CHAPTER 1

INTRODUCTION AND PROBLEM STATEMENT

1.1. INTRODUCTION

Spinal deformities, whether congenital or idiopathic, are multifactorial diseases. The arthroskeletal biomechanics within the spine and the dynamic neuromuscular mechanics are important factors.[1] There are numerous causes of spinal deformities in the paediatric population world-wide. Idiopathic scoliosis, Scheuermann's kyphosis and the postural round back are the most common of these conditions.[2,3] Although there are a variety of aetiological factors, there is no evidence of one specific causative factor.[4]

Adolescent idiopathic scoliosis tends to develop and progress during the adolescent growth spurt.[1,3,5,6] Carr *et al* (1993)[5] showed that growth alone is not the primary cause of an idiopathic scoliosis. A spinal curve can progress after skeletal maturity, indicating that growth alone cannot be responsible for this progression.[6] Curve progression could rather be caused by forces of an asymmetrical posture and asymmetrical muscle contraction.[6] Any factor independently influencing body symmetry, posture and growth, may lead to the development of idiopathic scoliosis.[7] There is also a strong genetic basis for the development of idiopathic scoliosis.[1,2,5,8]

Scoliosis can be defined as a lateral deviation of the vertebral column, with a consequent rotation of the spinous processes of a few vertebrae away from the midline position of the normal axis towards the concavity of the curve. The deformity is three-dimensional and progression of a curve leads to a permanent change in the orientation of the vertebrae.[2,8,9] The thoracic vertebral rotation causes a deformity of the rib cage. This will lead to a distortion in the relationship or capacity of the thoracic and abdominal contents.[2,9] Thus a scoliosis is not only a deformity of the vertebral column, but also a deformity of the whole trunk.[9]

A kyphosis is an excessive curvature or angulation of the spine in which the concavity faces anteriorly.[2] The exact aetiology is also unknown. The increase of a thoracic kyphosis is due to gravity, muscle imbalance and loss of bony integrity. In the standing and sitting postures, the spine is subject to the force of gravity. The amount of stress on any vertebral segment is related to the body mass of the individual and the spinal level.[10] The treatment of kyphosis would mainly include the reduction of body mass, postural control and hyperextension exercises of the thoracic spine.[11]

There is a relatively low prevalence of spinal deformities in the general population. However, the deformities can lead to more serious problems such as lung restriction and neurological involvement.[2,8,9] Conservative treatment consists of regular follow-up radiographs in mild cases, braces when the curves progress and regular exercise.[9,12] Physiotherapy is part of the conservative treatment of spinal deformities and is mainly prescribed to retain spinal mobility, but has little effect in the prevention of the progression of a curve.[9,13] Lehnert-Schroth (1992)[14] has achieved some decrease in scoliotic curves with her exercise programme, but curves were not totally corrected. This presents physiotherapists with a problem of credibility with regard to the treatment of scoliosis.

Braces are the benchmark of conservative treatment but their value is now disputed, [9, 15] especially in idiopathic scoliosis.[2] Bracing during adolescence can have a negative psychological impact on the patients because of concerns about their appearance. This may then result in non-compliance with regard to wearing the brace.[2] Modern brace treatment has proven effective in controlling the progression of spinal deformities in skeletally immature patients, [9, 15] but correction rarely occurs.[2, 12] Better results are obtained with kyphosis, except where a rigid structural deformity was present before treatment. [8, 10,14, 16]

Poor posture may very easily develop into a postural disorder such as kyphosis, lordosis and / or scoliosis.[14,17] The spine is the main axis of posture and is maintained by activities of the trunk muscles. The tone of the trunk muscles is automatically regulated by a postural reflex mechanism between the peripheral proprioceptors and the brainstem centre. Functions of equilibrium are gradually acquired during the growing period, keeping pace with physical growth. Spinal deformities can be regarded as a manifestation of postural failure, associated with disharmony in the postural control system.[18] Patients with idiopathic scoliosis demonstrate impairments in the control of equilibrium, but it is not possible to determine if idiopathic scoliosis is the cause or the result of these impairments.[1,8,19,20,21,22,23]

Specific developmental phases seem to be a prerequisite for well-organized psychomotor development and its absence may lead to deficits.[24] Certain motorskills or milestones, during the development of a baby, may occur late. This will lead to shorter intervals between the acquiring of motorskills, or could cause children to miss out on some developmental stages due to short lived hypotonia.[21] Bottos *et al* (1989)[24] found that long-term neurodevelopmental evolution was not influenced by missing the stages of crawling or creeping locomotor strategies. The children in this study were only followed up until the age of five years. Creeping is considered a hypotonic crawl variant,[25] while the process of crawling provides the opportunity for the development of eye-hand co-ordination, vestibular processing, improvement of balance and equilibrium, spatial awareness, tactile input, kinaesthetic awareness and social maturation. The ability to cross the midline presents the child with the ability to integrate the two symmetrical halves into a composite whole.[26]

Boachie-Adjei & Lonner (1996)[2] hypothesised that abnormal developmental milestones in young children may suggest a neuromuscular cause of a spinal deformity. However, in the literature review that was conducted, no evidence was found of any study to determine a correlation between certain developmental milestones and other factors (see the following paragraph) that may affect the neuromusculoskeletal system and the development of spinal deformities during adolescent years.

Due to the current unsuccessful treatment of spinal deformities by physiotherapists, it was decided to investigate the association between certain developmental milestones, namely sitting, crawling and walking, and spinal deformities. The possible role of other factors, such as position of lying, use of aids (sit chairs, walking rings and jolly jumpers), visual and auditory impairments, family history and sudden growth spurts, in the development of spinal deformities, was also investigated. The position of lying, visual and auditory impairments, family history and sudden growth spurts have previously been referred to in the literature as factors that could influence spinal curves.[1,2,3,5,6] The use of developmental aids is a fairly modern trend that may affect the normal developmental stages of babies. If this study shows that there is a relationship between developmental milestones and certain other factors (as given above), and the development of spinal deformities, physiotherapists could help to instruct young mothers in the stimulation of gross motor skills and the stimulation of hypotonic muscles in their offspring. This intervention should minimise the risk factors in the development of spinal deformities, thus leading to an important area of preventative treatment at a primary health care level by the physiotherapist. The high cost of medical services in South Africa is a problem. The estimated cost for a spinal fusion in the Pretoria Academic Hospital is between ten and fifteen thousand rand. This study may highlight the importance of giving mothers relevant advice on the care of their offspring, in order to minimise the risk of the development of spinal deformities. Early intervention at primary health care level may lead to an important reduction in medical costs, as well as a decrease in the concomitant problems associated with spinal deformities.

1.2. PROBLEM STATEMENT:

There is no single specific aetiological factor in the development of spinal deformities.[4] Postural failure and disharmony in the postural control system can influence spinal deformities.[18] Motor development and muscle tone are dependent on the specific developmental phases of a baby.[24] Late milestones or omission of certain developmental stages in babies may lead to low trunk muscle tone, which in turn may lead to postural problems and spinal deformities in adolescents. The position of lying, visual and auditory impairments and sudden growth spurts could add to body asymmetry, while the use of developmental aids could add to the omission of developmental stages or altered developmental phases.

Physiotherapy has little effect in preventing the progression of a curve, therefore other ways of treatment should be researched. The risk factors in the development of spinal deformities could be minimised by intervention during the developmental stages of babies.

1.3. RESEARCH QUESTION

Do abnormal developmental milestones and certain other factors of neurologically intact babies have an influence on the prevalence of spinal deformities in adolescents in Middelburg, Mpumalanga?

1.4. AIM OF STUDY

1.4.1. MAIN AIM

To investigate the association between certain developmental milestones, namely sitting, crawling and walking, and the development of spinal deformities in adolescents aged between twelve and seventeen years, in Middelburg, Mpumalanga.

1.4.2. SUB AIMS

1.4.2.1. To determine if a literature review shows any correlation between the developmental milestones of a baby and the development of spinal deformities in adolescents.

1.4.2.2. To determine if the following factors have any influence on the prevalence of spinal deformities:

Developmental factors:

- age at which the babies sat independently
- whether the babies crawled
- age at which the babies crawled
- age at which the babies walked independently

Other factors:

- family history of deformities
- period of gestation
- preference of lying position
- other ways of locomotion before the babies walked
- the use of aids such as a walking ring, a sit chair or a " jolly jumper "

- any auditory impairment
- visual impairment
- growth spurts
- height
- gender
- menarche in girls
- hip flexor tightness
- decreased hamstring muscle flexibility

1.5. HYPOTHESIS

Deviations of certain normal developmental milestones namely sitting, crawling and walking, as well as certain other factors, in neurologically intact babies, may influence the development of spinal deformities in adolescence.

1.6. TERMINOLOGY

- **Spinal deformity:** Any deviation from the normal kyphotic and lordotic curves in the sagittal plane, or deviation of the vertebrae in the coronal plane.[2]
- **Idiopathic adolescent scoliosis:** A spinal curvature presenting at, or about the onset of puberty and before maturity for which no specific cause is established.[27] This is a lateral deviation of the spine in the coronal plane.[2]
- **Kyphosis:** A change in the alignment of a segment of the spine in the sagittal plane that increases the posterior convex angulation.[27]
- **Kyphoscoliosis:** A spine with a scoliosis and a true hyperkyphosis.[27]

- **Abnormal developmental milestones:** Average ages for normal developmental milestones have been established.[28] In this study any deviation from the normal average was considered as "abnormal", although not pathological. Abnormal in this study can be described as "not within the normal averages".
- **Postural control:** The spine, the main axis of posture, is maintained by activities of the trunk muscles. The tone of these muscles are regulated by a postural reflex mechanism between the peripheral proprioceptors and the brain.[18,20]
- **Postural failure:** Disharmony in the postural control systems namely the postural reflex mechanism controlling the muscle tone.[18,20]
- **Muscle tone:** Although not an active contraction, muscle tone determines the body posture, range of movement of the joints and the feel of the muscle. Muscle tone is determined by physical, chemical and neural influences.[28]

1.7. SUMMARY

Although there are a variety of aetiological factors that could influence the development of a spinal deformity [4], a spinal deformity can be regarded as a manifestation of postural failure.[18] Physiotherapy has little effect in the prevention of the progression of a curve [9,13], therefore other ways of treatment should be researched. Abnormal developmental milestones and certain other developmental factors suggest a possible neuromuscular cause of a deformity [2].

The motivation, problem statement, research question, hypothesis, aims of the study and definitions of relevant terminology were given in this chapter. In the following chapter, chapter two, the literature review will cover all the aetiological factors of spinal deformities as well as the background for postural control and normal developmental milestones. Studies investigating the association between the presence of adolescent spinal deformities and developmental milestones, as well as certain other factors (which may influence posture), will also be discussed. Chapter three explains the research methodology. Chapter four will give an explanation of all the results and relevant diagrams, histograms and tables. A thorough discussion of the results will be included in chapter five, while chapter six concludes with shortcomings and recommendations.

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CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

The literature review will cover the pathology and aetiology of idiopathic scoliosis, Scheuermann's kyphosis and the postural round back as these are the conditions most commonly seen in the general population. The methods of evaluation and various evaluation instruments that are currently used during the evaluation of these spinal deformities, will be discussed. An overview of the basic principles and effectiveness of treatment of the aforementioned spinal deformities will also be given. Due to the fact that poor posture of an adolescent can lead to a spinal deformity, and because an adolescent with a spinal deformity usually has poor posture, the influences of posture will also be discussed. Normal developmental milestones as well as developmental aspects of babies that may influence the spine, will also be included in the literature review. The literature review was conducted by using the database MEDLINE from 1981 to 1998 and CINAHL from 1982 to 1987. A Cochrane search was conducted to determine if any similar studies have been registered. The reference list of each article was also screened for relevant articles. Only articles published in Afrikaans and English were considered. Keywords used were: spinal deformities, idiopathic scoliosis, Scheuermann's kyphosis, adolescent kyphosis, aetiology, postural control, developmental milestones, motor development, muscle imbalance, exercises.

2.2. SPINAL DEFORMITIES

There are numerous kinds of spinal deformities in the paediatric population. The causes of these spinal deformities could be idiopathic (80 % of cases)[14], congenital, neuropathic or myopathic.[9,29] Scoliosis is also seen in association with spondylolisthesis, but may be solely idiopathic and unrelated to the spondylolisthesis. The hypoplasia of the articular facet may allow an asymmetrical forward displacement and rotational shift of the vertebral body, or the scoliosis may be due to muscle spasm, and therefore be of a "sciatic" type.[35]

2.2.1. PATHOLOGY

What are the important pathological factors associated with idiopathic scoliosis, the postural round back and Scheuermann's kyphosis ?

2.2.1.1. IDIOPATHIC SCOLIOSIS

- **Definition of idiopathic scoliosis**:

  An idiopathic scoliosis can be defined as a lateral deviation of the vertebral column in the coronal plane.[2,9,14,30,31,32] A "normal" spine is supposed to appear vertical but this is seldom the case. [2,31] Some researchers state that a curve deviating laterally from the vertical by five degrees can be considered abnormal[29,33], whereas others[2,9,34] consider ten degrees as abnormal. This lateral deviation results in a rotation of a few vertebrae away from the midline position around the axial plane, with the spinous processes rotated towards the side of the concavity, causing a three-dimensional deformity.[2,9,30,31,32] The shifting of the centre of gravity leads to a static imbalance.[14]

- **Structural changes:**

Rotation of the thoracic vertebrae causes a deformity of the rib cage because the ribs are displaced posteriorly on the convex side of the curve, thereby causing a rib hump.[11,14,29,30] A costal depression or rib valley appears on the concave side, and a gibbus or rib hump develops on the convex side.[14] This rotation can also take place in the lumbar area, but is less apparent.[32] The vertebral rotation is related to the length and severity of the curve, with the most rotation taking place at the apex of the curve.[30]

Slight dorsal asymmetries become evident when a patient bends forward to touch his toes. The greater the rib prominence, the greater the torsion of corresponding vertebrae as ribs and musculature move with the rotation and develop dorsal elevations. If nothing is done to counteract the hump, one lateral half of the back may quickly enlarge due to the gibbus that develops as a result of an imbalance of muscles and biomechanical forces.[14] The shoulder girdle is drawn posteriorly above the rib valley and anteriorly above the costal convexity.[14] In a right thoracic scoliosis, for example, the right scapula is higher and is forcibly lifted by the rib hump.[32]

There is a distortion of the contents of the thorax and the abdomen.[9] Respiratory restraint is one of the main complications of chest distortion due to a structural scoliosis.[9,14] An idiopathic scoliosis is thus not only a deformity of the spinal column, but could also affect the viscera and respiratory function.[9,31] The presence of a hump may also lead to numerous psychological problems.[14]

- **Types of idiopathic scoliosis:**

A scoliosis is described according to the side of the convexity, either left or right sided. The position of the apex of the curve determines whether it is a thoracic, lumbar or thoraco-lumbar curve.[2,29]

A scoliotic curve can be structural or postural.[2,9,31] A structural curve leads to decreased normal flexibility of the spine and is seen in cases of idiopathic scolioses.[27] On forward bending, a postural deformity will straighten out, but in the case of a structural scoliosis a rib hump would be observed on the convex side of the deformity.[9,11,29] This is due to the fact that there is no vertebral rotation and a rib hump does not develop in the case of a postural scoliosis.[34] A postural scoliosis could be the initiating cause of a structural scoliosis, and usually has a single long thoraco-lumbar curve with a predominantly left convexity.[34] Postural scoliosis is attributable to compensatory lower limb growth or pelvic adjustments affecting the lumbo-sacral junction and poor posture.[9,32,34] Lower limb length discrepancy should be corrected by means of an orthosis.[9]

Idiopathic scoliosis may be divided into three groups:
-the infantile idiopathic scoliosis which develops between birth and three years
- the juvenile idiopathic scoliosis which develops from four to ten years
- and adolescent scoliosis which develops after the age of ten.[1,9]
The current trend is to describe scoliosis as either of early or of late onset, coinciding with the two peaks of rapid growth.[9,29]

- **Clinical features:**

Clinical features that the parents or patient may notice are an elevated shoulder, a prominent shoulder blade or breast, a high prominent hip, asymmetric flank or trunk shape, poor posture or the curve itself.[9] Backache is rare. If present, it is usually associated with a secondary problem such as Scheuermann's disease or spondylolisthesis.[9,35]

Different curve patterns can occur in idiopathic scoliosis.[11] In a thoracic spinal curve the entire thoracic spine is contained in the curve, and in 80 % of cases, the curve is convex to the right.[11,32,33.] Two curves could develop in the thoracic area, causing a double thoracic curve, which is usually convex to the left in the upper thoracic spine, and convex to the right in the lower thoracic spine.[11,32] The primary curve could also appear in the thoraco-lumbar area or in the lumbar area. In the lumbar area the spinal curve is to the left in 90 % of cases. A double primary curve may develop in any two spinal areas.[11,32]

In almost all cases of idiopathic scolioses there is a postural disorder in the sagittal plane with an anterior protrusion of the pelvis. The trunk deviates posteriorly from the lumbar region. The body adapts to the imbalance of the body equilibrium and finally adapts to the scoliotic state.[14]

The spine is mechanically less stable than other peripheral joints in the body and therefore requires good neuromuscular control to be correctly aligned. This makes the spine more sensitive to changes in muscle tone. Even a transitory difference in muscle tone could cause some structural changes.[1] The scoliotic curve changes the resting tension of some back muscle fibres due to alteration in the direction of pull of the back muscles.[36] Frequent illness episodes and reduced physical activity are found to be associated with trunk asymmetry.[37] An increased kyphosis of the thoracic spine was found to be a significant predictor of future scoliosis in girls.[7] However, a loss of thoracic kyphosis with spinal stiffening may develop into a scoliosis in pre-adolescent girls.[11] When the scoliosis is already present, the thoracic kyphosis tends to be reduced.[7,11,31] An increased lordosis of the lumbar spine can significantly predict scoliosis in boys, but not in girls.[7] The normal sagittal alignment of the cervical spine is altered in adolescent idiopathic scoliosis due to the diminished thoracic kyphosis, causing the cervical spine to be more flat or slightly kyphotic.[38]

- **Prevalence:**

According to different studies the prevalence of idiopathic scoliosis varies in terms of severity of curves as well as age differences of onset . During a school screening the following was found:

◊ 1.8 per 1000 children from eight to eighteen years have idiopathic scoliosis

◊ 0,2 per 1000 have curves greater than 20 degrees.[9]

◊ curves greater than 20 degrees have a prevalence of 2-3 %[9] in one or 0,3 - 13,6 % in another study[37]

◊ in the general population the prevalence is 0,5 %, but is 1,5 % for boys with a family history of scoliosis, and 5 % for girls with a family history.[9]

- **Gender:**

Idiopathic scoliosis is found more frequently in females than in males,[2,9,30,31] with a larger risk in girls from the age of nine to twelve years.[9] Puberty of adolescents with idiopathic scoliosis is not significantly different from normal.[5] However, in the literature the ratio of males to females varies.[9,29,31]

According to a literature review by Bentley & Donell (1994)[9] , researchers found that the female to male ratio was 3,5 to 1,0 , but increased to 7,2 to 1,0 for curves that require treatment.[9] Other researchers show the ratio of boys is half that of girls[31], and a five to one ratio is also reported.[34] Boys could be protected in some way.[31] Perhaps this could be because muscle strength is approximately the same in boys and in girls until adolescence, but during the growth spurt boys show a greater increase in muscle strength than girls.[1]

- **Skeletal maturity:**

Skeletal maturity is determined by means of radiographs of the iliac and ischial epiphyses.[2,29] According to the Risser method, the development of the iliac epiphyses is divided into four stages.[29] The ilium is divided into four equal areas and the fusion of each area is a stage of the Risser sign. [29] These epiphyses fuse to the iliac crest over a period of several years, averaging twenty four months in males and thirty months in females.[6] The fusion usually starts at the anterior superior iliac spine and progresses posteriorly to the posterior iliac spine.[6,29] The average age for fusion of the epiphysis to the liac crest is fourteen years in girls and sixteen years in boys, but it may vary from ten to eighteen years in girls and thirteen to twenty years in boys.[6] Dhar *et al* (1993)[6] felt that Risser did not take the actual fusion process of the epiphysis to the iliac crest into consideration, and therefore developed their own ten stages of skeletal maturity.[6] However, the four stages of Risser, namely the Risser's sign, is most commonly used.[2,29]

Radiographs taken to determine skeletal maturity are risky due to the adverse effects of radiation to the pelvic organs,[2,6] but the determination of skeletal maturity is important owing to its relevance to curve progression.[29] Skeletal maturity is difficult to determine due to the wide age range at which youths reach sexual maturity.[29]

- **Risks for progression of the curve:**

Scoliotic curve progression is more common in girls than in boys,[2,9,29,39] with a prevalence of 2 to 3 times more[29] or 5 to 8 times more in girls.[2] Risk factors for the progression of curves are periods of rapid growth, a Risser sign of nil to two, pre-menarche detection, a curve of more than 30 degrees, a double curve (especially in the thoracic area), a rib-vertebral angle of more than 20 degrees, females and where there is a family history.[2,9,11,14,29,40,41] A young patient with a low Risser sign and later onset of menarche has a greater risk of curve progression.[5] Progression of curvature in boys with idiopathic scoliosis of more than 25 degrees and a Risser sign of four, occurred in 15 % of cases.[15]

Curves can progress after skeletal maturity when the vertebral epiphyses have already fused. This means that an asymmetrical posture and muscle activity can lead to intervertebral joint and disc degeneration.[5,11,29] Minor curves sometimes have the tendency to resolve spontaneously.[41]

The dynamic mechanics of the human body have an influence on the curve progression as well as regression.[1] In girls the period of rapid progression is the time from the first signs of puberty and menarche.[3,29] During the period of rapid growth (ten to fifteen years) the progression of idiopathic scoliosis takes place[11,34,40], and it may increase by as much as one degree per month.[34] The more years of growth left after detection of a curve, the greater the progression.[29] Lonstein & Carlson (1984)[40] showed a curve progression of 23,2 %. A spontaneous improvement took place in 10,7 % of these cases. These patients were less mature and had curves of less than 15 degrees.[40] The flexibility of a curve is important in determining the curve prognosis as well as the response to treatment. Progression may lead to pulmonary and spinal dysfunction.[11]

- **Pulmonary complications:**

Restrictive lung disease in the presence of scoliosis occurs with a direct linear relationship to curve magnitude in patients with a thoracic deformity.[2,42] This effect is increased in patients with hypokyphotic or lordotic thoracic spines.[2] Significant pulmonary restraint does not occur until a curve magnitude of 90 to 100 degrees or more is reached.[2] Other researchers claim that patients, with idiopathic scoliosis who have curves of under 40 degrees, have normal pulmonary functions and only if the curve exceeds 45 degrees should pulmonary functions be measured.[11] Adult scolioses with a Cobb angle of more than 60 degrees are threatened by pulmonary hypertension and restriction of cardiopulmonary performance.[42] It is frequently assumed that respiratory impairment is negligible in scoliosis patients with a Cobb angle of less than 60 degrees. However, marked impairment of the respiratory mechanism and cardiopulmonary performance in scoliosis patients with a Cobb angle of less than 35 degrees has been noted. The asymmetrical breathing pattern of a scoliotic patient leads to an increase of the curvature, particularly in rotation, and restricted rib mobility.[42]

The lung work capacity and tidal volume are reduced in mild to moderate idiopathic scoliosis.[43] Hornstein, Inman & Ledsome (1987)[44] found a correlation between a decrease in vital capacity and other lung functions, and the severity of the curve, but Kearon, Viviani & Killian (1993)[43] found that the extent of this reduction depends on the severity of pulmonary impairment. Scoliotic patients adopt a low tidal volume and high frequency pattern of breathing, especially during exercise.[43,44] Reduction in thoracic cage compliance results in a higher energy cost of breathing.[8,44] Growth impairment of the rib cage and lungs, and reduced inspiratory muscle strength have been reported in patients with idiopathic scoliosis.[42] Pulmonary hypertension and cor pulmonale are seen in later stages of scoliosis, leading to cardio-respiratory failure in severe cases.[2,44] In patients with adolescent idiopathic scoliosis the incidence of cor pulmonale is exceedingly low; it is more often seen in untreated infantile scoliosis or severe congenital deformity.[2]

- **Psychological aspects:** The cosmetic aspects of the deformity itself, as well as the psychological effects associated with the wearing of a brace, have a negative effect on the self-esteem of a patient with a spinal deformity. The patient feels insecure and different from the rest of the community.[32]

2.2.1.2. KYPHOSIS:

- **Definition:**

  A kyphosis can be described as an excessive curve, convex posteriorly occurring mainly in the thoracic spine.[2] Kyphoses occur in a single plane and the biomechanics are therefore easier to understand than those of a scoliosis.[10] The curve may be gradual, as in the cases of postural kyphoses, or it can have a sharper curve or gibbus, in the case of Scheuermann's kyphosis.[2]

- **Clinical features of Scheuermann's disease:**

Scheuermann's disease is recognised as a condition affecting the thoracic spine in two forms, the thoracic form and the thoraco-lumbar form. The apex of the thoracic form is localized between the seventh and ninth thoracic vertebrae, while the apex of the thoraco-lumbar form of Scheuermann's disease is between the tenth and twelfth thoracic vertebrae.[45] Classical Scheuermann's disease is diagnosed as a kyphosis that exceeds 45 degrees, with more than five degrees of wedging of the anterior vertebral bodies of at least three successive vertebrae.[2,10,11,45,46,47,] This wedging is caused by damaged growth centres in the anterior portions of the vertebral bodies.[11,46,48]

Associated findings include Schmorl's nodes, vertebral endplate irregularity and narrowing of adjacent intervertebral discs.[46] The wedging of the three adjacent vertebrae observed on radiographs is used to differentiate between Scheuermann's kyphosis and a postural kyphosis. Patients who do not demonstrate these bony abnormalities and have a kyphosis exceeding 45 degrees, are considered to have a postural kyphosis or a postural round back.[47]

Another form of Scheuermann's disease which occurs in the lumbar region, has been reported.[45,46] Patients with this disease generally report low back pain and demonstrate vertebral endplate irregularity, anterior Schmorl's nodes and narrowing of the involved intervertebral discs on radiographs.[46] These patients are distinguished from those with the classic Scheuermann's disease by the location of involvement, the lack of thoracic kyphosis and marked wedging of the vertebral bodies.[46] Lumbar spondylolisthesis is frequently seen with hyperkyphosis.[17]

Scheuermann's kyphosis is a deformity that causes a painful back.[10,11] A very slight scoliosis may exist in the area of maximum kyphotic deformity.[11,45] This scoliosis can be on the level of the apex of the kyphosis, or above or below the kyphosis.[45] The forward bend test will show a typical dome when observed laterally.[11,48]

- **Spinal stress:**

In standing or sitting the spine is subjected to the force of gravity. The amount of stress on any one mobile intervertebral segment is related to the weight of the individual and the level of the spine (for example the fifth thoracic vertebra carries less load than the fifth lumbar vertebra).[10] There are other factors that add to this concept of spinal stress, namely motion stress, muscular forces and the position of a vertebra relative to the centre of gravity of the body.[10] The extensor muscles, supraspinous and interspinous ligaments, the capsular ligaments and the ligamentum flavum should counteract the natural tendency of the thoracic spine to develop a kyphosis.[10] The eighth thoracic vertebra lies most posterior to the central sagittal axis. This position is precarious as the extensor muscles are close to the vertebra causing a very short moment arm. In contrast, the flexor muscles lie in front of the eighth thoracic vertebra, and thus creating a strong moment arm. This is why the eighth thoracic vertebra is the most commonly involved vertebra in Scheuermann's disease.[10]

- **Gender**

Thoracic kyphosis develops more frequently in boys than in girls.[17] There is a wide range of normal thoracic curve values with a mean of 35 degrees.[8] The mean thoracic kyphosis tends to increase during growth and the mean lumbar lordosis seems to decrease in both sexes.[17] Nissinen (1995)[17] found that the most pronounced kyphosis was observed at a mean age of 12.8 years, and the least pronounced lumbar lordosis a mean age of 13.8 years in both genders.

- **Prevalence:**

  Scheuermann's kyphosis is seen in 0,5 - 8 % of the general population.[20] The prevalence rate increases between the ages of twelve and thirteen years.[31] Hyperkyphosis of more than 35 degrees was found in 13,5 % of adolescents and a thoracic kyphosis exceeding 45 degrees was found in 3,1 % of adolescents.[17]

- **Complications:**

  A neurological evaluation is essential in children with thoracic Scheuermann's disease. Although rare, cord compression due to stretching of the dural contents and a herniated thoracic intervertebral disc can occur.[48]

SUMMARY:

Idiopathic scoliosis and Scheuermann's kyphosis are both conditions that cause a structural deformity of the spine. These deformities could have a negative psychological effect on the adolescent, and also lead to complications influencing his/her quality of life.

2.2.2. AETIOLOGY

Are there any specific aetiological factors which cause idiopathic scoliosis and Scheuermann's kyphosis ?

IDIOPATHIC SCOLIOSIS:

Idiopathic scoliosis should be regarded as a multifactorial disease. No single factor has been demonstrated to cause scoliosis.[1] In 80 % of idiopathic scolioses the causes are unknown.[9,14,30] Posture, growth and factors leading to trunk asymmetry, independent of one another, may lead to the development of idiopathic scoliosis.[7] One out of four children is reported to have trunk asymmetry at the age of ten years.[49] Biomechanically, the axial skeleton might be more unstable in individuals with increased height and accelerated growth spurts of the spine.[1]

- **Growth:**

Idiopathic scoliosis has the tendency to develop and progress during adolescent growth.[5,6,7] Taller children are more prone to develop adolescent idiopathic scoliosis.[3,5] Growth alone, especially growth velocity *per se*, is not a primary cause of adolescent idiopathic scoliosis.[4,5,7,31] Compared to girls with normal spines, an increased level of growth hormones has been found in girls with adolescent idiopathic scoliosis.[1] In patients with a strong genetic susceptibility to the condition growth appears to be less important.[5] Growth velocity *per se* is unimportant, but adolescents with idiopathic scoliosis are taller than average.[31] The curve in adolescent idiopathic scoliosis can increase after skeletal maturity. This means that growth cannot be responsible for the increase, but rather that the spine is subjected to asymmetrical posture and muscle activity.[6] Other researchers claim that increased height should be regarded as a poor prognosis rather than an aetiological factor.[3] Carr *et al* (1993)[5] found no clinical evidence of generalized growth abnormalities that would account for the increased stature. Skeletal bone age was not significantly different from the chronological age, nor were the puberty ages significantly different from normal.[5] Curves progress rapidly during the adolescent growth spurt, which occurs in girls around twelve years and in boys two years later.[1] During the adolescent growth spurt the trunk increases more than the limbs in length.[1] Girls with adolescent idiopathic scoliosis are significantly taller than normal girls, but this is not the case with boys.[1] These girls start their growth spurt earlier, continue to grow for a longer period of time, but the age of menarche does not differ from normal girls.[1,4] The risk of trunk abnormalities is at its highest in the period between onset of adolescent growth and the onset of menarche.[3]

- **Family history:**

Adolescent idiopathic scoliosis appears to have a genetic basis.[1,2,5,9,11,29,32] Girls of mothers with scoliosis are more at risk to develop a scoliosis.[9] The prevalence rises from 0,5 to 5 % in girls and 0,5 to 1,5 % in boys with a family history of scoliosis.[9] Maternal age was found to be older in mothers of children with adolescent idiopathic scoliosis.[39] The genetic determination is regarded as dominant and is sex-linked to the X - chromosome, but is also influenced by maternal age.[1] Up to 33 % of parents and siblings of patients with adolescent idiopathic scoliosis have a scoliosis.[1] It has been calculated that if both parents have an idiopathic scoliosis, the chances for their off-spring to acquire a curve requiring treatment, can be fifty times that of the normal population.[1,11] Fathers transmit the disease to their daughters, and mothers transmit the disease to both genders.[1] Several familial cases with clinical combinations of lateral gaze palsy and progressive scoliosis have suggested an autosomal recessive hereditary trait.[22]

- **Posture and equilibrium:** (also refer to 2.2)

The importance of spinal posture of pubertal children is poorly documented.[17] Postural disequilibrium and abnormality of the vestibular functions, defective proprioceptive functions and ocular motor disturbances have been observed in association with adolescent idiopathic scoliosis.[17,18,22,32,36] Equilibrium functions are gradually acquired during the growth period, keeping pace with physical growth. If equilibrium development does not keep pace with growth, postural failure will result. Scoliosis is regarded as a manifestation of postural failure associated with disharmony in the postural control system.[18]

Information from skin sensation, ligaments and muscles combine together with signals from the optical apparatus and semicircular canals. All these signals are integrated and co-ordinated to control equilibrium by means of the muscles.[32] A vestibular imbalance can influence the tonicity of skeletal muscles via the vestibulo-spinal tracts in such a way that the individual leans and rotates away from sound side.[1] The spine demonstrates a lateral deviation and rotation leading to a functional asymmetry or scoliosis.[1] A vestibular imbalance exists in a high proportion of patients with idiopathic scoliosis, but it is difficult to determine whether it is a cause or an effect.[1] Asymmetric posture in children is very common.[37] Several postural stresses are experienced in daily living, schools and the use of computers.[50] An asymmetrical posture may be an early sign of the predisposition to develop scoliosis.[37] The spine is considered to be the main axis of posture and is maintained by activities of the trunk muscles. The tone of these muscles is automatically regulated by a postural reflex mechanism.[18]

Trunk asymmetry is a stage without axial rotation or with very little rotation.[37] In about 10 % of the adult population, a slight rotation of the fourth lumbar vertebra on the fifth lumbar vertebra is seen.[32] This is so common that it may be regarded as a manifestation of the anatomical and functional asymmetry of the human body.[32] In time this can become permanent due to the result of changes in the disc.[32] Reduced physical activity or hypokinesia may be affected by lifestyle and passivity during illness. Muscle power as well as static and dynamic endurance, and muscle tone decrease.[37] Physical activity is one of the factors that may affect posture quality.[37] Juskeliene *et al* (1996)[37] found an asymmetrical posture in 46-49 % of the 791 children in their study.

- **Developmental milestones:** (also refer to 2.4.)

At birth the entire spine is kyphotic. When a child develops head control, the neck extension produces a cervical curvature convex anteriorly. This is the development of the cervical lordosis. A similar lumbar lordosis develops when the child begins to sit and stand.[31]

There is a higher prevalence of scoliosis in Scotland than America. This could be due to the fact that babies in Scotland are positioned more often in supine than in prone during their first two years. Americans use the prone position for their babies in preference to supine.[1] Babies who are nursed in prone develop neck and spinal muscle control earlier than babies nursed in supine.[1] Prone positions may enhance the development of righting reflexes that develop later to keep the body in an upright position.[1]

- **Other:**

Total lateral gaze palsy, the most severe type of visual disequilibrium, has been reported in association with progressive scoliosis.[22] It is not clear if this is a cause or a result of idiopathic scoliosis.

Latissimus dorsi, muscles of the lateral abdominal wall, the intercostalis and the iliopsoas are important muscles in the development of scoliosis.[1] Histochemically more type I (slow-twitch) muscle fibres are found on the convex side of idiopathic scoliosis.[1,29,31,51] It is not clear if these changes are secondary to the curve, or whether they existed prior to the development of scoliosis. Higher postural tone was noted in muscles on the concave side of a curve compared to the convex side.[1] Early involvement of children in intensive swimming programmes exposes them to types of stress that can affect the growth and development of their musculo-skeletal systems in an adverse way, producing a disruption of normal growth patterns.[34] Structural idiopathic scoliosis was found in 6,9 %, and functional scoliosis with lateral curvature to the hand-dominant side of the body in 16 % of swimmers.[34] The presence of scoliosis in pre-adolescent and adolescent swimmers may indicate that motor developmental patterns could have a direct relationship on the skeletal growth of vertebrae and the spine.[34] An assumption is made that the repetitive motions required in swimming could produce a physiological adaptation, and thus a muscular adaptation, which leads to a contracted spinal curve.[34]

Malnutrition has been found to be associated with idiopathic scoliosis in South America, Europe and the United States of America. It was noted that too much carbohydrates and too little protein were consumed. In the Soviet Union the incidence of idiopathic scoliosis was four times higher in undernourished children.[52]

KYPHOSIS:

The aetiology of Scheuermann's disease is unknown but mechanical strain, such as strenuous labour and sports activity, repetitive trauma and tight hamstrings have been implicated.[48] Scheuermann's kyphosis shows an autosomal dominant hereditary pattern.[2,48] There is a positive family history in 15 - 20 % of patients with a Scheuermann's kyphosis.[11]

Left handedness, independent of gender, was also found to be a predictor of future hyperkyphosis due to the pronounced kyphotic posture needed for writing.[50]

SUMMARY: Evidence of a specific aetiological factor could not be found in the literature. It is clear that idiopathic scoliosis and kyphosis are multifactorial diseases. Growth, hereditary factors, gender and posture are clearly the most important aetiological factors.

2.2.3. EVALUATION AND INSTRUMENTS

Is there consensus with regard to the evaluation methods of spinal deformities?
A variety of evaluation methods and instruments are described in the literature.
The validity and reliability of these instruments differ. The most relevant methods will be reviewed in the following section:

School screening is important for the detection of deformities.[2,30] Screening is defined as the presumptive identification of unrecognised disease or defect by the application of tests, examinations or other procedures that can be applied rapidly.[31] A comprehensive history is necessary in order to elicit information about the deformity and other associated problems. Family history with regard to spinal deformities may suggest a genetic factor.[2,30] Relevant injuries and illnesses should be evaluated to determine the possible cause of any deformity. Skin pigmentation such as café-au-lait spots may indicate a diagnosis of neurofibromatosis.[2] The child and parents should be questioned as to how the deformity was discovered. The age at which the deformity was first noticed is important to determine the potential for further progression. The onset of menarche is important to assess the relative maturity and growth potential in female adolescents.[2,30] Boachie & Lonner (1996)[2] recommend a review of birth history, developmental history and childhood illnesses as important, and suggest that abnormal developmental milestones in young children may lead to spinal deformities. However, whether any of these factors indeed play a role has not been verified. Some authors suggest that hand dominance should be evaluated, but no correlation between hand dominance and idiopathic scoliosis could be found.[33,49]

Structural scoliosis is diagnosed by the presence of at least one positive physical sign: rib-hump, lumbar hump, spinal muscle imbalance, discrepancy of shoulder height or radiographic evidence of a curve.[33] A kyphosis is diagnosed by an increased kyphotic posture or a structural dome in the spine on lateral views of radiographs.[17]

- **Height:**

  Serial height measurements are useful in assessing growth and progression of deformity.[2,32] Height may decrease or remain static in growing children in whom curve progression has already occurred.[2]

- **Leg length discrepancy:**

  Leg length discrepancy has a high prevalence in the general population, but the level of significant leg length discrepancy is generally accepted as ten millimetres or more. This difference in leg length can cause asymmetry of the spine.[53] Leg length inequality causes pelvic obliquity and secondary scoliosis.[2] A postural deformity due to leg length discrepancy will straighten during forward bending.[9] Such a deformity can be corrected by means of a shoe lift.[2] Leg length inequality can be determined by means of a tape measure: the distance from the superior anterior iliac spines to the tip of the medial malleoli is measured.[53] Another method to determine leg length inequality is by placing boards of known thickness under the short leg until horizontal symmetry of the iliac crests or superior posterior iliac spines is obtained.[33,49,55] A palpation meter has also been used to determine leg length discrepancy. The iliac crests were used as landmarks and any difference in height was determined. The validity of the palpation meter has not yet been tested.[56]

Relative iliac crest height measurement is a standard evaluation technique in the structural examination of patients to determine pelvic girdle asymmetries and leg length discrepancy. Radiographic imaging is generally accepted as the most reliable method of leg length discrepancy measurement.[54] However, unnecessary exposure to X-rays should be avoided.

- **Passive straight leg raise:**

Tight hamstring muscles have been implicated in the aetiology of Scheuermann's kyphosis.[48] A passive straight leg raise is used to determine the flexibility of the hamstring muscles. The extent to which the leg can be lifted without discomfort, varies. Different averages of straight leg raise have been documented (80 degrees[53], 75 degrees[57], 83,4 degrees[58] of hip flexion). Normal range of movement in healthy individuals can vary from 50 degrees to 120 degrees.[58] The passive straight leg raise is performed to the onset of tightness or to the onset of symptoms, and is measured as an angle formed between the bed and the leg.[53,58,59] Other authors advocate raising the leg to a point where the contralateral thigh begins to move.[56]

- **Thomas test:**

The Thomas test is a specific test to detect flexion contractures of the hip and to evaluate range of hip flexion. The patient is supine, and as the one leg is moved passively into hip and knee flexion, the other leg should remain flat on the examination table.[53] The psoas muscle is draped over the anterior rim of the pelvis, which provides it with the ability to alter the position of the pelvis. Upward and downward pelvic tilting is related directly to the degree of respective flexion and hyperextension of the lumbar spine. Tightness of the psoas muscle will pull the anterior rim of the pelvis downward, causing an anterior tilt. Such a tilt will cause the sacrum to incline forward, resulting in a lumbar lordosis.[51]

- **Plumbline:**

A plumbline is dropped to determine the deviation of the spine from the vertical line.[2,32,60] A vertical plumbline from the seventh cervical spinous process usually passes straight to the natal cleft.[2,38] Any deviation of spinous processes from the plumbline is measured in millimetres.[2] A distance of less than 10 millimetres between the cleft and the string is considered normal.[36]

In the sagittal plane the tragus of the ear or the earlobe is transected by the theoretical plumbline.[61,62] The plumbline passes anterior to the seventh cervical vertebra in the sagittal plane, through the shoulder joint, midway between the back and abdomen, anterior to the first sacral segment and through the greater trochanter of the femur.[62,63]

- **Postural observations:**

Clinical evaluation of posture and the estimation of the range of kyphosis and lordosis are subjective and vary among different examiners.[64] Minor asymmetry of the trunk in school children is common and cannot be regarded as abnormal.[31,55] Trunk asymmetry may be considered a risk factor for adolescent idiopathic scoliosis,[49] and is more prevalent in girls.[7] Posture is assessed by visual assessment of shoulder or pelvic asymmetry or abnormal flank creases.[2,30,33,61,65,] During assessment of posture, the patient should stand in his/her normal relaxed posture and should not be corrected.[32,56]

- **Forward head posture:**

The natural head position is a standardised and reproducible position of the head in an upright posture, the eyes focused on a point in the distance at eye level, implying that the visual axis is horizontal. Natural head posture is subject to individual variations.[67] Forward head posture implies that the head is in an anterior position in relation to the theoretical plumbline.[60,61,62,68] Postural changes associated with forward head posture are a forward glide of the lower cervical vertebrae with the upper cervical complex extended, alteration of the upper thoracic kyphosis, protraction and elevation with rotation of the scapulae and elevation of the first and second ribs.[68,69,70]

Cervical inclination has also been determined by means of a lateral photograph.[71] The forward position of the head relative to the cervico-thoracic spine was determined by the position of the second cervical vertebra relative to the seventh cervical vertebra. An angle was calculated by means of a horizontal line through the seventh vertebra intersected by a line drawn between the second and seventh vertebrae.[71]

- **Hump size:**

Hump size is the most powerful predictor of scoliosis, and together with the angle of thoracic inclination, is useful for the screening of scoliosis.[7,72] Hump size is determined by means of the Adam forward bending test.[2,7,9,31,55,72] Symmetry of the ribs are assessed from anterior and posterior. Even minor deformities can be detected by this technique.[9] To quantify the transverse plane asymmetry, the height of the rotational prominence can be measured by means of a ruler and spirit level.[31,49,55,72] During screening, patients are referred for radiographs in cases where the hump size is six millimetres or more.[7,55] In a cohort study by Nissinnen *et al* (1993)[7], boys with a hump of six millimetres had a five-fold risk of developing scoliosis.

Accurate measurement of the vertebral rotation is important in scoliosis assessment.[72] The rotational prominence, or angle of trunk rotation, is measured by means of a scoliometer or inclinometer.[2,31,49,55,72] The thoracic hump measured at the curve apex using the scoliometer, correlates with the Cobb angle and apical vertebral rotation in thoracic scoliosis.[49,55,72] A hump size of six millimetres has been found to correlate with a Cobb angle of 10 degrees.[49] Some researchers consider five degrees of trunk rotation as an indication for referral for treatment,[31] while others consider an angle of trunk rotation of seven degrees or more to be associated with scoliosis, and this should prompt the physician to obtain radiographs of the spine.[2]

Symmetrical spines are seldom found (22 %).[55] Right sided thoracic humps and left sided lumbar humps are seen most frequently.[33,55] Girls are more inclined have a hump size of more than six millimetres.[33,49]

A kyphotic deformity and its region within the spine, can be evaluated by viewing the patient laterally during the forward bending test.[2]

- **Radiographs:**

Radiographs should include standing antero-posterior and lateral views of the spine from the occiput to the sacrum. The pelvis must be visualised so that skeletal maturity can be assessed.[2] Supine, right and left lateral bending films show curve flexibility and are important in the planning of surgery. The flexibility of the kyphotic curve is revealed by means of a lateral view with a hyperextended back.[2] Rotation of the vertebrae is seen by viewing the pedicles on an antero-posterior radiograph. In a normal spine no rotation should be present and the pedicles should be on the lateral border of the vertebrae.[2,72]

The measurement of Cobb angles on radiographs is the most effective way of determining the angle of deformity.[9,31,72] Radiographs are two dimensional and cannot reveal the true three-dimensional nature of scoliotic curves.[30,72] However, the Cobb angle can be affected by variations of the patient's position relative to the radiographic equipment.[72]

The vertebrae are defined on radiographs. Neutral vertebrae are those vertebrae which have no rotation. End vertebrae are those which are most inclined in relation to the horizontal in a standing position, while an intermediate vertebra is an end vertebra which is common to two adjacent curves.[32]

During the measurement of Cobb angles some researchers show an inter-observer agreement in the measurements of Cobb angles and skeletal maturity.[73] These researchers did not differ in determining the upper and lower end vertebrae, but they were, however, all associated with the same scoliotic clinic.[73]

In smaller curves the variability in the assessment was larger.[73] Other researchers found variability in selection of the end vertebrae, and this could result in inter-observer error and unreliability in the measurement of scoliotic curves, as well as in the measurement of the sagittal contours.[74,75] During the measurements of the sagittal contours, some investigators used the superior endplate of the fifth thoracic[47,76], or the fourth thoracic[77] or third[78] thoracic vertebrae as the upper line and the inferior endplate of the twelfth thoracic vertebra as the lower line of the Cobb angle. Other researchers used the superior endplate of the first thoracic vertebra to the inferior endplate of the twelfth thoracic vertebra for the measurements of the Cobb angles.[38] The vertebral endplates above the fifth thoracic vertebra are difficult to see on the radiographs due to the scapula that is superimposed on a lateral radiograph. Lateral radiographs are therefore considered to be unreliable for the level above the fifth vertebra.[47,76] The lumbar sagittal contour is measured from the superior endplate of the first lumbar segment,[76,79] (or other vertebrae that can be considered as an intermediate vertebra[76]), to the superior endplate of the first sacral vertebra[38,77,79] (or inferior endplate of the fifth lumbar vertebra[76]).

Tangential radiographic assessment of the lumbar lordosis showed less variability than the traditional Cobb method.[79,80] The fact that some vertebrae in the lumbar area are wedge shaped could also affect the reliability of the Cobb angles.[80] The Cobb method shows changes between the end vertebrae and does not represent the actual arc.[79]

The position of the arms during standing radiographs also varies. The arms are usually stretched out in front of the chest to 90 degrees.[76] This position can increase the thoracic kyphosis,[32] while other radiologists[77] feel that the hands should rest on a horizontal support in front of the pelvis.[77] Radiographs are impractical in the assessment of posture during the research of large samples, and are also considered a health risk.[65] Therefore the use of non-invasive instruments offers safer and more practical methods of assessing spinal curves.

- **Non-invasive instruments:** Non-invasive methods of measurement of spinal mobility include the use of a tape measure, standard goniometer, inclinometers and other special instruments (kyphometer[81], arcometer[82]).[7] The reproducibility of measurements by means of inclinometers have proven to be acceptable and indicative of spinal posture in the sagittal plane when compared to radiographic measurements.[75] Other researchers claim that apparent abnormalities in surface posture do not necessarily indicate that the underlying vertebral alignment is also abnormal.[16] A variety of inclinometers are available.[75]

As with the radiographs, a variety of spinal levels are used to measure the curves with instruments. Measurements with the Myrin inclinometer were done from the levels of the posterior superior iliac spines on the sacral level to the first lumbar spinous process for lumbar lordosis, and from the first lumbar spinous process to the first thoracic spinous process for kyphosis.[75] Measurements with the kyphometer for a kyphosis were done from the interspinous space of the second and third thoracic vertebrae to the interspinous space of the eleventh and twelfth thoracic vertebrae. The lordosis was measured from the eleventh and twelfth interspinous space to a point between the first and second sacral segments.[81] D'Osualdo (1997)[82] used any two spinous processes between the first and the twelfth thoracic vertebrae, which included the more evident kyphotic area, during measurements with an arcometer external method.

The precision of measurements using a kyphometer was found to be good.[81] D'Osualdo (1997)[82] showed a correlation between the measurements with an arcometer and radiographs during clinical measurements. Posture and curve variability may influence the measurements. In the arcometer measurements, the patients were standing with their arms stretched out forwards, while the arms were hanging next to their sides during other non-invasive methods.[56,65,83]

Spinal pantography is a method of evaluating the true sagittal curve by means of a low friction wheel which follows the contour line of the spinous processes, reflecting it onto a drawing board.[84] A photographic method with surface markings can also quantify the visible shape of a spinal curve and accurately measure the magnitude of the curve by means of a mathematical method.[65] These researchers compared their measurements to surface contours on the radiographs. Their measurements correlated reasonably well to radiographic measurements of the vertebral column. However, these researchers concluded that inclinometers, goniometers and flexible rulers quantify the relationship between the two end vertebrae but do not take the shape of the curve into consideration.[65] The use of a double inclinometer was found to be a valid method of evaluating spinal movement when compared to radiographs.[84] This study was only conducted on the spinal movements and not on static standing postures.

In two different studies, measurements by means of electro-magnetic devices were found to be accurate and reliable, when compared to previously validated and reliable methods using a double inclinometer. Radiographs were not used due to the fact that multiple films would have been needed, exposing the patients to too much radiation.[84,86,87,] Measurements by means of the Saunders Electronic Inclinometer are considered reliable if they are consistent, that is if they fall within approximately 10 % or five degrees of each other.[83] Measurements for standing posture have been tested by means of measurements at the interspinous spaces of the specific spinal junctions. This instrument is the most recent development in inclinometers.[83]

During the determination of reliability of the above mentioned non-invasive studies, the standing posture of the subjects was mostly with the arms next to the sides, but the gold standard for radiographs is standing with the arms in front of the chest in 90 degrees of shoulder flexion, which could possibly influence the sagittal curve. This could account for some of the non-invasive measurements that did not correlate with the radiographs.

The lack of a universal reliable non-invasive evaluation method, and the dangers and high cost of radiographs, make it difficult to determine the angles of curves accurately.

- **Normal values of spinal curves:**

Due to variations in the methods of selection of end vertebrae, measurement and technique differences, it is difficult to determine the normal values of curves.

Guidelines established by the Scoliosis Research Society determine that the normal range for a thoracic kyphosis using the Cobb method is 20 - 40 degrees, but should not exceed 45 degrees.[47] The normal value for a thoracic kyphosis is 20 - 45 degrees,[2,47,78,88] and for a normal lordosis 25 - 60 degrees[2] or 20 -60 degrees.[78] The latter was measured from the top of the first lumbar vertebra to the bottom of the fifth lumbar vertebra.[78] There is no significant difference between the kyphotic curve of boys compared to girls.[64,78]Others consider less than 20 degrees as a hypokyphotic curve and more than 40 degrees as a hyperkyphotic curve.[38] When using the landmarks of the fifth thoracic vertebra to the twelfth thoracic vertebra as a screening method, a measurement of more than 33 degrees can be considered a pathological kyphosis.[47] The mean for the lordotic curve for adults, measured from the first lumbar vertebra to the first sacral segment, varies from 72 degrees to 56 degrees, according to Stagnara (1988).[32]

The spinal curve changes with growth. The normal lumbar lordosis average measurement at the age of one year is approximately 40 degrees. By the end of puberty it is 50 degrees.[80] The least pronounced kyphosis in both genders is at the age of 10 -12 years, due to the fact that the growth rate is at its slowest.[64] The mean kyphosis measurement at the age of 10 - 14 years is 37,5 degrees, and at the age of 15 - 20 years is 38,5 degrees, while the mean lordosis at the age of 10 - 14 years is 56,1 degrees, and at the age of 15 - 20 years is 56,6 degrees.[78]

SUMMARY: It is evident that there are variations in the gold standards of evaluation methods for spinal deformities. Non-invasive methods are not as accurate as radiographs, but even the radiographs show variability. Non-invasive methods are sufficient to screen for spinal deformities.

2.2.4. TREATMENT OF SPINAL DEFORMITIES

The aim of treatment is to obtain a balanced and stable spine at skeletal maturity[84], but are spinal deformities currently being treated effectively ?

2.2.4.1. CONSERVATIVE TREATMENT

OBSERVATION: The key to successful treatment is early detection.[2] Certain factors, such as the patient's age, gender, presence of secondary sexual characteristics and the angle of the curve, should all be taken into consideration in planning the treatment of any spinal deformity.[12] The initial approach is always observation.[15,30] Non-progressive curves require no specific treatment apart from regular follow-ups.[9] The mainstay for the treatment of spinal deformities in the paediatric population is non - operative.[2] School screening, or non - invasive screening, is an important way of early detection of spinal deformities.[2,30] Various approaches to treatment are seen in different parts of the world.[1] In the United States 0,5 % of patients were treated for scoliosis, while in Scotland 30 % of patients were treated.[1]

Patients in early and late adolescence are considered differently, taking the maturity of the skeleton into consideration.[12] Skeletally immature patients with idiopathic scoliosis with a curvature of 10 - 20 degrees, merely need to be observed at four to six monthly intervals.[2,12,15] This is done until vertebral maturity is reached and the deformity shows no progression.[12,15] In the case of a non-progressive scoliotic curve of 20 - 29 degrees, no treatment is needed yet, but if this patient shows a five degree progression, a brace would be indicated.[2,12,89] Other researchers feel that a five degree increase in angulation would not need treatment, but if the progression persisted, intervention would be required to prevent severe curvature.[15] Patients with more significant curvatures and those entering the rapid growth phase of development, should be seen every three to four months for observation and radiographs.[2,15] Patients, with a scoliotic curvature greater than 20 degrees, need to be followed up for two to four years after skeletal maturity, to assess possible progression in adulthood.[15] An increase in the curve occurred in 70 % of patients who were initially only under observation.[9] As soon as a patient's curvature exceeds 30 degrees, conservative treatment such as bracing, exercises and postural retraining is introduced.[89] Results by means of conservative treatment are better in cases of patients with a Cobb angle of less than 30 degrees.[89] Opinion with regard to conservative treatment varies: some feel that it cannot stop curve progression, but that it can slow it.[89]

The treatment of kyphosis varies with the cause of the deformity. A postural round back or a flexible kyphosis is treated by means of reassurance, observation, and extension exercises. In the case of Scheuermann's kyphosis, the treatment is different and bracing is used more often.[2,10] Reports on long-term results of patients treated for Scheuermann's kyphosis, are rare.[88]

BRACING : Orthoses are the most common method of conservative treatment in scoliotic and kyphotic curvatures, despite the fact that their value is disputed.[2,9,15] They are used for progressive curves in the growing child, where the deformity is flexible and therefore correctable.[9,15] Some consider bracing the only non-operative modality that can control the progression of the scoliotic and kyphotic curves.[15,90] Orthotic devices are better at halting curvature progression than at reversing the deformity.[2,12,15,30] Bracing fails to prevent curve progression in less than 40 % of scoliotic patients.[5] The rib prominence, as a result of the vertebral rotation in scoliosis, is not decreased by bracing.[2] High scoliotic curves above the mid thoracic area are difficult to control in a brace.[9,15]

Although good results are seen with bracing, non-compliance remains a serious problem.[9,15] Bracing of adolescents can have a psychological impact because of concerns about appearance.[2,9] This is despite the fact that many new braces have been developed to improve the aesthetic aspect.[15] It has also been found that only 36 % of boys wear their braces.[15]

It is thought that bracing can affect the chest and abdominal mobility and thus cause respiratory dysfunction, but Refsum *et al* (1990)[91] found no evidence to indicate that a brace worn for six months can be associated with deterioration of pulmonary functions in adolescent girls with idiopathic scolioses.

There is also no specific answer regarding the timing and efficacy of bracing.[15] Bracing worn for 22 hours per day can prevent the progression of a deformity.[12] A 16 hour period of bracing is also suggested.[15] Braces should be worn until skeletal maturity is reached.[12,15] The weaning of boys at skeletal maturity should be delayed due to the fact that their curves increase more frequently than those of girls after discontinuation of bracing.[15] Exercises are indicated for the period when the brace is removed.[12,15,90] Contractures of soft-tissue around the spine progress during the period of bracing because of the immobilisation.[36] The final removal of the braces results in small losses of the correction in scoliotic curves, especially in the thoraco-lumbar and lumbar regions, and this may also become more severe in late adolescence.[12,15] Night time bending braces, where the patients are held in a markedly reversed position to the curvature, show 83 % of satisfactory control of the scoliotic curvature.[15] This is not yet proven in double major curves.[15]

If a skeletally immature patient presents with a scoliotic curvature of 30 degrees or more, bracing is indicated.[2,12,15,30] Other researchers commence bracing as soon as the scoliotic curve exceeds 20 degrees.[90] In young patients with persistent progression, intervention by means of bracing is needed to prevent severe scoliotic curvatures.[15] In unusual situations, where a young child with a significant genetic history presents with a scoliotic curvature of less than 20 degrees, in cases of boys with a progressive curve exceeding 25 degrees including those who have reached skeletal maturity, bracing will be considered for the patient.[15] Regular follow-up clinical evaluations every three to four months are needed to evaluate the efficacy of the braces.[15] Braces are contra-indicated when the scoliotic curve is greater than 45 degrees, when they are not tolerated by the patient, and at skeletal maturity.[8,12] Other researchers consider bracing to be ineffective in controlling a scoliotic curve of more than 50 degrees.[15] In cases where the patient presents with a flexible, well balanced spine and a scoliotic curve of 40 to 50 degrees, bracing is still considered.[15] If significant hypokyphosis is present, orthosis may increase the hypokyphosis and then aggravate the scoliotic deformity.[15,31] When patients have not benefited from an orthosis, surgery is necessary,[12] and this occurs in 10 % of patients treated in braces.[15]

Results with bracing for kyphosis are excellent, except when a rigid structural deformity is present before treatment commences.[10,15,16] Kyphosis of more than 50 degrees can be treated successfully with a brace with a 40 % improvement.[15] Unsuccessful treatment (failure to reduce the kyphosis to less than 45 degrees) is more likely in patients where wedging is more than 10 degrees in more than one vertebra, where the initial kyphosis is more than 65 degrees (74 degrees according to other researchers[88]), and where initial treatment was started after the iliac epiphyses had closed.[15] Since the apical vertebra in a typical case of Scheuermann's disease is the eighth thoracic vertebra, it is understandable why an underarm orthosis has minimal effect while the higher braces (cervico-thoraco-lumbo-sacral-orthoses) have better results.[10] The brace should be worn until growth stops and then the child is gradually weaned from it.[10] Excellent results can be expected, provided the diagnosis is made promptly, the brace fits well and is worn faithfully, and treatment is continued for an adequate length of time.[10,45] To maintain correction in Scheuermann's kyphosis, braces are worn until vertebral wedging decreases to five degrees.[15] Although good initial results are obtained with braces in kyphosis, a five year follow-up study showed a significant loss of correction after the bracing was discontinued.[88]

PHYSIOTHERAPY: Bentley *et al* (1994)[12] refers to previous research where it is stated that physiotherapy is ineffective to prevent progression of the scoliotic curve. Unfortunately the research articles that are referred to are old (1967 an 1979) and no mention is made of the method of research. Emphasis is on physical activity and spinal exercises to maintain flexibility of the spine.[9,12,13]

Solberg (1996)[92] suggests that the treatment rationale for idiopathic scoliosis should include appropriate mobilisation therapy, as well as improving imbalances between agonistic and antagonistic muscle groups associated with the spine and releasing the muscle contractures on the concave side of the spine.[92] The lateral deviation of the spine may also reduce the ability of the intervertebral discs to distribute weight effectively and a decrease in disc height may occur. This could result in abnormal weight bearing by the facet joints and an alteration of the facet joint alignment. Therefore, one of the aims of treatment would be to encourage awareness of the use of the spine in everyday life, and to teach the application of mechanical principles of kinetic handling in activities of daily life.[92] Individual supervision of an exercise programme for idiopathic scoliosis is recommended.[92] Unfortunately, details of the exercise programme were not included. Only ten subjects were used, and although the researcher reports a significant improvement, no mention was made of the p value. No mention was made of the sampling method or the use of a blind researcher for the measurements of improvement. This study was done on black school children in South Africa and is difficult to compare to other international studies due to the differences in ethnic background as well the lack of detail with regard to the trial.

According to Weiss (1992)[41] the treatment of choice for idiopathic scoliosis in the United Kingdom is surgical correction, but in Germany physiotherapy is included in the treatment schedule. Exercise therapy is generally the sole treatment for patients with a Cobb angle of up to 20 degrees.[41,93] If the angle increases, exercises are combined with an orthosis. Katharina Schroth, a physiotherapist from Germany who had a scoliosis, conceived a three-dimensional approach to the treatment of scolioses; initially to correct her own appearance, but also to apply the programme to patients later on. Currently it is the method of treatment for all patients at the Katharina Schroth Deformity Centre in Germany.[14,41,93] Research done by Weiss (1992)[41] showed that this exercise programme has improved the curvature, pain, vital capacity and poor posture.[41,93] A retrospective study of 118 patients, making use of a sample of convenience, showed an improvement of 5 degrees or more in 43% of the patients. The researcher mentioned that significant results may have been observed if a randomised, controlled clinical trial were carried out with a control group who received no physiotherapy. The three-dimensional method is based on sensori-motor and kinaesthetic principles.[41] The principle of treatment is to develop a new awareness of body image for an imbalanced posture as well as for a balanced posture, trying to develop an opposite appearance to what the scoliotic body shows.[14]

Weiss[93] hypothesises that these systematic exercises can reduce the extent of the scoliotic posture and thus have a corrective effect on spinal growth. According to a retrospective study, retrieving data from the records at the Katharina Schroth Centre multiple joint dysfunction which develops due to unilateral trunk tensioning, causes pain and can be reduced by means of the Schroth method of exercising.[14] Approximately 1200 patients attend the Katherina Schroth Centre a year. Total pain relief in 85 % of the patients was observed.[14] The vital capacity increased was also improved by the exercise programme that was followed at Schroth Centre.[14] A study done on 813 patients showed a significant improvement, in patients younger than 24 years, of the vital capacity and chest expansion with the help of the Schroth rotational breathing exercises. The torsion of the trunk could be reduced by means of rib movements.[14,41,93] Rotational breathing leads to a significant increase in rib mobility and thus vital capacity; sagittal respiratory excursion is also improved and this may be of great importance in improving a flat back.[14,42] During rotational breathing exercises, the patient learns to direct the air consciously to the concave side of the thorax and deliberately tenses the muscles on the convex regions.[42] Unfortunately no control group was used in this study.

The laws (according to which Schroth worked) for the treatment of scoliotic curves are to assume a asymmetric starting position for exercises which could lead to reflex activation of the correcting portions of the postural muscles.[93] It is hypothesised that active side-shift of the trunk, away from the convexity of the curve, may provide an active correction of the curve by using the shift of the centre of gravity of the body.[30,36] This movement may improve the dynamic equilibrium which is essential for a well balanced posture during locomotion.[36] It was found that the greater the curve, the more difficult it is to correct by means of the side-shift or asymmetrical posture.[36] A new movement pattern, aimed at achieving postural normality and mental re-education by means of conscious repetitive de-rotation exercises and muscle training, will later be carried out automatically and adapted into activities of daily life.[14] Active stabilisation is necessary to develop a good body shape, and to avoid passive support by the spinal ligaments only.[14] This is achieved by isometric exercises in the corrected posture.[14] Each scoliotic person has to continue exercising throughout life. During the first period of treatment with the Schroth exercise programme the patients have to exercise for six to eight hours per day.[41,42] Patients are educated in doing home exercises and are monitored at regular intervals.[41] Passive corrections by means of cushions, achieved in a relaxed position are also used to assist in the proprioceptive re-education.[93] Braces help to support the obtained corrections. [14,41] These are evidence based outcomes.

According to the research done by Weiss (1992),[41] curves of less than 19 degrees tended to progress less than curves of 20 - 29 degrees and those of more than 30 degrees when treated by means of the Schroth method. The curves of 20 to 29 degrees progressed most when treated only with exercises.[41] Subjects were not randomly selected and there was no control. The researcher stated that it is unethical to withhold physiotherapy from scoliosis patients in Germany.[41]

Some researchers feel that early physical therapy could prevent severe progression and avoid surgery[89], while others show that the mean curve improvement between patients who followed an exercise programme, and those who did not exercise, is non significant.[90] These exercises were mainly pelvic tilt exercises in different positions, back extension and trunk lateral shift exercises.[90] Weiss (1992)[93] hypothesises that an exercise programme should be implemented to filter out patients who may benefit from rehabilitation programmes, before surgery is attempted.

In pre-adolescent children with kyphosis, exercises may be sufficient to correct the deformity.[15] Other researchers state that exercises alone cannot improve the curve.[45] Back extensor muscle strength is important in the maintenance of good posture.[94] Sinaki *et al* (1996)[94] significantly proved in a study done on 65 volunteers that an increased strength of back extensors seems to decrease the thoracic kyphosis, but it could increase the lumbar lordosis. If the exercises commonly used for improving back extensor strength are not used in combination with exercises for decreasing lumbar lordosis, the increased lumbar lordosis will decrease the efficacy of extension exercises.[94] Unfortunately this was not a randomised controlled trial.

2.2.4.2. SURGERY:

Surgery for idiopathic scoliosis is indicated when conservative treatment, to control the curve progression in a growing child or in an adolescent with marked cosmetic deformity and trunk asymmetry, is unsuccessful. Surgery is also advocated if a curve, greater than 50 degrees before skeletal maturity, is present.[9,30] Other researchers consider surgery when a 40 degrees curvature is reached in skeletally immature patients,[2,15] and when a curvature of 50 degrees is reached in a skeletally mature patient.[2] A scoliotic deformity associated with pain is also considered for surgery.[30] The aim of surgery is to correct the deformity as much as possible, to stabilise the spine and to achieve alignment of the shoulders, upper trunk and pelvis.[9] Complete correction of an asymmetric deformity, notably the ribs, is very difficult.[9] The presence of severe thoracic lordosis prevents the use of braces and these patients are also treated surgically, regardless of the angular value of the scoliosis.[12] Mullaji *et al* (1994)[94] observed that a mean progression of 4 degrees of the Cobb angle (of the scoliotic curve) occurred after a successful posterior fusion, but there is little change in the kyphosis. This showed that there was a significant anterior vertebral growth in 30 skeletally immature patients, but the progression was not severe enough to warrant combined anterior and posterior fusions.[95] No randomised controlled trial was done and no mention was made of any blind researcher that was used to do the Cobb measurements.

Surgery is not needed in cases of flexible Scheuermann's disease, but it is indicated in late adolescence and young adults who have both pain and a significant deformity.[10] About 5 % of patients with Scheuermann's disease, who receive conservative treatment after observation, will require surgical correction and stabilisation. Surgery is done in cases where the curve exceeds 75 degrees in adolescents.[45]

SUMMARY: No evidence of a significant improvement with any of the conservative methods of treatment of a spinal deformity was found. In idiopathic scoliosis, increase of the curve is prevented by means of conservative treatment, but the curve is not reversed. Surgery is the last resort in cases of severe deformities, as it affects the quality of life negatively due to the rigidity of the spine after surgery.

2.3. POSTURE

What are the factors that influence normal posture and how does posture affect the spinal column?

Posture is the position or attitude of the body and the relative arrangement of body parts for specific activities.[96] The erect posture places a considerable strain on the structures of the vertebral column. The central nervous system maintains the postural equilibrium by means of a complex system of reflexes and muscular controls.[97] Postural tone depends largely on the stretch reflex in the extensor muscles of the trunk. The stretch reflex acts so that any external factor which brings the body out of equilibrium, will stretch the appropriate extensor muscles and their spindles, inducing a contraction in the stretched muscles and thus restoring the body to its position of equilibrium.[98] The integration of the sub-systems of the neuromusclo-skeletal system is important for the stability and the normal functioning of the lumbar spine. This involves stability under static and dynamic conditions.[99,100] Dynamic stability requires muscular tension and co-ordination. A balance between agonistic and antagonistic muscle groups must exist and normal proprioception is essential for this muscular co-ordination.[23,99] As muscular fatigue occurs, there is a decrease in control of primary movement (movement in the sagittal plane), leading to altered spinal kinematics and resulting in dysfunction.[99] Muscles of the trunk are active whether an individual is sitting, standing, lifting or rolling.[101] The infant must be able to maintain a static upright posture and compensate for sway associated with walking.[102] A good posture consumes minimal energy and does not stress joints, musculature or connective tissue. A poor posture may very easily progress to a postural disorder such as kyphosis, lordosis or scoliosis.[14]

2.3.1. THE DEVELOPMENT OF POSTURE

The vertebral column of the new-born has primary thoracic and sacral curves which are concave to anterior. At about three months of age, the baby begins to hold its head up and, in association with this, a secondary curve appears in the cervical area which is convex to anterior.[97] Postural responses develop in a cephalo-caudal direction, with the neck muscle responses appearing first (four months), followed by trunk muscle responses (five to eight months) and leg muscle responses (ten to fourteen months), coinciding with the developmental stages of voluntary control.[102,103] Postural control matures at an age of between seven to ten years.[13,104]

As babies begin to sit they adopt a total kyphotic posture which is a normal phase of spinal development.[32] As the ability to sit improves, the cervical and lumbar lordotic curves appear and these curves are controlled by the postural muscles of the vertebral column. These secondary curves may fail to develop at the expected time should there be any delay in the development of the postures of sitting and holding the head up.[97] During the creeping stage, the centre of gravity is supported in a very stable manner by this quadrupedal posture, but as soon as the infant rears him/herself, an unstable stance due to the higher centre of gravity occurs.[97] Many children from the age of one to five years go through a temporary period where they stand with a marked lordosis. This should cause no concern unless the lordosis persists or worsens, especially towards the pubertal growth spurt; however, this lordosis usually resolves itself.[32,97] Numerous children adopt a "bad" posture when sitting, usually a complete kyphosis. Some children adopt a lumbar lordosis during standing, others a thoracic kyphosis and some a combination.[32] If poor posture persists or deteriorates and becomes less reducible, it becomes necessary to do special tests to identify the possible start of a structural kyphosis or lordosis.[32]

A most important factor in posture is the tilt of the pelvis in relation to the horizontal. The pelvic tilt is determined by the postural pull of the muscles of the back, abdomen, and thighs, and these forces are in turn influenced by the way the individual habitually stands. An over exaggerated upright posture will increase the anterior tilt of the pelvis, carrying the lumbar spine forwards and with it, the centre of gravity.[97] If this posture is routinely held, the muscles which have pulled the pelvis out of position, may shorten and their antagonists lengthen. Theoretically in the case of a slack posture the pelvic tilt will decrease and the centre of gravity will pass backwards, increasing the thoracic kyphosis and causing neck extension with a poking chin.[97]

All muscles contribute to postural control, but the deep muscles with attachments to the vertebrae appear to have a specific role for joint support.[105] The trunk extensor and the muscles of the abdominal wall muscles control trunk stability.[93,106,107,108]

2.3.2. POSTURAL CONTROL

Postural control involves adjustments by means of voluntary movements to control the body in cases of equilibrium disturbances.[109,110] Afferent inputs trigger a specific muscle activation pattern. This pattern is modulated by somato-sensory, visual and vestibular input.[102,109] Training or motor learning can accelerate postural control.[19,104,109] The position of the trunk, specifically the lumbar spine, plays an important role in the central nervous system's control of posture.[19] A stable posture is essential before the onset of locomotion.[102]

The upright posture requires an elaborate extensor musculature to support the body against the forces of gravity. The vertebral column is exposed to new patterns of force by means of different weight distributions and muscle tension. A narrower base needs an intricate system of balance reactions, and the trunk is the foundation for such a mechanism.[106]

The spinal stabilizing system consists of three sub-systems: the passive musculoskeletal sub-system (vertebrae, facet articulations, intervertebral discs, spinal ligaments and joint capsules), the active musculoskeletal sub-system (muscles and tendons surrounding the spinal column) and the neural and feedback sub-system.[110] Dysfunction of the spinal stabilizing system occurs when there is malfunctioning in any of these sub-systems.[110]

Motions of the head, relative to the trunk, are primarily directed towards orientating and stabilizing the position of the eyes and head in space.[111] Tilting of the head and body would elicit the vestibular reflex and activate proprioceptors in the neck muscles to bring the head toward an upright position.[111] The activation of muscle patterns for motor control of the head is dependent on previous experience of the head-neck motor system.[111] Vision plays a more important role in novel situations of postural control, such as learning to stand, while vestibular inputs serve a referential function and are critical in resolving conflict between somatosensory and visual inputs.[19,103,104] Removal of the visual cues could, however, increase the sensitivity of the proprioceptive and vestibular cues.[104]

2.3.3. POSTURAL DYSFUNTION

Panjabi (1992)[96] hypothesises that postural fault takes place when there is a deviation from the normal alignment but no structural changes have taken place. Postural dysfunction refers to an adaptive shortening of involved soft tissues and muscles.[96] The postural theory according to Soderberg (1986)[51] notes that the spinal column is a matter of balance between the antero-posterior curvatures of various areas of the spine. The greater the lordosis, the greater the thoracic kyphosis and even the cervical lordosis, in order to balance the vertebrae. In a lordotic posture there is tightness of the hip flexor and lumbar extensor muscles, whilst a flat low back posture has tight trunk flexor and hip extensor muscles, and elongated and weakened lumbar extensors and hip flexors. According to this theory the postural round back or increased kyphosis has a tight anterior thorax and stretched or weak thoracic erector spinae and scapula retractor muscles. The development of a scoliosis shows a tendency towards tightness on the concave side, and a stretched and weak convex side.[96]

The psoas muscle, extending from the upper lumbar spine to an insertion on the lesser trochanter of the femur, has a complex function due to multiple segmental attachments. The muscle is draped over the anterior rim of the pelvis, providing a mechanism to alter the position of the pelvis. Upward and downward tilting of the anterior rim of the pelvis is directly related to the degree of flexion and extension in the lumbar spine. Thus tightness of the psoas muscle pulls the anterior rim of the pelvis inferior, causing a downward or anterior tilt. The sacrum is now inclined further forward and the fifth lumbar vertebra is more anterior, thus increasing the lumbar lordosis.[51] The sensory input received from the position of the trunk, specifically the lumbar spine, together with other sensory and proprioceptive motor systems, is important for the central nervous system during the control of posture.[51] No explanation as to how these biomechanical and neural statements were arrived at was given.

Herman *et al* (1985)[19] postulated that due to the organisational pattern of the descending motor pathways controlling the symmetrical actions of the musculature, it is conceivable that functional changes in vertebral alignment will be created. This is possible due to altered positive feedback of somato-sensory information to the brainstem or cortical structures, and/or by modified perceptual analysis of sensory data during the interpretation of erect vertebral alignment. Defective proprioceptive inputs from the joints, ligaments and tendons, to the neural mechanism, has been implicated as a possible aetiological factor of idiopathic scoliosis.[20,21,23] Other researchers[112] postulated that the neurotransmitters or neurohormonal systems in the pineal body, are major contributing factors for the balanced and symmetrical development of proprioception and paraspinal muscles. The unbalanced proprioception between left and right sides will lead to inappropriate and asymmetrical contraction of multifidus. This asymmetry will eventually cause the spinous processes to rotate towards the unaffected side.[112] Altered perception of proprioceptive signals from the axial motor system is a likely feature of idiopathic scoliosis and may contribute to postural instability during dynamic activities.[19] Visual and vestibular information also converge upon the brainstem and cortical structures, causing impaired integration and disturbance in the orientation of the vertebral spine and in postural stability.[19] Researchers[20] determined that idiopathic scoliosis may therefore represent a specific impairment of the higher cortical functions. This study was conducted on 26 female patients with idiopathic scoliosis and showed that there was a statistical positive correlation between brainstem function and curve progression.[20] The trial was not randomised and there was no control group. Yekutiel *et al* (1981)[21] also suggest that the muscle spindle system may be at fault in adolescent idiopathic scoliosis, and support the hypothesis that equilibrium reactions may be abnormal.

SUMMARY: There are a variety of factors which influence normal posture. The central nervous system and the musculature work together to obtain postural stability. Postural control and normal spinal curvature develop, and voluntary control matures during normal developmental milestones of a baby and child. Malfunction of the postural control system can lead to the development of spinal deformities.

2.4. NEUROMOTOR DEVELOPMENT

Normal new-born babies have considerable sensory capabilities with which to experience the world. Primitive reflexes form the basis for future learned behaviour. The proper sequencing of motor events is required, so that primitive reflexes disappear before voluntary activities begin. At the age of four months, reflexes disappear and actions become more voluntary.[113]

The literature review of neuromotor developmental theories is limited to possible factors that may influence spinal deformities.

2.4.1. NORMAL DEVELOPMENTAL MILESTONES

What are the specific neuromotor developmental milestones which babies should achieve at certain ages?

Certain age ranges at which a specific skill is attained, have been indicated from studies of normal development. The later some skills appear, the shorter the interval between two subsequent developmental stages. Normal developmental skills are attained over a wide age range.[25] The passage through specific developmental phases seems to be a prerequisite for well organized psychomotor development, and its absence could lead to deficits.[24]

The spine is relatively straight in the new-born except for two flexion curves; a shallow thoracic curve with its apex located at the fourth to sixth thoracic levels and gently sloping to the seventh cervical vertebra, and a flexed sacro-coccygeal area. In the spine, extension as well as lateral and rotational ranges of motion are limited. Spinal mobility increases rapidly during the first six months of life. Limited hamstring length and hip capsule tightness are also present.[114]

2.4.1.1. SITTING

Head righting develops gradually from birth and is only fully complete by the end of the fifth month. Until then, when a baby is pulled up into the sitting position, the head remains unstable and lateral head control cannot develop.[114] Lateral flexion righting of the trunk can be elicited by five months.[114] By six months of age a baby has sufficient postural tone to maintain many postures against gravity.[114] A great variety of sitting postures can be observed as each baby is unique with regard to postural control, control of balance and preferred patterns of postural alignment. Some babies tend to keep their centre of gravity forwards over their hips, while others have a more flexed spine resulting in the centre of gravity to be displaced posteriorly behind the pelvis.[114]

Complex postural responses are necessary before a baby can sit indepedently.[109,115] Although a baby can sit independently by the age of six to nine months, total postural control in sitting continues to develop. In the normal development of postural adjustments during sitting, three phases can be distinguished. The first phase is the primary variability phase, which is characterised by a large variation in direction-specific postural responses, and cannot be adapted to task-specific conditions. This phase starts at a pre-sitting age and lasts until nine to ten months.[116] The posterior muscles for postural control mature earlier than the anterior muscles. This leads to a temporary solution for balance problems by using a fixed extensor synergy when starting to stand and walk.[115] The second or transient toddling phase is typified by the invariant use of complete direction-specific response patterns and a relative high level of antagonist activation. The focus of adaptation lies close to the support surface and affects the caudally located muscles most. This phase extends from nine to ten months until two and a half to three years. During the third or the secondary variability phase, variations in the direction-specific response patterns return. The postural adjustments are less energy-demanding and consist of variable activation of agonistic and antagonistic postural muscles. The focus of adaptation is now located in the neck muscles. This phase starts at two and a half to three years and continues into adulthood.[116]

At the age of six months babies sit without assistance, but are not yet independently mobile.[102,113] This is also the age at which babies reach across the midline.[113] This ability, to cross the midline, enables the infant to integrate the two symmetrical halves into a composite whole.[26]

Postural synergies active in controlling the sitting position, include the erector spinae, abdominals, hip extensors and sometimes the hip flexors. At the age of seven months babies can sit independently with their hands free to play. They can maintain a more erect trunk for longer periods, with a more stable pelvis and improved control of weight shift.[25,114] Although lumbar extension has developed in prone, the lumbar spine is not held in extension during sitting until much later, when the baby develops the ability to control the entire trunk in an upright position.[114]

2.4.1.2. CRAWLING

The quadruped position can be attempted by seven months. By eight months the baby develops sufficient shoulder girdle, trunk and pelvic control to rotate from sitting to quadruped. During the next few months postural control and co-ordination will improve. Some babies will crawl at nine months, but most are ready to crawl by ten to eleven months.[114]

During this stage there are five locomotor sequences that may develop. Eighty two percent of infants are crawlers. Other ways of locomotion observed by Robson (1984)[25] are shufflers (9 %), creepers (1 %), rollers (1 %), while 7 % of the infants stood up and walked without any other preceding form of locomotion.[25] Some infants have short lived hypotonia which prevents them from being standard crawlers, and they use other methods of locomotion. They also achieve their other milestones at a later stage than normal crawlers. This hypotonia usually resolves at an age of two to three years.[24,25,117]

Crawling on hands and knees is the major pre-standing locomotion activity, appearing after a short period of creeping or rolling.[25] There is a large variability of normality, and consequently the possibility exists that infants with motor strategies other than creeping and crawling, may also develop normally.[24]

Bottos et al[24] found that at an age of five years there was no asymmetry in motor activity of children who crawled as babies. Children who shuffled or just stood up and walked did show asymmetry in their motor activities. Hypotonia in the central trunk is related to the choice of locomotion before walking.

The process of crawling provides a state of eye-hand co-ordination, vestibular processing, improvement of balance and equilibrium, spatial awareness, tactile input and kinaesthetic awareness.[26]

2.4.1.3. WALKING

The most fundamental motor skill in humans is the maintenance of upright posture and bipedal locomotion. Humans do not acquire sufficient postural control to stand upright and walk until the last month of their first year.[102]

The child's ability to maintain an upright posture becomes more efficient and functional during the last trimester of the first year. The lumbar spine extends through a greater range and the normal curve of the spine is seen more consistently, providing mechanical and muscular stability for postural alignment.[114] Standing, while holding onto something stable, starts at nine months, but children demonstrate the ability to walk unsupported at about one year.[113,119]

The ten to twelve month old baby explores the surroundings in more upright positions.[114] Although some babies walk as early as nine months and others as late as seventeen months, most babies walk by the end of their first year.[114,119] Children who do not walk by eighteen months are usually evaluated for possible causes of developmental delays.[119] During the first year of life the centre of weight moves closer to the legs, and this increases the efficiency of locomotion. Strength of the limb and trunk muscles increase for support, and a balance between flexor and extensor muscle groups develops. Control of posture and balance are important factors in the process of learning to walk.[119] From three years onwards, once the child has mastered walking skills, the fixed extensor synergy is discarded, and postural adjustments affect anterior muscles more than posterior muscles.[115]

2.4.2. OTHER FACTORS THAT INFLUENCE DEVELOPMENT

Abnormal balance, the presence of a motor problem and abnormal minor neurological problems are more significant in low birthweight babies.[113,120] Boys are more frequently affected than girls.[120] Impaired balance may inhibit children's play activities and consequently their development.[120] Negative environmental influences such as poverty, abuse and neglect place infants at risk for developmental delays.[113]

2.4.2.1. LYING POSITIONS

An infant is born with mechanisms which provide some motor control in the early months. One of these mechanisms is an imbalance between flexor and extensor muscle tone, so that flexor tone dominates, contributing to an overall flexed posture of the new-born infant.[114] Voluntary kicking movements of infants in the supine position are associated with simultaneous activation of agonist and antagonist muscles.[119] The movements of a baby are related to its level of arousal, gestation age and position in which it is nursed. Babies are more active when in supine than in prone.[114,121] Babies who lie supine are rarely symmetrical, but slightly tilted to one side.[114,121] By the end of the fifth month movements in supine become more symmetrical.[114] Weggemann *et al* (1987)[121] found that babies moved their heads more frequently to a preferred side when in supine than in prone, and showed a tendency towards asymmetry and a possible risk of positional deformity. Posterior pelvic tilting and an increase in the length of the hamstrings were also observed by the fifth month as the baby began to reach for his/her feet[114].

Prone encourages symmetrical positioning. The low incidence of idiopathic infantile scoliosis in North America, and the higher incidence in Britain, has been attributed to the increased use of the prone sleeping position in North America.[121] Even in prone, asymmetrical extension is used to turn the head to one side in the early stages (one to two months). By the end of the second month the infant can lift the head symmetrically.[114] In prone the pelvis of the baby is lifted off the surface due to the flexed posture, causing the centre of gravity to be more cephalic.[114] The contour of the low back also changes from relatively flat at birth, to concave posterior by the end of the fifth month, with increased activity of the erector spinae and multifidus muscles in prone.[114]

Lying on the right or left sides is also likely to cause trunk asymmetry, but is the best position for open airways.[114,121]

Other researchers found that sleeping positions significantly influence the age of achieving the gross motor developmental milestone of rolling over. Infants who sleep in the side or supine position, roll over later than infants who sleep in the prone position.[122] At about four months the baby plays with his/her feet, but can lose control over the symmetry, causing him/her to roll over. Soon the baby will begin to use abdominal muscles, including the obliquus abdominus, to control some of the pelvic movements.[122]

2.4.2.2. FREEDOM TO MOVE

Over protective parental behaviour leads to limited freedom of movement granted to the child, with consequent conditioning of locomotor choices of the parent and limitation of locomotion experience of the child. The infants have to move according to the choice of the parent.[24] Bottos et al (1989)[24] feel that babies should be allowed to move freely on the ground during the first year of life, so that they may choose their own locomotor strategies.

2.4.2.3. DEVELOPMENTAL COORDINATION DISORDERS

The terms "clumsy" or developmental co-ordination disorder, are often used to indicate that a child's performance of daily activities which require basic motor co-ordination, is below the expected age and intelligence levels; but the child is otherwise normal. It is hypothesised that these motor-control difficulties may be related to subtle central nervous system dysfunction and not to developmental delays.[123,124] Previous findings suggest that the subtle central nervous system dysfunction most often manifests itself as an inability to organise and execute voluntary movements consistently. This motor-control deficit is frequently observed in tasks that require functional asymmetry, both gross motor as well as fine motor skills.[123,124,125]

SUMMARY: Although there is a wide age range in which to achieve certain developmental skills, it is important that these skills must develop before a certain age. The developmental skills or milestones have an influence on the development of a normal spine. Asymmetry in the development of skills may also influence the development of spinal deformities.

2.5. SUMMARY OF LITERATURE REVIEW

Idiopathic scoliosis and Scheuermann's kyphosis are both conditions which cause a structural deformity of the spine. Evidence of one specific aetiological factor could not be found in the literature. It is clear that idiopathic scoliosis and Scheuermann's kyphosis are multifactorial diseases. Growth, hereditary factors, gender and posture appear to be the most important aetiological factors.[1,2,5,7,8]

The central nervous system and the musculature work together to obtain postural stability.[18] Postural control, normal spinal curvature and voluntary movements occur during the normal developmental milestones of a baby and child. Although specific developmental skills can be attained within a wide age range it is important that these skills must develop before a certain age. Asymmetry in the development of motor skills could also influence the development of spinal deformities.[24]

Current treatment methods do not result in the correction of deformities, but reduce the progression of the deformities.

There are various gold standards for the evaluation of spinal deformities. Non-invasive methods are not as accurate as radiographs, but are effective for the screening of deformities. Boachie & Lonner (1996)[2] recommend a review of the birth history, developmental history and childhood illnesses. Although not researched, they suggest that abnormal developmental milestones may lead to spinal deformities. The above mentioned statement motivates the necessity for this study. In the following chapter the research methodology for this study will be described.

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