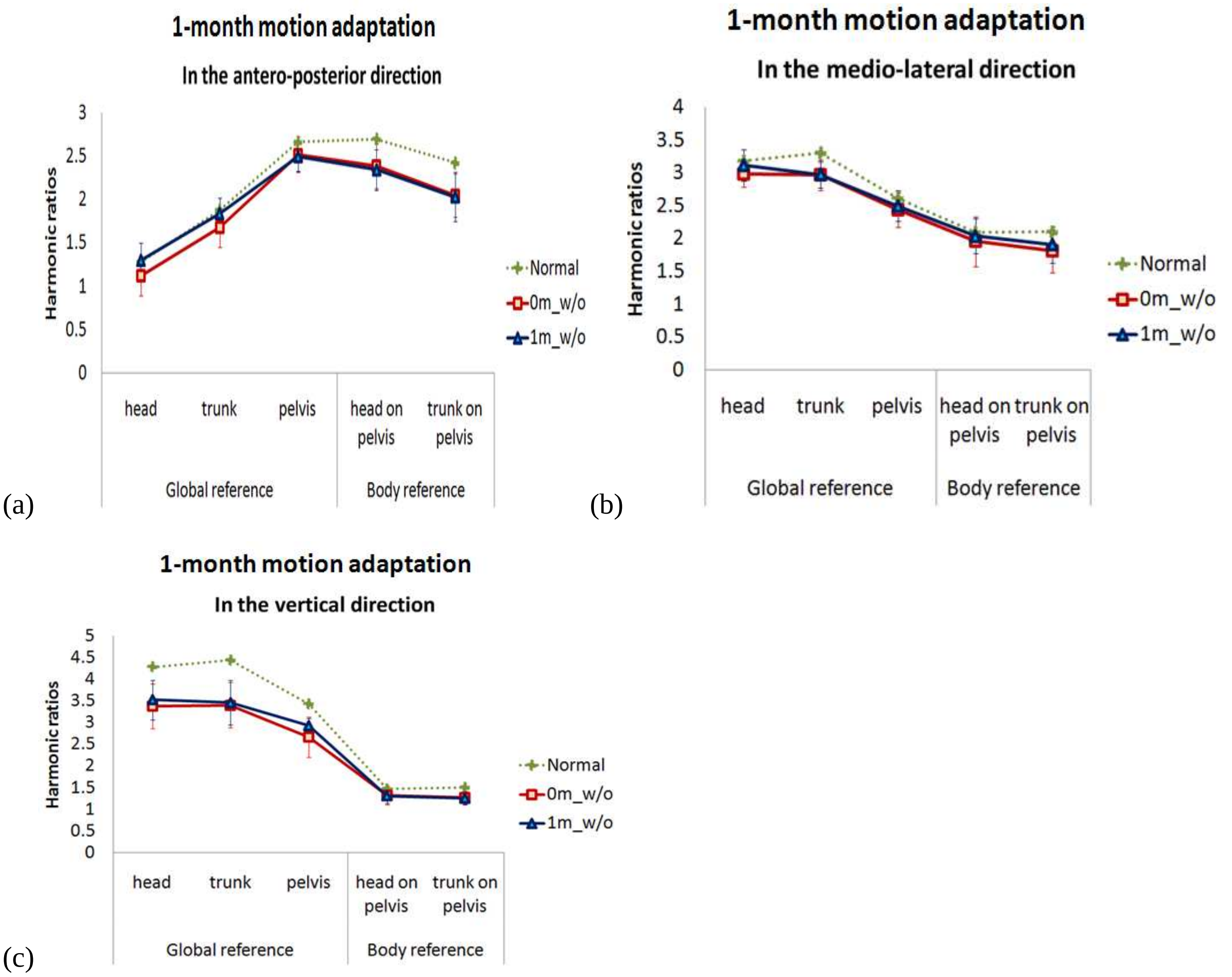


Figure 3 One-month motion adaptation on the walking rhythm on the head, trunk and pelvis in the global reference view, and on segments of head on pelvis and trunk on pelvis in the body reference for all AIS patients. (a) HR in the antero-posterior direction. (b) HR in the medio-lateral direction. (c) HR in the vertical direction. The error bars represent 95% confidence interval.

2.2 One-month motion adaptation in segmental rotations and obliquities during walking for AIS patients

The peak-to-peak ranges and offset of segmental obliquity and rotation were not significantly different between the condition of the out-brace condition after one-month brace treatment and the condition of the pre brace in AIS patients (**Figure 4**).

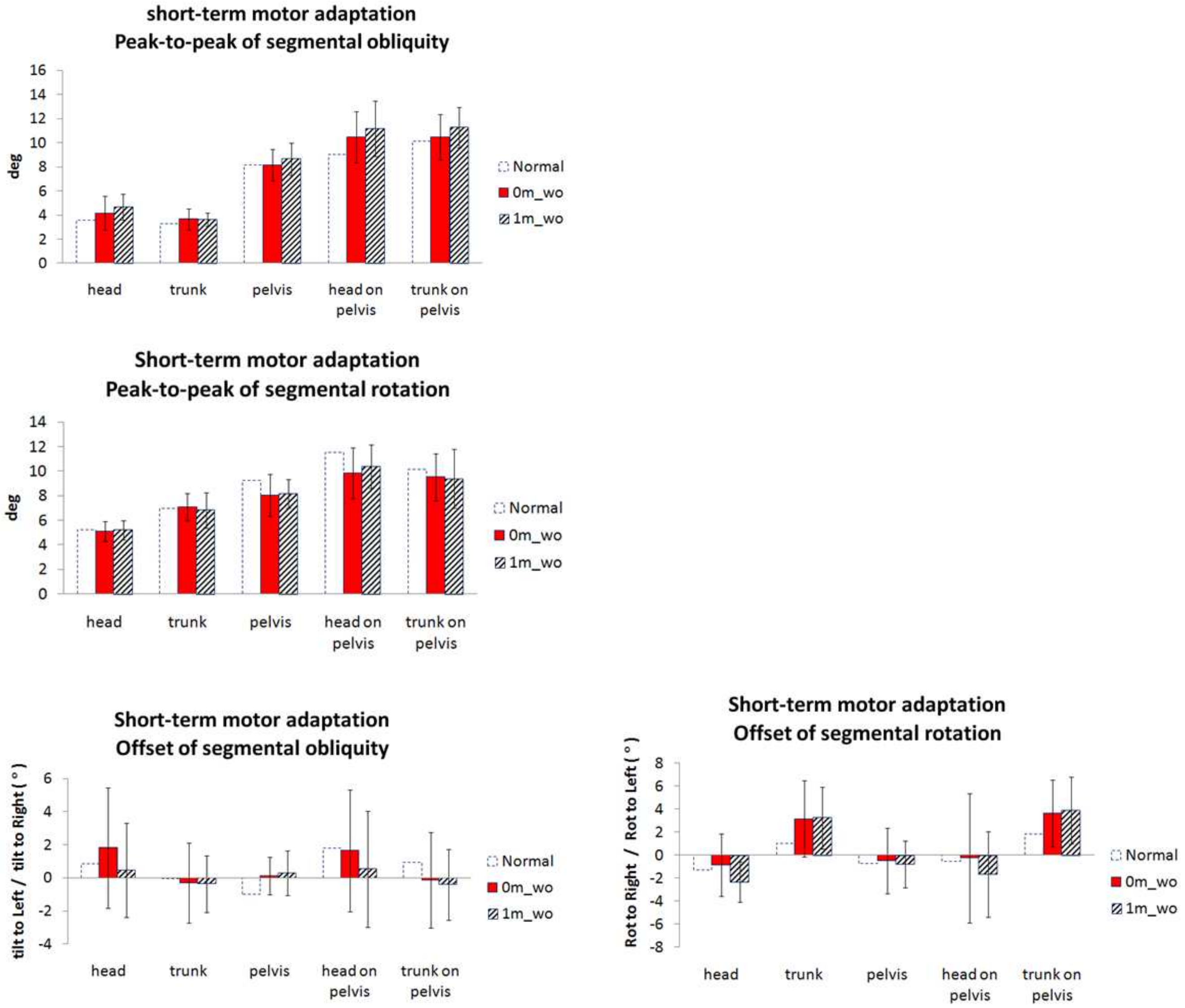


Figure 4 One-month motion adaptation in segmental ranges of obliquity(up-left) and rotation(up-right), and offset of obliquity(down-left) and rotation(down-right) during walking for AIS patients. The error bars represent 95% confidence interval.

Appendix C

The results of nonparametric analysis of the parameters, which were segmental offset during gait, standing balance, postural orientation, head decompensation and harmonic ratios in AIS patients with double curve, for AIS patients with four-month brace treatment were showed below.

1 Segmental Offset During Gait

The segmental offset was similar among the four conditions (2 time x 2 brace) of the brace treatment in AIS patients with double curve of right thorax and left lumbar during gait in the transverse planes (**Table 1 & Table 2**).

The brace did not alter the abnormal offset of trunk–pelvis rotation.[18]

Table 1 Offset in the frontal plane in AIS patients with double curve of right thorax and left lumbar

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Head	-.8	2.1	-.8	2	1.9	3.5	.5	2.3	$\chi^2[6,3]=5$	.1
Trunk	-.6	2.1	1	2.5	-.7	1.8	2.5	3.5	$\chi^2[6,3]=5.6$	.1
Pelvis	.4	3.1	-1.9	1.8	-1.1	2.5	-.5	2.5	$\chi^2[6,3]=3.2$	.3
Head on pelvis	-.5	2	1.6	2.3	2	2.5	2.2	3.1	$\chi^2[6,3]=2.6$	.4
Trunk on pelvis	-2.6	1.6	3.3	3	1.3	2.3	3.4	3	$\chi^2[6,3]=4.4$	.2

The unit was degree, positive value was meant the orientation tilted to right side; negative value was meant the orientation tilted to left side.

Table 2 Offset in the transverse plane in AIS patients with double curve of right thorax and left lumbar

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Head	-.1	2.1	.6	3	.5	2	1	2.8	$\chi^2[6,3]=2.6$	.4
Trunk	4.4	2.1	4.2	2.6	3.2	2.8	3.7	2.3	$\chi^2[6,3]=1$	.8
Pelvis	-3.1	2.3	-5	1.8	-2.7	3.8	-4.1	2	$\chi^2[6,3]=2.7$	.4
Head on pelvis	5.2	2.5	6.8	3.3	-.2	1.5	4.5	2.6	$\chi^2[6,3]=6.2$	.1
Trunk on pelvis	4.1	2.3	7.3	3.1	5.7	1.8	7.7	2.6	$\chi^2[6,3]=3.4$	.3

The unit was degree, positive value was meant the orientation rotated to left side; negative value was meant the orientation rotated to right side.

2 The standing balance

For AIS patients with the non-thin group, nonparametric analysis of COP parameters showed only significant difference in COP sway area in closed eyes standing (p=.03) among two time of 0-month and 4-month, and the two conditions of out brace and in brace (**Table 3)**. However, in the pairwise comparison, there was similar COP sway area in closed eyes standing in the comparison of 0-month in-brace condition with 0-month out-brace condition (immediate effect of bracing), of 4-month in-brace condition with 0-month out-brace condition (4-month effect of bracing), and of 4-month out-brace condition with 0-month out-brace condition (4-month motion adaptation) (**Figure 5)**.

Nonparametric analysis of COP parameters showed no significant difference among the four conditions in AIS patients with the thin group (**Table 4**).

Table 3 Standing balance parameters in AIS patients with the non-thin group

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Pace_open (mm/sec)	14.8	2	18.1	3.5	14.1	1.7	15.7	2.7	χ^2[4,3]=4.5	.2
Pace_close (mm/sec)	18.3	1.5	25.8	3.7	21.2	2	21.1	2.7	χ^2[4,3]=6.9	.07
Area_open (mm^2/sec)	38.4	1.5	60.9	3.5	50.3	2	48.2	3	χ^2[4,3]=6	.1
Area_close (mm^2/sec)	66.2	1.2	111.8	3.7	86.1	2	94.5	3	χ^2[4,3]=8.7	.03*
MP_open (sec)	3.4	3.7	1.9	1.5	2.3	2.5	2.3	2.2	χ^2[4,3]=6.3	.09
MP_close (sec)	2	3.5	1.3	1.5	1.5	2.7	1.3	2.2	χ^2[4,3]=5.1	.1
MD_open (mm)	2.3	2.2	2.5	3	2.1	1.5	2.4	3.2	χ^2[4,3]=4.5	.2
MD_close (mm)	2.8	2.2	3.5	3.5	3.2	1.5	3.2	2.7	χ^2[4,3]=5.1	.1

***:meant p< .05 among the 4 conditions (2 time x 2 brace) of the brace treatment in AIS patients with the non-thin group**

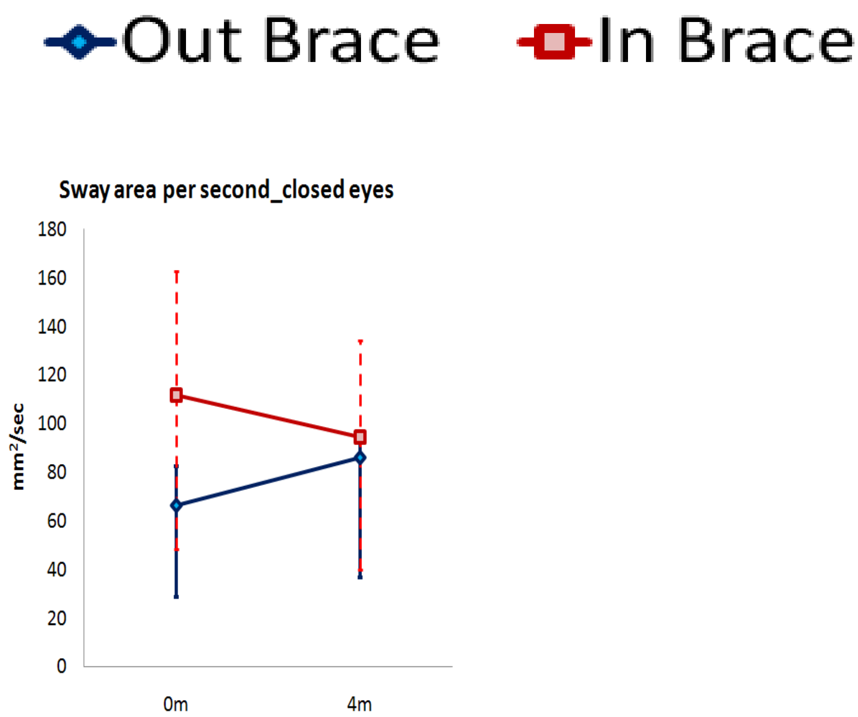


Figure 5 COP sway area in closed eyes standing condition in two time of 0-month and 4-month, and the two conditions of out brace and in brace for AIS patients with the non-thin group ([height (cm)/cube root of weight (kg)]<44). The value was presented by median ± upper/lower quarter.

Table 4 Standing balance parameters in AIS patients with the thin group

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Pace_open (mm/sec)	14.6	2	16.2	3.5	13.7	1.5	15.8	3	χ^2[2,3]=3	.3
Pace_close (mm/sec)	17.9	2	23.5	4	18.1	2	20.4	2	χ^2[2,3]=3.6	.3
Area_open (mm^2/sec)	38.4	2.5	42.8	2.5	39.4	2	51	3	χ^2[2,3]=.6	.8
Area_close (mm^2/sec)	67.4	2.5	95.9	4	62.7	1.5	79.2	2	χ^2[2,3]=4.2	.2
MP_open (sec)	2.4	2	2.8	3	3.5	3	3.3	2	χ^2[2,3]=1.2	.7
MP_close (sec)	2	3	1.5	1.5	3	3	2.9	2.5	χ^2[2,3]=1.8	.6
MD_open (mm)	2.1	2.5	2.3	3	2	1.5	2.2	3	χ^2[2,3]=1.8	.6
MD_close (mm)	2.5	2	3.3	4	2.5	2	2.7	2	χ^2[2,3]=3.6	.3

3 Postural Orientation in Standing

Postural orientations were similar among the four conditions (2 time x 2 brace) of the brace treatment in AIS patients with double curve of right thorax and left lumbar (**Table 5 & Table 6**).

The brace treatment did not change the postural orientation on segments of the pelvis and the trunk on pelvis. The brace did not significantly reduce the rib hump and de-rotate the vertebrae.[55,18]

Table 5 Postural orientation in the transverse plane in AIS patients with double curve of right thorax and left lumbar

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Head	0	2.8	-1.6	2.1	-1.6	2.6	0	2.5	χ^2[6,3]=.8	.8
Trunk	2.2	2.8	2.9	2.8	.2	2.3	.2	2	χ^2[6,3]=1.8	.6
Pelvis	-4.5	2.3	-3.3	2.3	-4.5	3	-5.3	2.3	χ^2[6,3]=1.2	.7
Head on pelvis	4.2	2.5	2.6	2.1	5.8	2.8	3.1	2.5	χ^2[6,3]=.8	.8
Trunk on pelvis	5.4	2.6	6.5	2.5	6.4	2.6	6.3	2.1	χ^2[6,3]=.6	.8

The unit was degree, positive value was meant the orientation rotated to left side; negative value was meant the orientation rotated to right side. w/o: without brace; w: with brace.

Table 6 Postural orientation in the frontal plane in AIS patients with double curve of right thorax and left lumbar

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Head	.4	2.3	.4	2.3	1.5	3	.5	2.3	χ^2[6,3]=1.2	.7
Trunk	-1.4	1.8	.8	3.1	-.9	2	1.8	3	χ^2[6,3]=5	.1
Pelvis	1.1	3.1	-1.5	1.6	.7	3.1	-1.9	2	χ^2[6,3]=6.6	.08
Head on pelvis	-1.1	2.3	2.1	2.8	1.1	2.3	1.6	2.5	χ^2[6,3]=.6	.8
Trunk on pelvis	-2	1.5	2.5	3.3	-2.2	1.8	3.9	3.3	χ^2[6,3]=6.6	.08

The unit was degree, positive value was meant the orientation tilted to right side; negative value was meant the orientation tilted to left side. w/o: without brace; w: with brace.

4 Head Decompensation

Head decompensation was similar among the four conditions (2 time x 2 brace) of the brace treatment in AIS patients with double curve of right thorax and left lumbar (**Table 7**).

In our results, the head decompensation was not changed between pre-brace and post brace conditions. In Hubert's study,[55] although they used the angle between the line linking T1 to L5 and the gravitational vertical line in frontal plane to measure the spinal frontal balance, their results were in agreed with ours.

Table 7 Head decompensation (cm) in natural standing and upright standing in double curve and lumbar curve of AIS patients

	0 month				4 month				Friedman test	p
	Out Brace		In Brace		Out Brace		In Brace			
	Median	Rank mean	Median	Rank mean	Median	Rank mean	Median	Rank mean		
Double curve	1	2.5	1.3	2.1	1.5	2.6	1	2.6	χ^2[6,3]=.6	.8

The unit was centimeter, positive value was meant the head deviated to left side; negative value was meant the head deviated to right side. w/o: without brace; w: with brace

5 The effect of bracing and motion adaptation in AIS patients with double curve

<u>The effect of brcaing</u>

For the immediate effects of bracing, the harmonic ratios were significantly decreased in the medio-lateral direction on the head (p=.028) and trunk (p=.028) in the immediate in-brace condition compared with the condition of the pre brace in AIS patients with double curve. For the immediate effect of bracing, the harmonic ratios were significantly decreased in the antero-posterior directions on segments of the head on pelvis (p=.02) and the trunk on pelvis (p=.02) in AIS patients with double curve (**Table 8**).

For the four-month effect of bracing, the harmonic ratio was significantly decreased in the medio-lateral direction on the head (p=.018) in the four-month in-brace condition compared with the condition of the pre brace in AIS patients with double curve (**Table 8**).

Table 8 The immediate effect and four-month effect of bracing on walking rhythm for AIS patients with double curve

		Immediate effect of bracing			Four-month effect of bracing		
		0 month_ w/o Median	0 month_ w Median	P value	0 month_ w/o Median	4 month_ w Median	P value
Head	**AP**	.8	1.2	.051	.8	1.2	.1
	ML	2.7	2.5	.028	2.8	2.5	.018
	V	3	2.9	.4	3.1	3	1
Trunk	**AP**	1.5	1.7	.5	1.5	2	.2
	ML	2.8	2.5	.028	2.8	2.7	.1
	V	3	2.9	.1	3.1	2.7	.09
Pelvis	**AP**	2.6	2.2	.1	2.6	2.3	.4
	ML	2.5	2.6	.051	2.5	2.6	.4
	V	2.4	2.8	.1	2.4	3.2	.6
Head on pelvis	**AP**	2.4	1.9	.02	2.4	2.3	.4
	ML	1.8	1.8	.4	2.1	1.8	.1
	V	1.2	1.3	.2	1.2	1.6	.3
Trunk on pelvis	**AP**	2.1	1.4	.02	2	1.9	.3
	ML	2	2.1	.2	2	2.2	.2
	V	1.2	1.2	.3	1.2	1.4	.2

Motion adaptation

For the four-month motion adaptation, the harmonic ratio in the medio-lateral direction on the head (p=.018) significantly decreased in the out-brace condition after 4-month brace treatment compared with the pre brace condition in AIS patients with double curve (**Table 9**).

For the four-month motion adaptation, the harmonic ratios in the vertical directions on segments of the head on pelvis (p=.04) and the trunk on pelvis (p=.01) and in the medio-lateral direction on segment of the head on pelvis (p=.02) significantly improved in the out-brace condition after 4-month brace treatment compared with the pre brace condition in AIS patients with double curve (**Table 9**).

Table 9 The four-month motion adaptation on the walking rhythm for AIS patients with double curve

		Four-month motion adaptation		p value
		0 month_ w/o	4 month_ w	
		Median	Median	
Head	**AP**	.8	1	.8
	ML	2.8	2.6	.018
	V	3.1	3.3	.1
Trunk	**AP**	1.5	1.7	.7
	ML	2.8	2.8	.1
	V	3.1	3.3	.2
Pelvis	**AP**	2.6	2.5	.8
	ML	2.5	2.3	.2
	V	2.4	2.7	.4
Head on pelvis	**AP**	2.4	2.8	.3
	ML	2.1	1.9	.02
	V	1.2	1.5	.04
Trunk on pelvis	**AP**	2	2.3	.3
	ML	2	1.7	.1
	V	1.2	1.5	.01

In addition, for the four-month motion adaptation in all AIS patients and AIS patients with double curve, the harmonic ratios showed a trend of improvement in the antero-posterior direction on segments of the head on pelvis and the trunk on pelvis (**Figure 6**).

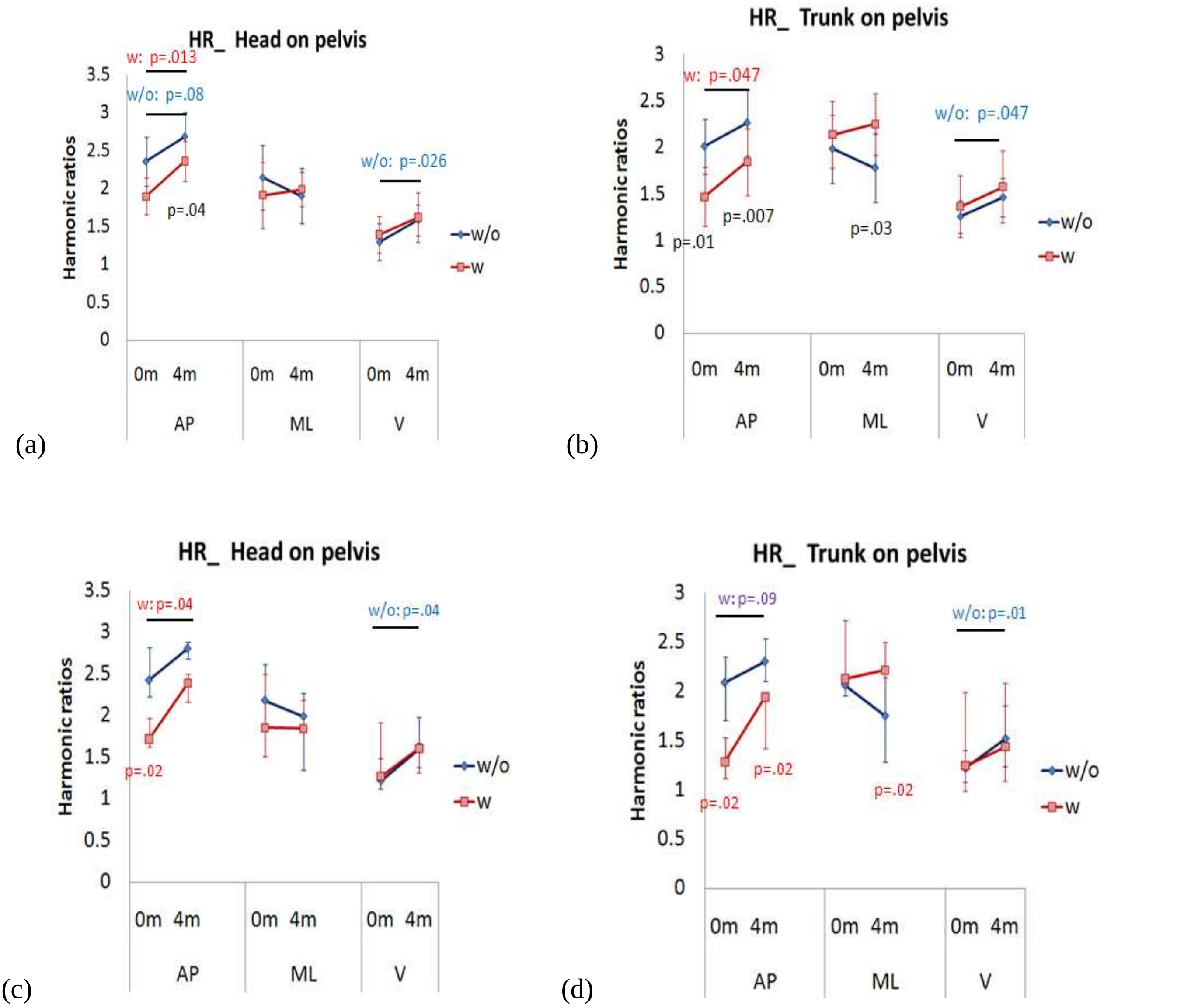


Figure 6 The effects of the brace (in-brace and out-brace) and the treatment time (0-month and four-month brace treatment) for harmonic ratios on segments in all AIS patients (a)-(b) and in AIS patients with double curve (c)-(d). The error bars represent 95% confidence interval in (a)-(b). The value was presented by median ± upper/lower quarter in (c)-(d). w/o: without brace; w: with brace.