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The Impact of Spinal Deformity on Gait in Subjects with Idiopathic Scoliosis

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1. Introduction

Walking is one of the most coordinated activities of a human being. It is a natural way of changing position among others, the avoiding or overcoming of obstacles, going upstairs and downstairs or changing directions. Efficiency of walking depends on mobility of the joints, activity of the muscles, coordination and rhythm of the movements as well as the ability to smoothly move the center of gravity. An ordinary gait pattern in healthy persons can be described by means of modern systems of movement analysis in space.

Any impairment in muscular, skeletal or nervous system can be the reason for which changes occur in an ordinary gait pattern. Different kinds of pathology in walking can be compensated by the movement of various body parts. They may involve greater forces and changes to the range of motion (ROM). Identification of a dysfunction follows recognition of any subtle substitute mechanisms and prediction of possible trauma. Scoliosis is one of the spine deformations affecting quality of movements and walking.

Scoliosis defined by the *Society on Scoliosis Orthopaedic and Rehabilitation Treatment* (SOSORT) is a lateral deviation of the normal vertical line of the spine which is greater than ten degrees when measured by x-ray method. Scoliosis consists of a lateral curvature of the spine with rotation of the vertebrae within the curve. The changes in the frontal and transverse planes are associated with the lack of physiological alignment in the sagittal plane. Such a three-dimensional deformity results in changes to body mechanics and induces motion asymmetry.

The cause of idiopathic scoliosis and its development still remain unknown. Scientists tend to analyze scoliosis in three dimensions: frontal, sagittal and horizontal planes. There are many studies focusing on the structure of the spine and activity in subjects with scoliosis. They have been carried out according to the recommendations of WHO contained in the *International Classification of Functioning, Disability and Health* (WHO, 2001). Their results confirm the presence of structural disorders such as limitations of the range of motion, muscle dysfunctions, deep sensation and balance disorders. Some studies discuss the biomechanics of the spine in persons with scoliosis. Others point out activity abnormalities in a sitting or standing position leading to postural or movement asymmetry.

Some studies demonstrate the impact of spine deformity on gait in subjects with scoliosis. Their authors describe various walking disorders in subjects with different types of scoliosis measured by appropriate systems and instruments.

2. Stance ability and walking in subjects with scoliosis

It is reported that the patients with idiopathic scoliosis demonstrate balance problems in stance phase (Giakas, 1996) and have a poor postural stability and present higher sway area than the control group subjects (Chen, 1998).

Kramers -de Quervain et al.(2004) observed significant asymmetry in the trunk's rotational behavior in the transverse plane during double limb stance in girls with a left-lumbar and a right - thoracic curve. Syczewska et al. (2006) described abnormal position of the pelvis and an increased range of motion of the pelvis in the sagittal plane in girls with double curve idiopathic scoliosis. Lateral tilting in the frontal plane and improper position of the pelvis in the transverse plane were also observed during gait in the majority of the patients under assessment. Another abnormality revealed in this research was asymmetrical EMG of the greatest gluteal muscles and extensor muscles of the trunk along the lumbar and thoracic part of the spine. Mallau et al. (2007) noticed a decrease in the walking speed while performing different tasks and the disturbed stabilization of the head in patients with idiopathic scoliosis. Mahaudens et al. (2009) pointed out a significant decrease in muscle efficiency, reduction in shoulder, pelvis and hip motion and prolonged muscle activation in female subjects with left thoracolumbar or lumbar primary curves. Pasha et al. (2010) emphasized changes in three - dimensional pelvic movements during gait in female patients with adolescent idiopathic scoliosis and stated that different alignment of the pelvis dictated the biomechanics during movements.

Stępień et al. (2007) demonstrated that scoliosis induces asymmetry in feet load in subjects with scoliosis. It was assumed in that study that the effect of body weight while standing and walking was represented by the ground reaction forces and that spinal deformity had an impact on right and left foot load in separate gait periods. The authors observed various gait patterns depending on the type of scoliosis.

61 subjects, aged 10-18 (14,4), with idiopathic scoliosis were qualified to participate in the gait analysis. One of the conditions required to take part in the study was a diagnosis of right thoracic and/or left lumbar curve.

Three groups were formed for individual scoliosis type: L - 16 subjects with single left lumbar curve or double curve scoliosis with dominant left lumbar curve (difference between lumbar and thoracic curve from 5 degrees up), E - 17 subjects with equal double curve scoliosis with the same extent of right thoracic and left lumbar curve (difference between curves up to 5 degrees) and T - 28 subjects with single right thoracic curve or double curve scoliosis with dominant right thoracic curve (difference between thoracic and lumbar curve from 5 degrees up).

The Computer Dynography (CDG) system was used to assess feet load during walking. 8 sensors fixed in special shoes registered vertical reaction forces while walking (Figure 1). The values of the forces registered by the sensors were assigned to each gait phase of stance: Initial Contact (IC), Loading Response (LR), Mid Stance (MSt), Terminal Stance (TSt) and Pre Swing (PSw).

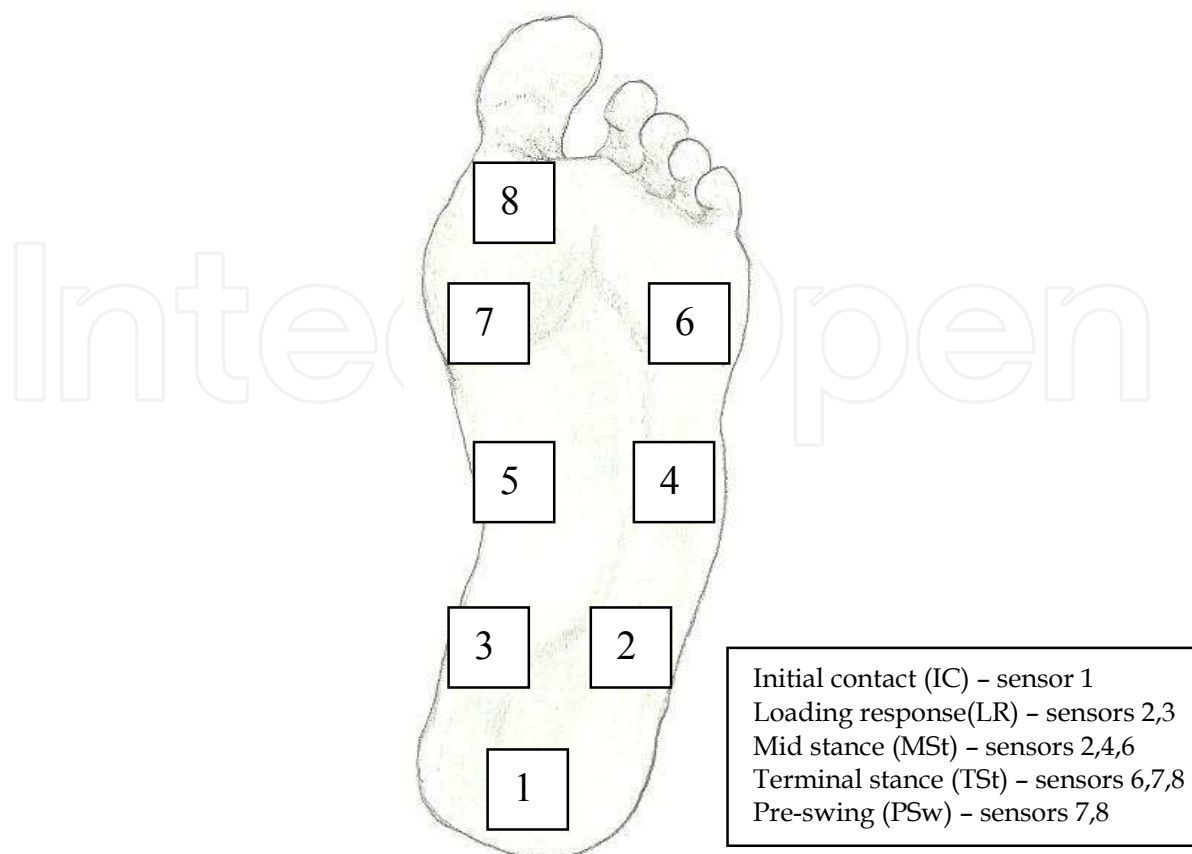


Fig. 1. Registration of vertical ground reaction forces - sensors localization depending on the division of stance phase.

The final results presented a specific and repeated pattern for the right and left foot load in each group. Some differences between the groups were recorded.

Increase in ground reaction forces for the lateral part of the right foot in thoracic scoliosis group (T) in MSt was observed in 75% subjects. In case of the lumbar scoliosis group (L) increasing ground reaction forces were found for the lateral part of the left foot in 63% subjects. No differences between feet load in E group were recorded.

Significant differences between the values of vertical reaction forces for the right and left foot were found in TSt and PSw. The ground reaction forces in TSt and PSw were bigger for the left foot than for the right one. Dominant left foot load compared with the right one was registered in over 90% subjects with double curve scoliosis. More significant differences between the left and right foot load were detected in these adolescents (T, E groups) than in the subjects with dominant left lumbar curve (L). Left foot load was significantly bigger in T group than in the subjects with dominant left lumbar curve. It suggests that the thoracic curve provokes the increasing differences in feet load in TSt and PSw phases during walking.

2.1 Reasons for change of gait pattern in subjects with scoliosis

What is the cause of walking asymmetry in people with idiopathic scoliosis? There are a few hypotheses for each gait phase that explain this phenomenon. The capability to remain in upright standing position is fundamental to develop the ability to walk. The stability in

quiet standing is determined by keeping the vertical axis of the body, proper muscle activity, joints mobility, balance, feet structure and others. These factors are essential also for gait pattern.

2.1.1 Alignment of the body

Proper alignment of the head, trunk and pelvis is a necessary factor to improve effectiveness of sitting, standing and walking (Adler et al., 2008) in the light of the concepts in the field of physiotherapy of international renown such as PNF (represented by International Proprioceptive Neuromuscular Facilitation Association – IPNFA) or The Bobath Concept (represented by International Bobath Instructors Training Association - IBITA) are.

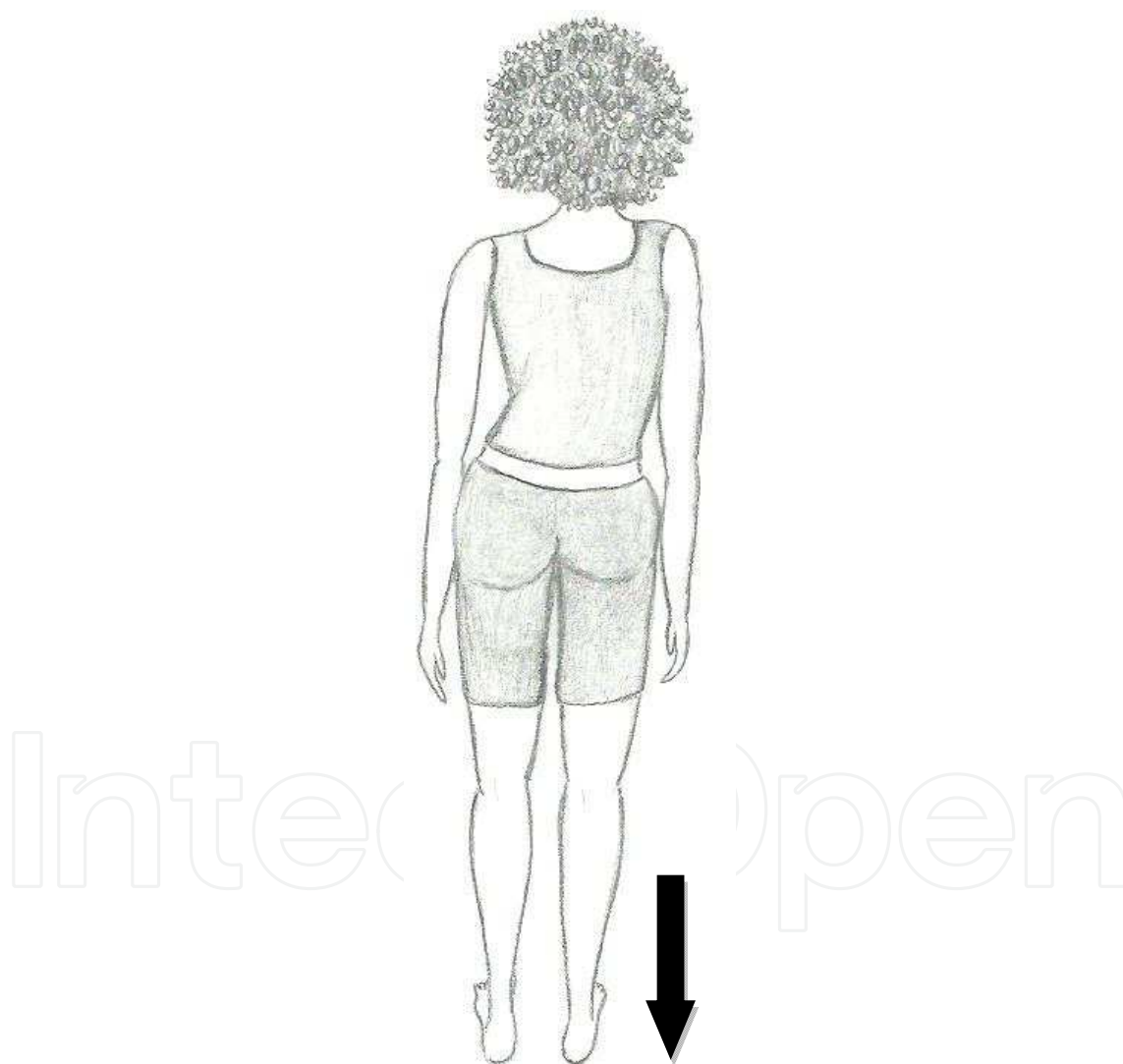


Fig. 2. The lateral shift of the body overloads the lower limbs unilaterally.

Continuous effort to bring the center of mass forward is one of the biomechanisms which is specific for walking. The alignment of the body decides on the localization of the center of mass (COM) and the quality of ground reaction force. Any deviation from the physiological

curves of the spine, lateral, forward and backward shift from the upright posture results in changes to feet load in standing position and decides on the stability in stance phase. Forward or backward link of the body carries the center of plantar pressure to the anterior or posterior part of both feet, respectively. A lateral shift of the COM in relation to the pelvis and the base of support increases weight bearing to the unilateral lower leg (Figure 2).

Scoliosis is defined as three - dimensional change in spinal alignment. Some studies took into consideration three - dimensional changes of the body in people with scoliosis.

Mac - Thiong et al. (2003) found out changes in physiological curves of the spine and the pelvic incidence in the sagittal plane. Stępień (2008) observed increased anterior pelvic inclination in adolescent girls with idiopathic scoliosis compared to girls without scoliosis. The lower thoracic kyphosis and higher lumbar lordosis observed in subjects with scoliosis can hinder the activity of the muscles responsible for the stability, upset the postural control of the body and change the feet load in stance (Figure 3).

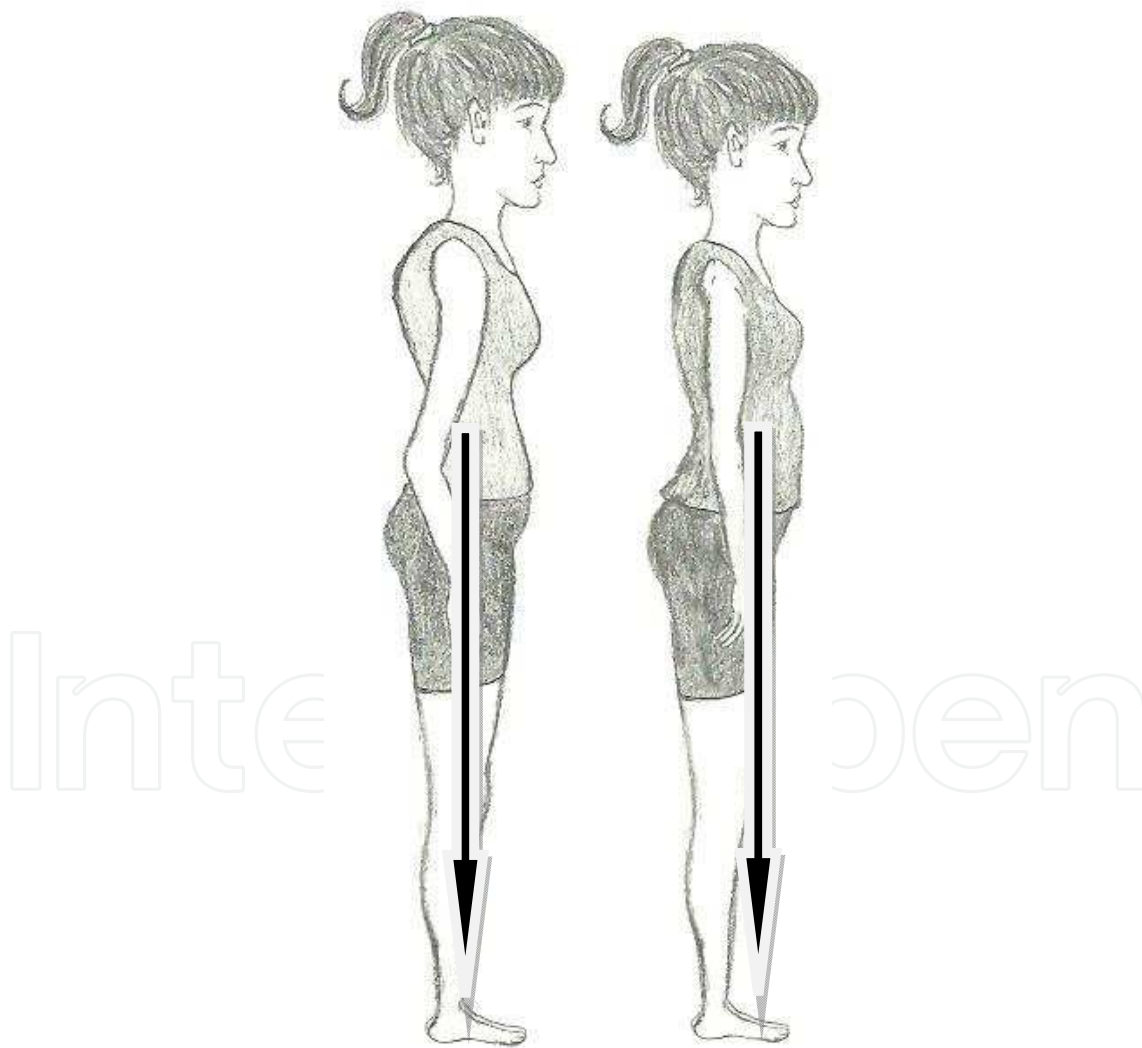


Fig. 3. Influence of the spine alignment in the sagittal plane on feet load in stance. Lower thoracic kyphosis and higher lumbar lordosis move the center of mass forwards changing the feet load.

Zabjek et al. (2008) demonstrated that persons with different types of the spinal curvatures (right thoracic, left thoracolumbar and right thoracic – left lumbar curve) were characterized by disparate posture in the space, represented by different orientation of the pelvis, shoulders and shoulder blades. It was also noticed that persons with scoliosis had larger amplitude of anterior – posterior displacement of T1 – S1 spinous processes in reference to the base of support in comparison with the subjects with no pathology (Zabjek et al., 2005). Some investigators gave their attention to improper pelvic alignment (Gum et al., 2007).

These significant differences in the sagittal, frontal and transverse plane can have an effect on the quality of feet load in the standing position and stance phase in gait.

A few authors demonstrated in their studies that spine deformations provoke displacement of the center of mass (COM), change the placement of the center of pressure (COP) and disturb balance. A decrease in standing stability was observed by Nault et al. (2002) as an increase in displacement of COM, COP and a greater neuromuscular demand. Dellau et al., (2007) also found out higher variability in COP in adolescent girls with scoliosis in comparison with the control group. Szulc et al. (2008) observed a specific pattern of the plantar pressure in scoliotic persons in the standing position. Dalleau et al. (2011) revealed high values of COP range and COP speed in adolescent girls with idiopathic scoliosis. Stępień et al. (2007) found out the correlation between the displacement of the vertical plumb of the body and the lateral – medial feet load in girls with dominant lumbar or dominant thoracic curve.

2.1.2 Muscle activity

Muscle activity is another determinant influencing the stability in quiet standing and gait pattern. The primary function of muscles is to stabilize the body. Postural control depends on cooperation of many muscles and muscular chains. Important role in body stability is played by the following muscles: multifidus muscles, m. transversus, m. obliquus external, m. obliquus internal, m. gluteus medius and minimus, muscles of the pelvic floor and the diaphragm (Haase, 2006).

M. transversus is regarded as the main muscle responsible for the stability of lower trunk, which is active just before every movement of the upper and lower limbs (Hodges & Richardson, 1996; 1997). Any dysfunction of these muscles results in the worsening of postural control which may influence walking. Muscle stability is difficult especially in single limb support as body weight transfers over the supporting limb.

Some authors focused their attention on muscle activity in people with scoliosis. Lin et al. (2010) described abnormal position of scapulas and different muscle contraction activity on both sides of the thoracic curve in the standing position during arm elevation in female patients with scoliosis. They identified higher contraction activity of lower trapezius muscle on the convex side and lower contraction activity of lower trapezius and serratus anterior muscles on the concave side in comparison with the control group.

Well coordinated movements of shoulder blades and arms are essential for economic gait. Alternating arm swing supports the lower legs in their motions during the stance or swing phase and it is coordinated with the trunk muscles changing activity. Anterior elevation of

the scapula supports the unilateral lower limb to keep the weight of the body in stance phase. On the other hand posterior depression of the scapula supports stance phase on the contralateral lower limb. Alternating movements of the scapulas reinforce rotational control of the trunk and stability in single and double limb stance (Proprioceptive Neuromuscular Facilitation – Adler et al., 2008).

Any muscle dysfunction around shoulder blades can be the cause of walking disturbance. New physiological and biomechanical theories state that human body acts through stimulation of muscle chains activity and any impairment of muscle function can provoke changes in the whole body and trigger new movement patterns in daily activity. This knowledge is the base in physiotherapeutic concepts like PNF (Adler et al. 2008; IPNFA) and close to the theories of muscle chain activity (Myers, 2009).

Haumont et al. (2011) found significant differences in posture control under perturbation conditions between female patients with scoliosis and the control group. Differences were observed especially as earlier onset and prolonged activation of the left multifidus on the lumbar convex side and the right gastrocnemius on the lumbar concave side. The results of these studies are useful for gait analysis, because both the multifidus and the gastrocnemius muscle play a significant role in walking.

2.1.3 Optimal mobility

Optimal mobility in hip joints is one of the conditions necessary for efficient and coordinated walking. Any limitation on passive or active range of motion (ROM) with regard to extension, abduction or rotation disturbs symmetry of walking. The above-mentioned limitations will influence MSt, TSt and PreSw phases in particular and provoke a chain of compensations. Some authors showed in their studies that there were hip joints dysfunctions in persons with scoliosis. The results of their studies imply that most patients with idiopathic scoliosis have asymmetric range of passive hip rotation arising due to transposition of the sector of motion in both hip joints (Kotwicki et al., 2008). The dysfunction of the hip joints in the transverse and sagittal plane in patients with idiopathic scoliosis also occurs during walking (Syczewska et al, 2006). Asymmetrical position and range of motion in the hip joints in many patients with scoliosis is a consequence of incorrect spatial orientation of the pelvis.

2.1.4 Feet structure

Feet are the base for human body. Any deviation from the proper structure of a foot/ feet has a negative impact on the correct position of the whole body. The feet and the body influence each other. Improper alignment of the body results in the change of feet load, consequently, incorrect feet structure changes the orientation of the trunk and pelvis. Orientation of the pelvis in the transverse plane is one of the essential determinants affecting the feet position. Rotation of the pelvis to the right moves the load to the lateral part of the right foot and lowers the medial arc of the left foot. That explains the type of feet asymmetry in subjects with scoliosis characterized by the right pelvic rotation noticeable mainly in patients with the main right thoracic curve (Figure 4). Structural feet asymmetry in patients with scoliosis may influence the feet load during walking.



Fig. 4. Example of asymmetrical feet structure in the boy with scoliosis.

2.1.5 Disturbed counter rotation

Disturbed counter rotation of the upper trunk in relation to lower trunk and pelvis can be one of the factors resulting in gait asymmetry in TSt and PSw (Stępień et al., 2007) in subjects with scoliosis. Double limb stance with the right lower limb moved forward and the left one behind the body requires rotation of pelvis and vertebrae in the lower part of lumbar spine to the left, which is in harmony with thoracic vertebrae movement to the right. Stepping forward with the left lower limb is combined with the rotation of the pelvis and lumbar vertebrae to the right and the rotation of thoracic vertebrae in the opposite direction. It means that stepping forward with the right lower limb is in harmony with rotation of the left lumbar curve and rotation of the right thoracic curve in subjects with double curve scoliosis. On the other hand swing phase of the left lower limb requires activity in these persons against deformity of the lumbar curve in the frontal and horizontal plane and rotation of thoracic curve in the opposite direction. This situation can lead to occurrence of asymmetry in alternating movements of the trunk, pelvis and limbs in walking. All movements in those “with” scoliosis are easier for skeletal and muscular system, so any step forward with the right lower limb is associated with higher values of left foot load. It is likely that ground reaction forces in stance for the right foot

in subjects with double curve scoliosis in TSt and PreSw are reduced due to the movement being in discord with the rules of the mechanics present in scoliosis.

Disturbed counter rotation was taken into consideration as the basic hypothesis in the following study project (Stępień, 2008). The aim of that study was to determine the influence of a spine deformation type on the trunk and pelvis range of motion in horizontal plane in adolescent girls with idiopathic scoliosis (Stępień, 2011). The additional aim was to describe the trunk and pelvis angular motions in the sagittal plane that occur during rotation.

59 girls with adolescent idiopathic scoliosis and 30 asymptomatic girls at the age of 10-18 participated in the study. Right thoracic curve or/and left lumbar curve in spine radiography were the criteria for further measurements in the girls with scoliosis. Four groups were formed of the girls with different types of deformity: L - single left lumbar curve or double curve scoliosis with dominant left lumbar curve (14 girls), E - equal double curve scoliosis (16 girls), T1 - double curve scoliosis with dominant right thoracic curve (22 girls), T2 - single right thoracic curve (7 girls).

Measurements were made in quiet standing and in the standing position with the left or right lower limb at the front (position imitating double limb stance). The pelvis was fixed when the trunk was rotating and the shoulder girdle with upper trunk was stabilized during the pelvic motions. A specially designed prototype axial rotation tester with a computer system was used to assess ROM of the trunk and pelvis rotation and the angular coupled motions in the sagittal plane. An angle of rotation and associated motions were registered by the unit placed on the thorax and thoracic vertebrae (Th5 - Th7) or on the pelvis and lumbar vertebrae (L4 - S1). Special sensors placed under the first metatarsal bones signaled movements of the feet while rotation of the pelvis came about. Each participant's task was to perform pelvic rotation without taking metacarpal bones away. 6 movements of the trunk and 6 movements of the pelvis (3 right, 3 left) were taken in account into the analyses. The results were presented in numerical and graphic form (Figure 5).

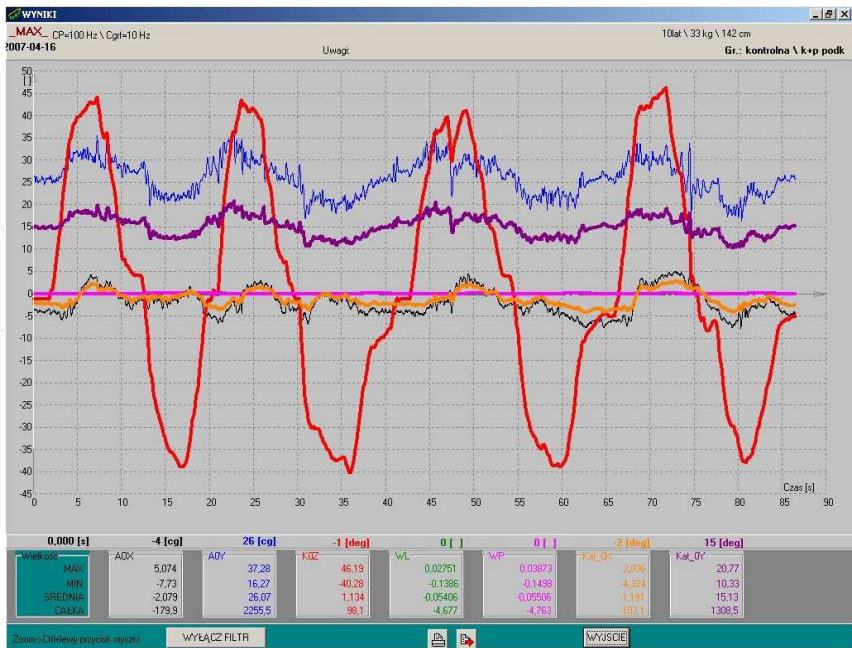


Fig. 5. Exemplary results in a graphic form - a range of trunk rotation in the transverse plane and coupled angular motions in the sagittal and frontal plane.

The results indicated many significant differences, particularly, between the girls with double curve scoliosis with dominant right thoracic curve (T1), the girls with single or double curve scoliosis with dominant left lumbar curve (L) and those from the control group.

A significant limitation of the trunk and pelvis rotation in the horizontal plane was observed in the girls with double curve scoliosis with dominant right thoracic curve. It was found that dominant left lumbar curve resulted in an increase of pelvic rotation compared to the control group and provoked asymmetries between ROM of the left and right rotation of the pelvis.

The limited rotation of the trunk and pelvis in the girls with double curve scoliosis was compensated in anterior – posterior movements in the sagittal plane.

Many significant differences between the values of the left and right rotation in each group and differences between the groups indirectly pointed out disturbed motions in the transverse plane as a potential reason of characteristic gait pattern in people with different spine deformations. The limited rotation in subjects with double curve scoliosis can affect the observed changes in feet load during walking in TSt and PSw. In both studies (Stępień et al., 2007; Stępień 2008) the adolescent subjects with scoliosis were grouped according to the same guidelines and the results of both projects showed the influence of dominant thoracic curve on increasing asymmetry.

2.1.6 Balance

One of determinants causing walking disorders in subjects with idiopathic scoliosis, taken into consideration by scientists, are balance disorders. It was stated that balance disorders in adolescent patients with idiopathic scoliosis could be the result of the detected morphoanatomical changes in the vestibular system (Shi et al., 2011).

Balance means the ability of equal or optimal distribution of the weight amount in different positions to keep proper alignment of the body. Balance activities require integration of the visual, auditory, kinesthetic, tactile, and vestibular senses to effect the proprioceptive processes that help to reduce injuries and improve performance. Balance is a global reaction of the body, when the head is positioned over the sacrum and pelvis, shoulders tend to stay horizontally and the mass of the trunk is transferred to the vertical axis of the body. That is possible thanks to three dimensional reaction of the whole body in the frontal, sagittal and transverse plane. Any dysfunction or local biomechanical failure of the spine results in disturbance of balance and compensations. Proper balance is the base for human daily living activities in sitting or standing position. Every forward, backward, lateral trunk leaning and movements of upper and lower limbs involve three dimensional reaction of the body. Also walking requires complex reaction of the body.

Some authors study balance reaction in patients with idiopathic scoliosis in stance and walking but the first step in analysing the balance should involve three dimensional assessment of the body in sitting position.

The alignment of the spine in sitting is associated with the pelvic position. Improper alignment of the pelvis in the sagittal plane has influence on the position of the cervical, thoracic spine, sternum and ribs (Kiebzak et al., 2010). The lateral displacement in the frontal

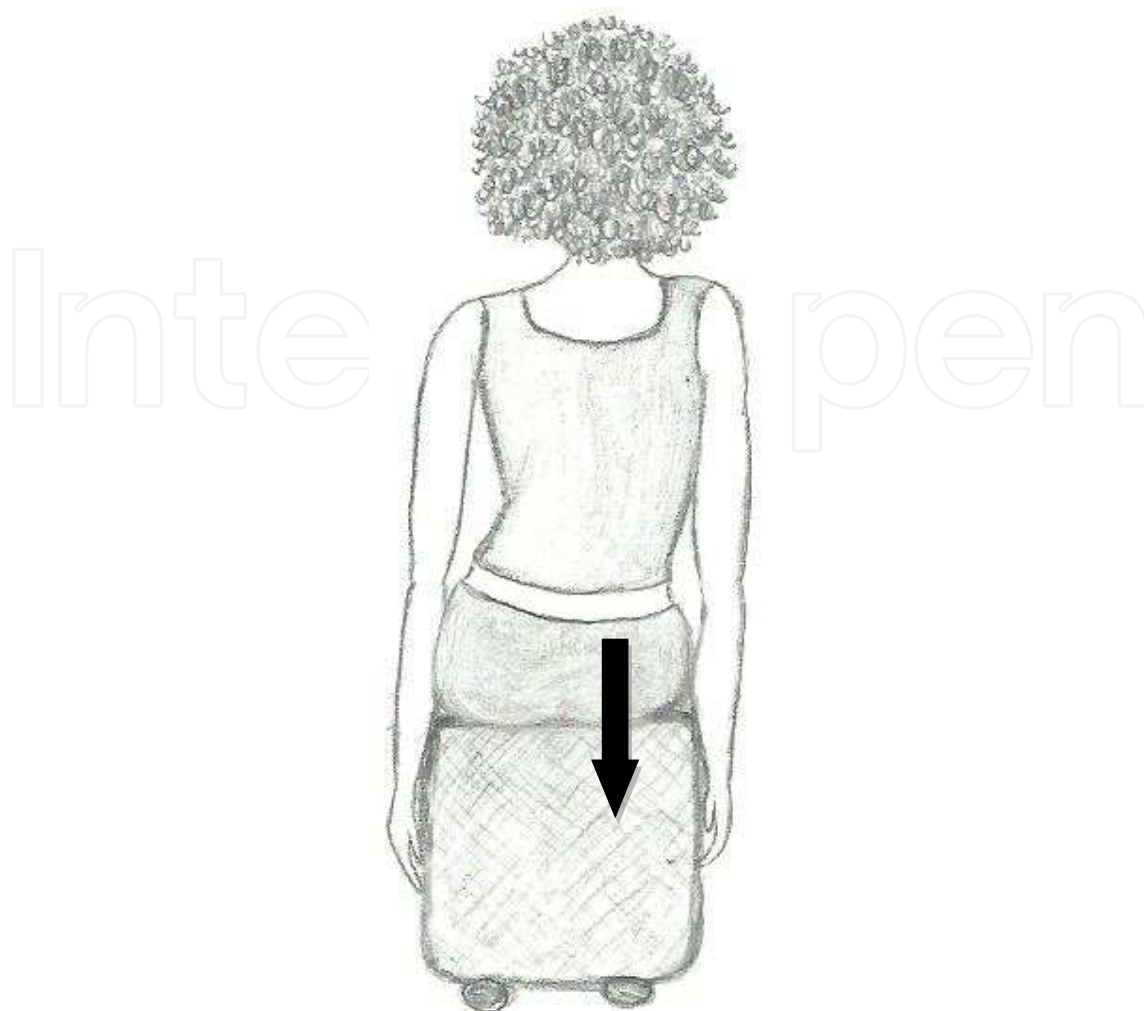


Fig. 6. Improper sitting position. The lateral shift of the trunk to the right increases load onto the right ischiadic tuber.

plane causes a different load of the right and left ischiadic tuber (Figure 6). It creates different position in the right and left hip joints (Stepień, 2010a,b). Tubers load depends on the type of scoliosis. The patients with left lumbar curve have a tendency to transfer load toward the left ischiadic tuber while the persons with thoracic curve usually shift the weight in the direction of the right one. Asymmetry in sitting may increase while daily activities. Improvement of the trunk and pelvis control in the sitting position is the first step to regain better trunk control in stance and walking.

The preliminary results of the studies being currently carried by the author et al. involving girls with double curve (thoracic right and lumbar left curve) in sitting revealed balance disorders and possibility of compensation in this group. Each girl under the study had to demonstrate her usual sitting position and then shift her trunk laterally to the left and then to the right. The trunk's rotational behaviour in the transverse plane was analysed at the time of the lateral shift of the trunk.

The results showed that local lumbar limitation of the active lateral shift of the spine to the right in the sitting position was compensated in the transverse plane in the thoracic part of the spine. Compensation was noticeable as an increased rib hump (Figure 7 a,b,c).

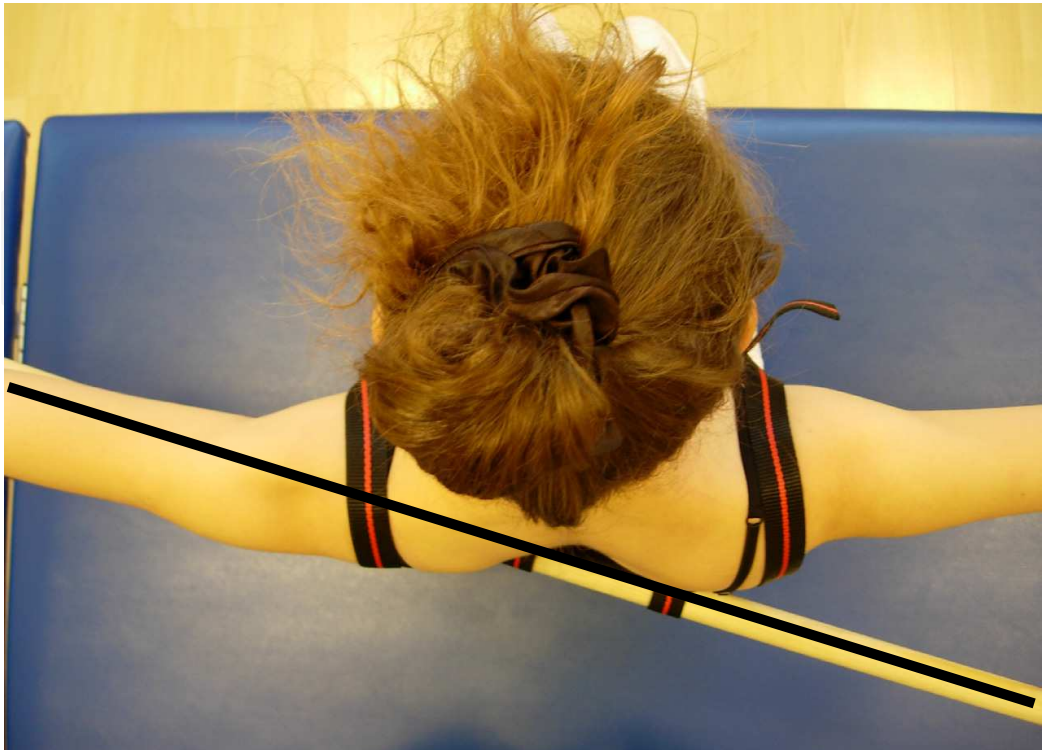


Fig. 7a. Sitting position. Top view.



Fig. 7b. Lateral shift to the left in sitting. Top view.

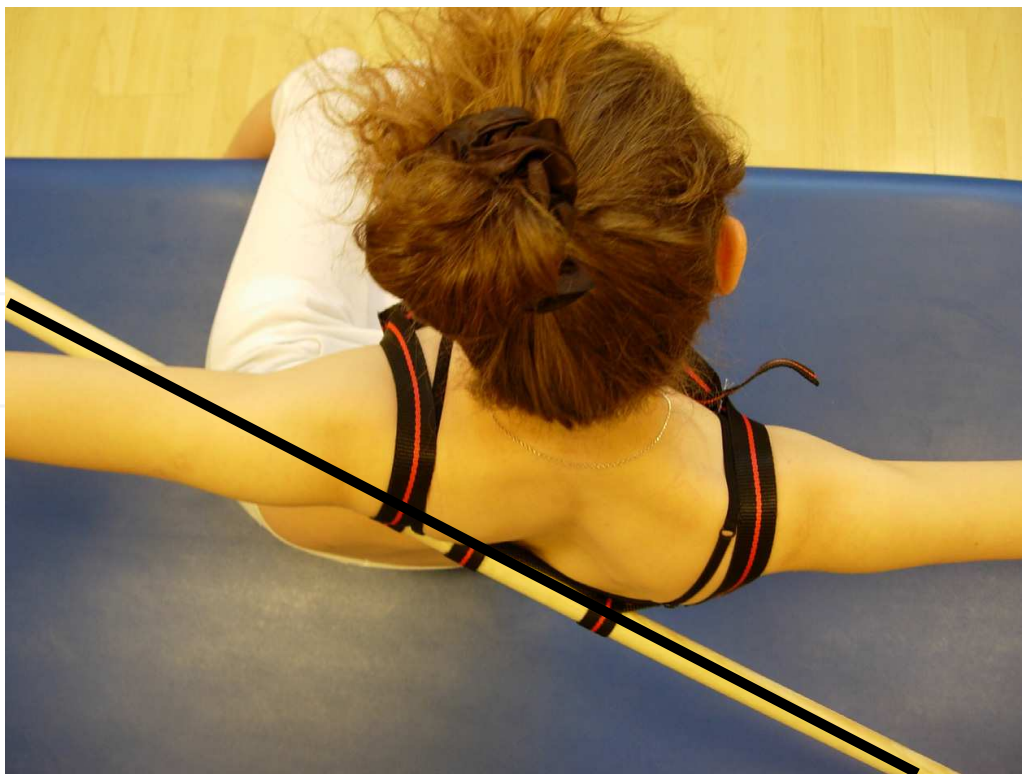


Fig. 7c. Lateral shift to the right. Top view.

The results suggested that the active shift of the trunk over the right lower limb during single limb support could provoke compensations noticeable in the thoracic spine rotation and anterior elevation of the right scapula.

These coupled motions of the spine can be the following factor which creates favorable conditions of development of walking disorders and acceleration of scoliosis progression.

A few authors have undertaken the studies to describe coupled motions in scoliosis. Stępień (2008) noticed coupled motions in the sagittal plane occurring during rotation of the spine. The relation between the movements in the frontal and transverse plane was described by Adam et al.(2008). These authors stated that lateral curve preceded vertebral rotation. Pasha et al. (2010) noticed that movement of the pelvis in one plane caused the change of position in the other two planes.

All these findings mentioned above can be accepted as hypothetical disorders resulting in gait asymmetry.

2.2 Gait pattern in subjects with scoliosis

There are two basic periods in every gait stride: a stance and swing phase. The proportion of the two phases is about 60% to 40% of the time between consecutive heel strikes of the same lower limb (Perry, 1992). The stance is more demanding phase due to the need of shock absorption at the time weight acceptance and recovery of the stability during single limb support. The stability during single and double limb support phases depends on many factors such as the alignment of the spine and lower limbs, muscle strength, joint mobility, coordination or balance of the body.

The stance phase includes: Initial Contact (IC), Loading Response (LR), Mid Stance (MSt), Terminal Stance (TSt), Pre Swing (PSw). The swing phase is divided into: Initial Swing (ISw), Mid Swing (MSw) and Terminal Swing (TSw). On account of the importance of stance phase including weight acceptance and involvement of many structures keeping dynamic stability of the body, the stance phase will be mainly discussed below.

2.2.1 Stance phase

Initial Contact (IC)

It is a very short and difficult phase which lets the balance be retained after lower limb swing. The peak of arms displacement during walking occurs at IC (shoulder extension) and TSt (shoulder flexion), so any difficulties in IC and early LR can be compensated in the range of arm motions what is noticeable in persons with scoliosis, dependent on the speed of walking.

Initial Contact requires proper muscle activity around the lower trunk. Multifidus is bilaterally active at the time of every contact of the heel with the floor, so any functional impairment of multifidus, observed in stance under balance perturbation conditions (Haumont et al., 2011) can result in walking disorders. Initial Contact is characterized by asymmetric activity of extensors muscle along the lumbar part of the spine (Syczewska et al., 2006) and increased knee flexion what was observed in girls with double curve scoliosis.

Loading Response (LR)

Weight acceptance and acceleration in LR require a very compound mechanism of the body control. A rapid lateral drop of the pelvis of the contralateral side observed in this phase in healthy people forces higher muscle activity (mainly hip extensors, abductors and knee extensors) to decelerate this movement. A disturbed function of hip abductors and extensors can be the next cause of gait asymmetry in LR and MSt what was pointed out in the studies (Syczewska et al., 2006).

Prolonged muscle contraction of the quadratus lumborum, erector spinae, gluteus medius found by Mahaudens et al. (2009) in AIS female patients suggests modification in gait in LR, MSt and TSt compared with the persons without scoliosis although, no kinematic or EMG left-right asymmetry was observed in this study.

At the moment of pelvic drop the pelvis begins its rotation forward. The differences in pelvis position in the transverse plane in persons with specific scoliotic deformation (Pasha et al., 2010) at the beginning of forward rotation on the right and left side can be the cause of the asymmetric gait pattern in LR and PreSw.

Also the preliminary results of the study conducted in our University pointed out the differences between 13 girls with double curve scoliosis (thoracic right and lumbar left) and 11 girls from the control group of the same age, height and weight. The goal of the study was to measure acceleration of the pelvis along the vertical, anterior - posterior and transverse axis of the body in individual gait phases in both groups. A measurement unit was placed on the pelvis and measurement was taken during walking with normal speed on a flat ground. Significant differences between the groups were mainly noticed along the anterior-posterior axis of the body in LR, MSt and PSw phases. The girls with scoliosis were

characterized by lower values of acceleration when compared to the control group (Żyłka, 2010). Further studies are necessary to discover the reasons for the lower values of pelvic acceleration in girls with scoliosis.

Proper activity of the quadriceps and well - coordinated cooperation of the trunk muscles associated with the change of direction of arm movements are necessary for dynamic stability in LR. Until now no studies have demonstrated abnormalities in these structures.

Mid Stance (MSt)

The centre of gravity normally moves over to the foot being on the ground during walking in MSt, while the other limb moves forward. Feet load in MSt is influenced by body alignment.

In the study Stępień et al. (2007) observed evident relation between the body vertical axis shift and feet load in stance phase. The lateral displacement of the plumb line in adolescent with dominant right thoracic curve (T) and dominant lumbar left curve (L) was linked to the direction of dominant curve of scoliosis – the plumb line displacement to the left was observed in L group, whereas in case of T group – to the right. The shift of upright posture line of the body in subjects of the groups under study was correlated with the greater load on lateral edge of the foot at the same side, i.e. more often the lateral edge of the left foot in subjects from L group and the lateral edge of the right foot in subjects from T group were loaded additionally. It means that any lateral deviation of the plumb line from proper upright posture of the body is an important determinant influencing the feet load value in MSt and any action taken to correct the upright posture in persons with scoliosis can contribute to the improvement of their walking.

Bringing the center of gravity over the supported foot is possible thanks to proper muscle activity of such muscles as gluteus medius, gluteus maximus, tensor fasciae latae. The precise evaluation of physical condition of the person with scoliosis in single limb support often demonstrates weakness of hip joint abductors, mainly on the concave side of the lumbar curve. The left lumbar curve is usually associated with excessive pelvic tilt to the left during single support on the right limb (Figure 8). Any muscle dysfunction of these muscles increases the pelvic drop of the contralateral side of the body and changes the gait pattern.

Terminal Stance (TSt)

TSt is completed by the other foot support on the ground to regain stability. Forward transfer of body weight requires proper balance reaction, muscle coordination and undisturbed movements of the spine and lower limbs. The lumbar and thoracic components of the erector spinae in healthy people begin their coordinated action in TSt and continue through PSw. M. multifidus is active whenever any heel strike. Increasing muscle activity around the ankle joint and foot is necessary in this phase. This increased muscle activity observed in terminal double limb stance, demonstrated in higher values of the ground reaction forces, also depends on the ability to change the direction of trunk rotation and upper limbs movements.

It has been established that there is a significant asymmetry between the right and left foot load in TSt and PSw in adolescents with scoliosis, and the observed differences were conditioned by the type of scoliosis (Stępień et al., 2007) (Figure 6).

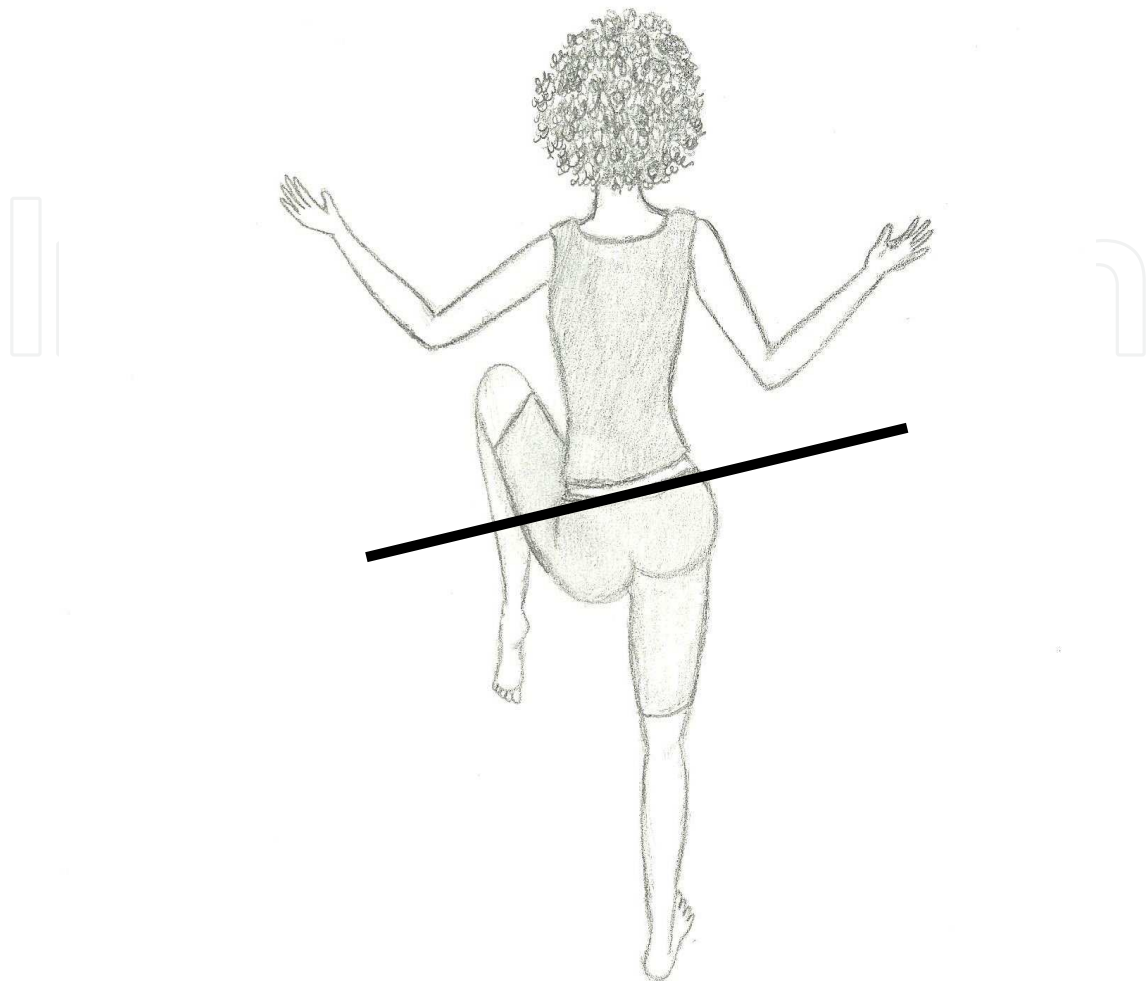


Fig. 8. Example of abnormal lateral pelvic tilt in a patient with scoliosis.

Other authors also indicate that structural spine impairments influence gait abnormalities in double limb stance in the subjects with scoliosis. Kramers- de Quervain et al. (2004) revealed asymmetry in the trunk rotation in the transverse plane during double limb stance in girls with left lumbar and right thoracic curve. Pasha et al. (2010) noted significant changes in pelvic motions during walking in female patients with idiopathic scoliosis compared with persons without spine deformation. It was observed that differences were especially noticeable in subjects with the thoracic right and lumbar left curve. One of achieved results were differences in pelvic motions in the transverse plane. In the majority of the evaluated patients the dominant direction of pelvic rotation was the same as the major curve (right). The authors concluded that the change to one parameter in one of the planes resulted in changes in the other two planes. This conclusion is unanimous with observations made by Stepień (2008), presented above.

Studies carried out by Syczewska et al. (2006) and Kotwicki et al. (2008) showed the differences between the range of rotation in the right and left hip joint in the majority of the assessed patients with idiopathic scoliosis. This mechanism stands for the compensation of

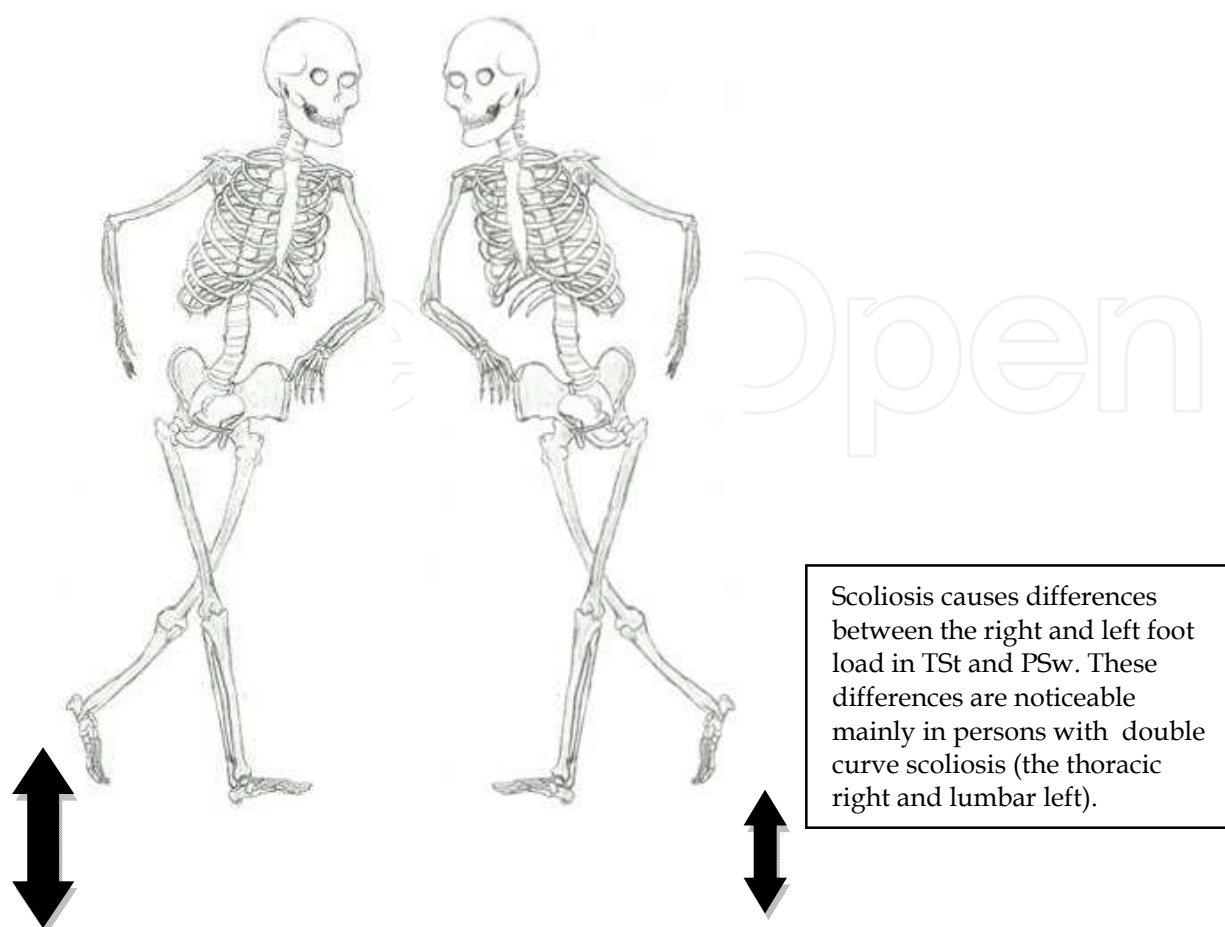


Fig. 6. Differences between the values of the vertical ground reaction forces for the left and right foot in the patient with double curve idiopathic scoliosis.

scoliosis rather than the cause of deformity but it may influence walking and cause differences in feet load in TSt and PreSw.

Pre Swing (PSw)

The load of the foot rapidly decreases in this phase as a result of weight acceptance by the other lower limb. Optimal range of motion in the hip joint is still one of the conditions required for normal gait.

2.2.2 Swing phase

Unfortunately it is not well known what occurs in swing phases in persons with scoliosis. Many authors analyze stance phase considering it to be the most important issue for walking. In normal gait the peak action for abdominal muscles (external oblique muscles) occurs during late Mid Swing and early Terminal Swing. Structural deformations of the spine and rib cage in persons with scoliosis can be the factor disturbing the proper functioning of the muscle chain including external oblique muscles nevertheless it has not been assessed until now.

Improper position of the feet was established in one study of adolescents with idiopathic scoliosis. Syczewska et al. (2006) observed that the feet were dorsiflexed in the ankle joints in the swing phase and there was an internal rotation of the feet with relation to the shanks.

3. Conclusion

The studies presented in this chapter show that gait pattern in subjects with scoliosis depends on the parameters of the spine deformity such as the number of curves in scoliosis, extent and direction of the dominant curve. It is likely that the observed asymmetries during walking are a sign of compensatory mechanisms and they can be a factor leading to pathology and trauma. There are many types of scoliosis under different classifications, so it is necessary to describe the pattern of walking in people with each type of scoliosis. The next step is to correlate the structural dysfunctions related to them. The structures and functions are interrelated. On the one hand, any structural disorder provokes asymmetry or limitation of the movement as well as a change to the quality of an activity. On the other hand a spontaneous position of the body and asymmetry of movements in everyday activities can cause structural dysfunction therefore walking can be one of the reasons for scoliosis progression. The most essential issues, i.e. the reasons of gait asymmetry and those of scoliosis– remain unanswered. Some potential hypotheses are still waiting for research and explanation.

Further studies are necessary to form physiotherapeutic programs to prevent increasing compensations and other secondary deformations such as ribs asymmetry (Zhu et al., 2011) or the temporomandibular joints dysfunctions (Smieciuch, 2011). Another goal is to concentrate on the improvement of gait pattern in persons with idiopathic scoliosis as long as the modern physiotherapy has appropriate means to facilitate gait in patients with different pathology (Adler et al., 2008) including scoliosis.

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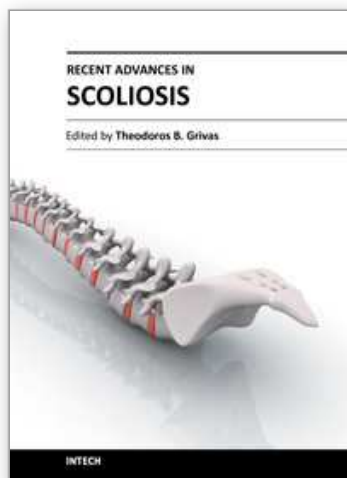
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- www.sosort.mobi/ - Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT)



Recent Advances in Scoliosis

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This book contains information on recent advances in aetiology and pathogenesis of idiopathic scoliosis, for the assessment of this condition before treatment and during the follow-up, making a note of emerging technology and analytical techniques like virtual anatomy by 3-D MRI/CT, quantitative MRI and Moire Topography. Some new trends in conservative treatment and the long term outcome and complications of surgical treatment are described. Issues like health related quality of life, psychological aspects of scoliosis treatment and the very important "patient's perspective" are also discussed. Finally two chapters tapping the untreated early onset scoliosis and the congenital kyphoscoliosis due to hemivertebra are included. It must be emphasized that knowledgeable authors with their contributions share their experience and enthusiasm with peers interested in scoliosis.

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