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THE EFFECTS OF PATIENT POSITIONING ON THE TOPOGRAPHY OF THE BACK; EXPERIMENTAL AND CLINICAL INVESTIGATIONS

by

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B.Sc. (Kinesiology) University of Waterloo,
Waterloo, Ontario, 1978

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ABSTRACT

The purpose of this study was to examine the variability in the shape of body surfaces resulting from three common patient postioning practices which are used in conjunction with Moire topography. Moire topographs were obtained by means of a Clinical Shape Monitor (CSM).

In Stage I of the study three normal subjects were randomly positioned ten times in each of three positions and Moire topographs were taken. Four premarked cross-sections on each Moire topograph were digitized using a semi-automated system. Digitized data were analyzed using a shape analysis program.

An assessment of the Clinical Shape Monitor, by the National Research Council, determined that its accuracy was within ±2.7 mm.

Analysis of the repositioning data using the normal-scores correlation test showed that twenty-eight of the forty-five data sets were normally distributed. Consequently it was not possible to compare the positioning methods on the basis of their average coefficients of variation because of unequal numbers of variables per position.

The coefficients of variation were ranked by positioning procedure, subject and variables measured. There was no one method of positioning which was clearly less variable than any other. Ranking by variables showed that the least variable parameter measured was arclength ratio.

In Stage II of the study one subject with a spinal deformity was repositioned ten times in each of the three positions. The normal-scores correlation test of the measurements for each position was done. Eleven of fifteen data sets were normally distributed. Each positioning procedure was rated by determining the coefficient of variation of the normally distributed variables. The least variable method of positioning was free standing (CVaverage/100 = 0.043, n = 4), while the next was inclined positioning (CVaverage/100 = 0.250, n = 3) and finally seated positioning (CVaverage/100 = 3.538, n = 4).

A clinical case study was conducted concurrently. A scoliotic patient was monitored using inclined positioning over a period of 1.42 years. Predictions of changes in the scoliotic curve were made using the five variables (lateral deviation, arclength ratio, hump height, rib hump index and hump angle) used in Stage I. Predictions of curve increases and decreases made from the above five variables did not correspond with any of the Cobb angle measurements from the radiographs.

Until the inherent variability of topographical measurements is reduced, it is not possible to assess whether skeletal changes are reflected in changes of topography which relate to the cosmetic aspect of the condition.

In conclusion, the greatest improvements in the reliability of clinical shape monitoring will result from the improvements in procedures for patient positioning.

ACKNOWLEDGEMENTS

The Medical Engineering Resource Unit and the Spinal Deformities Clinic of Children's Hospital deserve many thanks for the financial, physical and topical support which they gave to me while I worked towards my M.Sc. degree.

I am grateful to Dr. Tredwell, the Department of Orthopaedics and the patients of the Spinal Deformities Clinic of Children's Hospital for their ongoing cooperation, valuable input and the clinical education they gave me.

I would also like to thank the subject of my case study for her tremendous commitment of over a year to my project.

During the completion of the thesis the Department of Statistics and Mathematics of Simon Fraser University have been a valuable resource. Dr. M. Stephens and Dr. L. Weldon both spent many hours reviewing and advising on the project's data analysis questions.

In the absence of my senior supervisor the chairman of graduate studies in Kinesiology, Margaret Savage, stepped in to advise on the completion of the thesis.

The contributions of all of these individuals were felt and are reflected in the quality of the final version of my thesis presented in the following pages.

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INTRODUCTION

A desire to establish a standardized clinical procedure of photographing Shadow Moire Topographs has been expressed at both the First (1980) and the Second (1982) International Symposia on Moire Fringe Topography and Spinal Deformities. In these symposia it was claimed that Shadow Moire Topography is an inexpensive and accurate method of recording shape. However, the variability of recording the shape of human subjects remains in question. The procedures for patient positioning which are currently followed are based on the researchers' biases from experience and previous practices.

In order to determine the variability of positioning procedures, the investigator has examined three methods of positioning in a systematic, empirical manner. Conclusions based on data collected in different positions should be viewed critically. That is, significant variability of the back shape occurs from one method of positioning to another. Thus data collected using different positioning techniques should not be directly compared. As a result of this study recommendations for standardized procedures for the evaluation of spinal deformities have been made.

One of the objectives of this work was to establish a procedure by which to monitor the shape of the back of an individual who had been diagnosed and was undergoing treatment for idiopathic scoliosis. This procedure was formulated and used to monitor the Case Study patient.

OBJECTIVES

The overall objective of the project was to formulate a procedure for the assessment of the changes of surface shape due to increases or decreases of spinal curvature and/or rotation. Specifically, this research was aimed at:

1. quantification of the variability of three patient positioning procedures
2. specification of a procedure for assessing topographical shape changes of the back and
3. reporting of the observed changes of the back surface shape of a scoliotic patient who underwent a 1.42 year period of observation and treatment during the collection of data for this study.

REVIEW OF LITERATURE

In the treatment of scoliosis, the early detection of spinal curve progression is very important. Moe et al. (1978) make this observation. With early detection the treatment prognosis is good. Structural changes of the vertebral column are examined with the aid of radiographs. Currently, associated changes of shape of the body are noted by clinical observation aided with crude tools which have limited reliability.

Personal observation indicates that in order to examine internal structural changes, radiographs may remain an important technique. However, data or observation from radiographs are not clearly related to the external changes of the shape of structures which are attached to and affected by the changes of the shape of the spine.

Researchers began to study the use of the Shadow Moire Topographic technique for this purpose. The first conference to draw_these researchers together was held in Vermont in 1980. The topics of concern included instrumentation, school screening, Moire Contourography and quantitative measurements as well as contourography and the computer.

A brief review of scoliosis, Shadow Moire Topography, and the problems encountered with each follows. This will demonstrate the need for the information derived from this study.

Scoliosis

The vertebral column performs three main functions:

1. it supports the head and trunk and transmits their weight to the lower extremities through the pelvic arch
2. it protects the spinal cord
3. it allows considerable movements by the intervertebral joints and discs.

Essentially the spine comprises 24 stacked vertebrae. Large three-dimensional displacements and interconnections with numerous ligaments and muscles make the spine an extremely complex structure. Interactions with ribs, trunk and the extremities further complicate the mechanics of the spine. During growth and aging the components of the spine themselves change as well as their interaction with the other elements (Moe, Winter, Bradford, Lonstein, 1978).

Scoliosis is the lateral bending and associated axial rotation of the vertebral column (Dorland's Illustrated Medical Dictionary, 1981). The severity of the scoliosis can vary greatly. It is possible for untreated spinal curvature to increase in angulation to the point that secondary physiological complications become life threatening. For this reason, the medical field is investigating assessment procedures which will aid in the early detection of the symptoms of the disease.

Idiopathic scoliosis is one type of scoliosis. As the name implies, its cause is unknown. This type can be further classified by age at which the deformity was first observed. The curve which is observed may react in one of three ways at some time during the person's maturation as follows:

the curve can 1. remain the same
2. spontaneously correct its alignment or
3. increase in magnitude (Moe, Winter, Bradford, Lonstein; 1978).

Currently there are no measurements which reliably predict which curves will react in each of these three ways (Lonstein, Carlson, 1984).

Clinical Characteristics

~~It~~ is important for the orthopaedic surgeon to perform a complete evaluation on the initial visit of patients with spinal deformities. Documentation of the patient's physical condition and complications arising as a result of the deformity (pain, respiratory capacities and neurological signs) is necessary. This information is vital to determine the correct diagnosis and to reevaluate a patient at a future date.

A number of characteristics should be noted during the physical examination. In the general evaluation sitting height and standing height, arm span and weight are measured. Flexibility of the spine is evaluated using bending tests. The patient is asked to flex at the hips, extend, and bend to both the right and left sides. The range of motion during these bending tests, especially side bending, is indicative of the flexibility of the curve. A favourable response to treatment would be an arrest of a progressive curve with a cosmetically acceptable result.

The forward bending test is an evaluation which is done in scoliosis screening and clinical evaluation to check for a rib hump. A rib hump indicates vertebral rotation and thus the presence of a structural curve. Patients bend forward allowing their arms and head to hang. Knees should be straight. Evaluation of the subject in this standardized position is important so that it is possible to see if there is a lateral prominence in the upper thoracic or lumbosacral area. If a curve is present, its location, length and sharpness should be noted. Characteristically, a thoracic curve will be accentuated by the presence of a rib hump prominence. If the curve is in the lumbar region there may be prominence of the iliac crest on the side of the concavity of the curve. On forward bending there will appear to be a prominent area on the convex side of the curve due to the rotation of the vertebral bodies.

If spinal curvature is suspected as a result of the initial clinical evaluation, the orthopaedist proceeds to specify the amount of curvature by radiographic evaluation (Personal communication Dr. S. Tredwell, 1980).

Radiographic Evaluation

Radiographs yield information about the spinal deformity including location, size and flexibility of the curve, the presence of vertebral anomalies, along with bone age of the patient.

The standard series of radiographs taken to supply the above information for scoliosis includes standing anteroposterior, lateral, supine, and right/left bending views. A radiograph of the left hand and wrist is also taken to determine bone age of the patient (Moe et al. 1978).

The supine radiographs show the alignment of the spine with the effects of gravity removed. If the curve measurement is comparable in standing and supine positions, the curve is probably structural in nature. Treatment will still aim to arrest progression of the curve.

Side-bending films are used to determine the flexibility of the curve. These are taken with the patient supine. Active bending illustrates the ability of the muscles to correct the deformity. The amount of correction gained is determined by comparing these films with standing and other supine films. In some institutions these are done as part of the routine radiographic assessment while in others they are used only as a pre-surgery examination.

The positioning of the patient for each radiograph must be done with care. A patient with a flexible curve can easily exaggerate it either by moving or by bearing weight unequally. The measurement of the spinal curvature could also be inaccurate if the film is taken with any degree of obliquity (Blount, Moe, 1980).

In-house studies done in the Spinal Deformities Clinic, Children's Hospital, Vancouver found an intrameasurer variability of ± 4 degrees for measurement of a scoliotic curve (Personal communication Dr. S. Tredwell, 1980). This compares positively to the measurement variability reported by others. Cochran and Nachemson (1985) reported intermeasurer variability of ± 4 degrees for the measurement of anteroposterior radiographs.

Radiographic Dosages

Radiographic exposure is an invasive data collection technique. Many efforts have been made tc minimize both the exposure and therefore the risk

2

of this type of evaluation. Nottage, Waugh & McMaster (1981) measured the exposure directly which their patients were receiving. The mean gonadal doses were 19 mrem in males and estimated at a maximum 95 mrem in females. The mean entrance skin dose was 174 mrem. There was a lack of uniformity of radiographic techniques between technicians. The dosages received were within accepted annual limits. The average dose received by the general public per year from the environment is 100 mrem (Nottage, Waugh & McMaster 1981).

Radiographic exposure in the Children's Hospital Radiology Department for a standard anteroposterior radiograph of a scoliotic patient has been measured at an average gonadal dose of 3.38 mrad (1 mrad is approximately equal to 1 mrem, Children's Radiology Dept., Personal Communication, 1985)(McDormand & Pel, 1985). It should be noted that both of these facilities are large well-equipped specialized centres. Smaller assessment centres may not have the same ability to minimize radiographic exposure.

Curve Measurement

The location of the curve is classified as cervical, thoracic or lumbar depending on the position of its apex. It is also classified as right or left by its convexity.

Typically the curve is measured according to Cobb's method. The end vertebrae of the curve are determined. These are the last vertebrae which are tilted into the concavity of the curve being measured. A line is drawn along the end-plate of the upper end of the most cranial vertebra in the curve. A second line is drawn along the end-plate of the lower end of the most caudal vertebra. Lines are drawn perpendicular to the end vertebrae lines. The angle formed by these two lines is the angle which is measured. Figure 1 illustrates the tilting which is referred to.

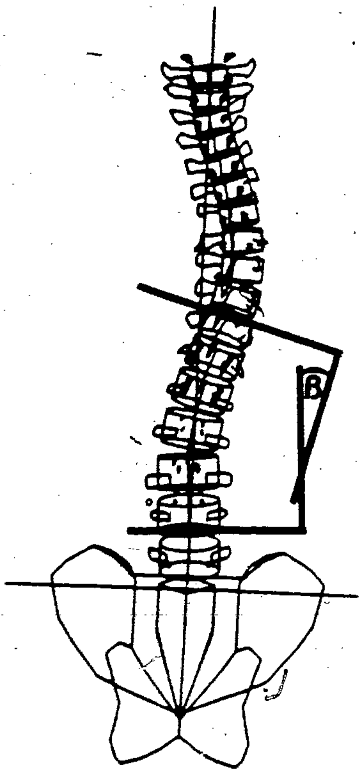


Figure I Curve identification and measurement by Cobb's method. The angle of Cobb equals the angle subtended by the arc of the curve.

One method of classifying vertebral rotation is according to a system of grades. The shadows of the pedicles are examined to determine the grade of rotation. The grading system is illustrated below (Nash and Moe, 1969).

Grade 0 Grade I Grade II Grade III Grade IV

Figure II Classification method of spinal curve rotation.

The Children's Hospital clinic now grades rotation by measuring the surface rotation of the back when the patient is in a forward bend position (Bunnell 1983), and by measuring the spinal rotation using a nomogram, developed through the Alfred I Dupont Institute and sold by Metronic Neuro, to measure the apical vertebral rotation of the spine.

Once the curves have been identified, the end vertebrae, which have been specified, are used throughout the course of treatment for reevaluation of the sizes of the curves.

Incidence

Organized screening programs are conducted in North America, Europe and Japan to identify children suspected of having spinal curvature. Commonly, an incidence of 5% of the population is estimated to have a persistent small flexible curve. In areas which do intensive screening programs the incidence is reported to be higher (Moe, Winter, Bradford, Lonstein, 1978). In Japan where Shadow Moire Contourography and Low Dose X-rays are employed, the incidence has been reported to be as high as 9.5% (Ohtsuka, Shinoto, Inoue, 1981). The difference in the rigour of the screening in these areas could account for the discrepancy of the reported incidences.

The clinical incidence of curves ten degrees or greater is 23 per thousand of the population. The clinical incidence of curves thirty degrees or greater is 2 per thousand of the population (Lonstein, Carlson 1984).

The incidence in the population, at maturity compared to the degree, is shown in the following graph.

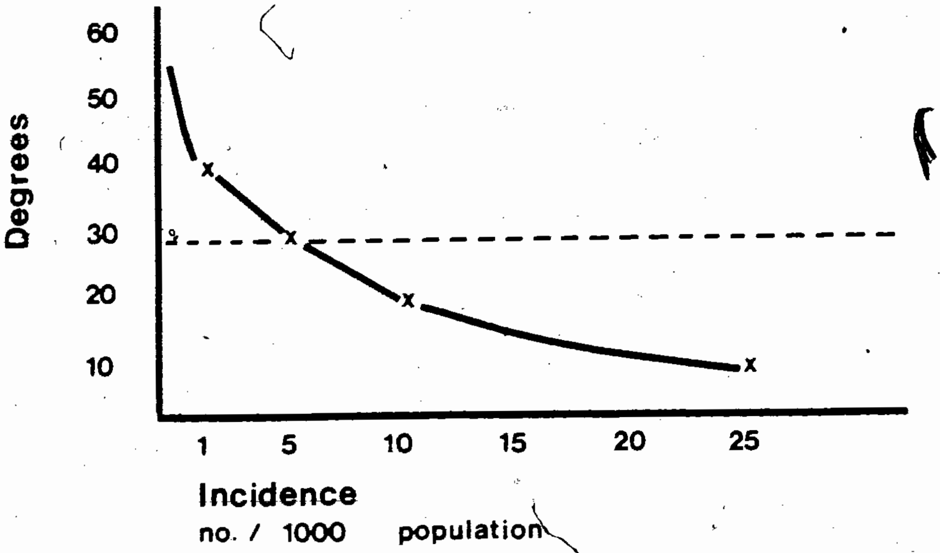


Figure III The relationship between the degree of curvature and its incidence at maturity.

Curves below thirty degrees will cause neither back pain nor pulmonary complication in adult life. Curves greater than forty degrees tend to progress in adult life and may cause significant medical problems. Clinically it is important to prevent curves from progressing to greater than thirty degrees. A non-invasive method of monitoring is important so that the nonprogressive group will not receive a high exposure to x-rays.

Etiology

The etiology of the disease has remained elusive since its first observation. Diet, muscle activity of the paravertebral muscles, metabolism and alterations of metabolism of connective tissue, joint tendon and ligamentous elasticity, structural disturbances of the bones, discs or ligaments as well as enzymatic and genetic factors are among those examined in the search for the cause(s) of scoliosis.

Moe, Winter, Bradford and Lonstein (1978) showed Zorab's (1970) work on simultaneous acceleration of spinal curve angulation and growth (Figure IV). To date the role of hormonal changes on spinal curvature remains unresolved.

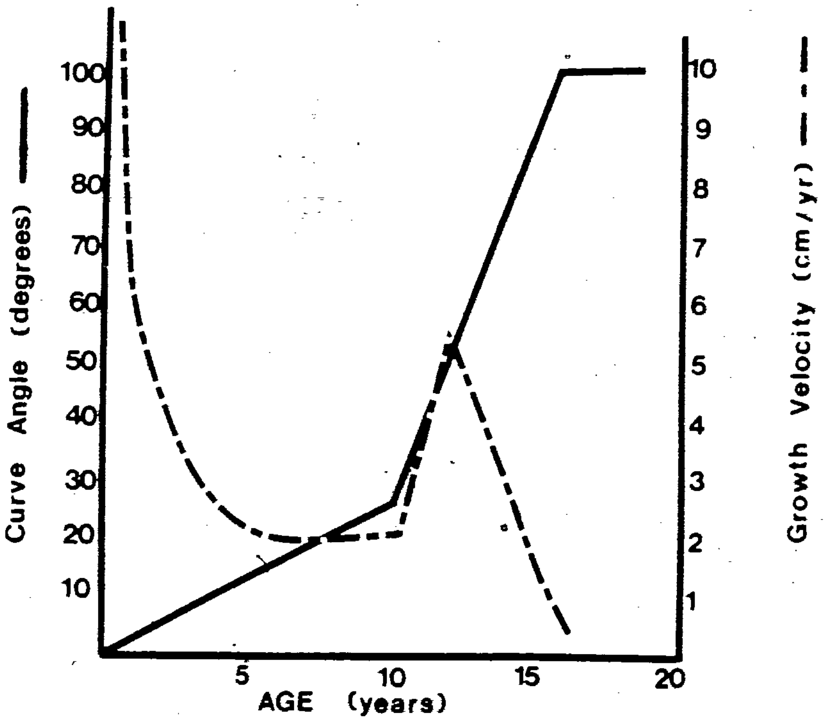


Figure IV The relationships of both angulation and velocity of growth to age (Zorab, 1970).

After the bones of the vertebral column have matured the curvature which exists can not be reduced by any means other than surgery. The law of asymmetrical epiphyseal growth partially explains the resulting bony deformity which exists in scoliosis. That is, vertebral growth is influenced by the amount of pressure exerted on each vertebral body. On the concave side of the curve, the vertebral bodies are in contact, retarding the rate of growth on that side. Conversely, on the convex side of the curve the vertebral borders are separated and bone growth results in wedging of the vertebral bodies. Early treatment and observation are desireable to limit the increases of spinal curvature which would occur if allowed to progress naturally (Moe, Winter, Bradford, Lonstein, 1978).

Muscular Implications

Increasing curvature changes the orientation of the skeletal components so that there is an increased mechanical demand on the system. Concurrently, muscular effectiveness is decreased. As the spine bends laterally, the tension about the facets, discs and ligaments is distorted in a way that causes the vertebrae to rotate. Rotation contributes to decreased muscle leverages. Changes in alignment increase the amount of force required to effect movement. As the components of the spine fall out of line, their own weight perpetuates malalignment.

Theoretical calculations demonstrate that the centre of gravity of the upper body is in line with the apical vertebra until the curve reaches 40 degrees. As 40 degrees is approached there is an increasing bending moment. Beyond 40 degrees, the centre of gravity falls within the concavity of the curve. At this point it is only the tension of the ligaments and tendons on the convex side of the curve which are supporting it. As the spine bends laterally, the tensions about the facets, discs and ligaments are distorted in a way that causes the vertebrae to rotate. The vertebral bodies in the curve tend to move towards the convex side of the curve, pulling the ribs with them. The ribs follow the vertebral body as it rotates. As the curvature increases the heads of the ribs are less directed towards the vertebral body. The ribs also change from their normal downward angle to a more vertical position (Moe, Winter, Bradford, Lonstein, 1978).

Deformation of the thorax eliminates the corrective capabilities of the muscles. Lateral leverage is lost as the lines of force begin to cross the central axis of spinal motion. In fact, muscles which normally have corrective actions could become contributors to the deformity (Moe, Winter, Bradford, Lonstein, 1978). The following conclusions were drawn from the theoretical analyses of the biomechanics of scoliosis correction by means of trunk muscle stimulation (Schultz, Haderspeck, Takashima, 1981). Their findings indicated that changes in the lateral curve, sagittal curve and relation about the longitudinal axis generally take place independently of each other. If the muscle spans the convex or the concave side of a curve, it will correct or increase that curve respectively. If the muscle is anterior or posterior to the spine, its contraction will decrease or increase a lumbar lordosis and increase or decrease a thoracic kyphosis, respectively. These authors noted that it was difficult to predict from elementary considerations which change about the longitudinal axis will occur and what will happen when several different muscles contract at the same time to produce a balanced upright trunk.

Treatment

Purpose of Treatment

The purpose of treatment is to identify the group which faces the risk of spinal curve increase and to arrest the spinal curvature. The reason for this is twofold. First, spinal curvature which is allowed to increase to an extreme will become life threatening by disrupting pulmonary and vascular functioning (Moe, Winter, Bradford, Lonstein, 1978). Second, cosmetic appearance has a definite effect on the patient's personal body image and therefore his/her social interaction (Kahanovitz, Snow, Pinter, 1984).

Types of Treatment

It is possible for a young flexible curve to correct spontaneously. If this does not occur, treatment must attempt to arrest the progression of the curve (Moe, Winter, Bradford, Lonstein, 1978). Three treatment alternatives currently exist:

1. bracing
2. electrical stimulation
3. and the final alternative - operative intervention.

Other non-medical sources of treatment include naturopaths, chiropractors and acupuncturists.

The most common treatment for spinal curvature is by orthotic management. Bracing supports the body shape and relies on correction to come from the patient exercises both in and out of the brace.. Several common orthoses which are used at Children's Hospital in Vancouver are the Milwaukee Brace, the Thoracolumbar Sacral Orthosis (sometimes referred to as a Boston Brace) and adaptations thereof.

Electrical stimulation offers an alternative to orthotic management. Electrical stimulation elicits the contraction of specific muscle groups which straighten the spine by a prescribed amount. There are two tested approaches. One uses subcutaneous electrodes next to the spine while the other uses cutaneous electrodes located lateral to the spine (Bobechko 1972, Axelgaard 1983).

Operative intervention is only used when the size of the spinal curve has become so large that the spine begins to collapse. Without stabilization of the spine, complications arising from its collapse are inevitable.

Prescription Criteria

Brace treatment is recommended in the case of increasing spinal curvature of twenty-five degrees or more with associated vertebral rotation (Dr. S. Tredwell, Personal Communication 1980).

The Scoliosis Clinic of Children's Hospital, Vancouver commonly prescribes the Milwaukee Brace for cases in which the curve is located in the high thoracic region and/or is difficult to control. The Thoracolumbar Sacral Orthose (TLSO) is commonly used for the control of lumbar curves. It is also used for some thoracic curves which it is able to stabilize.

Treatment Effectiveness Studies

Studies have compared the effectiveness of treatment on the basis of correction of the spinal curve (measured in degrees or percent correction), decompensation of the rib hump (measured in centimetres or percent decompensation) or a percieved cosmetic appearance (on a subjective scale).

A long-term follow-up study of 85 patients treated with the Milwaukee Brace was reported by Cochran and Nachemson in 1985. Conclusive data to suggest that the Milwaukee Brace always acts in a predictable manner were not produced. As in previous studies, it seemed to function sometimes as a corrective device and sometimes as a holding device. Overall results were called "successful" since few curves progressed beyond fifty degrees. Rudicel and Renshaw measured the decompensation achieved using the Milwaukee Brace. Following treatment, decompensation ranged from 0 to 3.1 centimetres. The study concluded that in spite of compliant brace treatment the results were unpredictable.

Reports of the effectiveness of bracing with the TLSO suggest that it is most effective in the treatment of curves with an apex at the eighth thoracic vertebra or lower (Laurnen, Tupper, Mullen 1983; Willner & Pettersson 1983; Jonasson-Rajala, Josefsson, Lundberg, Nilsson 1984). These studies did not deal with the predictability of the results of curves treated with the TLSO.

Moire Topography

Principles

Moire topography utilizes a simple photographic technique in order to create a three dimensional map. The expression "Moire Fringe" is used for a striped pattern that occurs when two or more different types of patterns are overlapped.

Moire is not a new technique. It was known to the field of stress analysis as the oblique shadow method. The high curvature which is characteristic of some regions of the human body have presented specific problems for medical applications of the Moire method (Takasaki 1981).

It is possible to create Moire patterns by several methods. In each case the interrelationship of the grating and its shadow is uniquely determined by the geometry of the system.

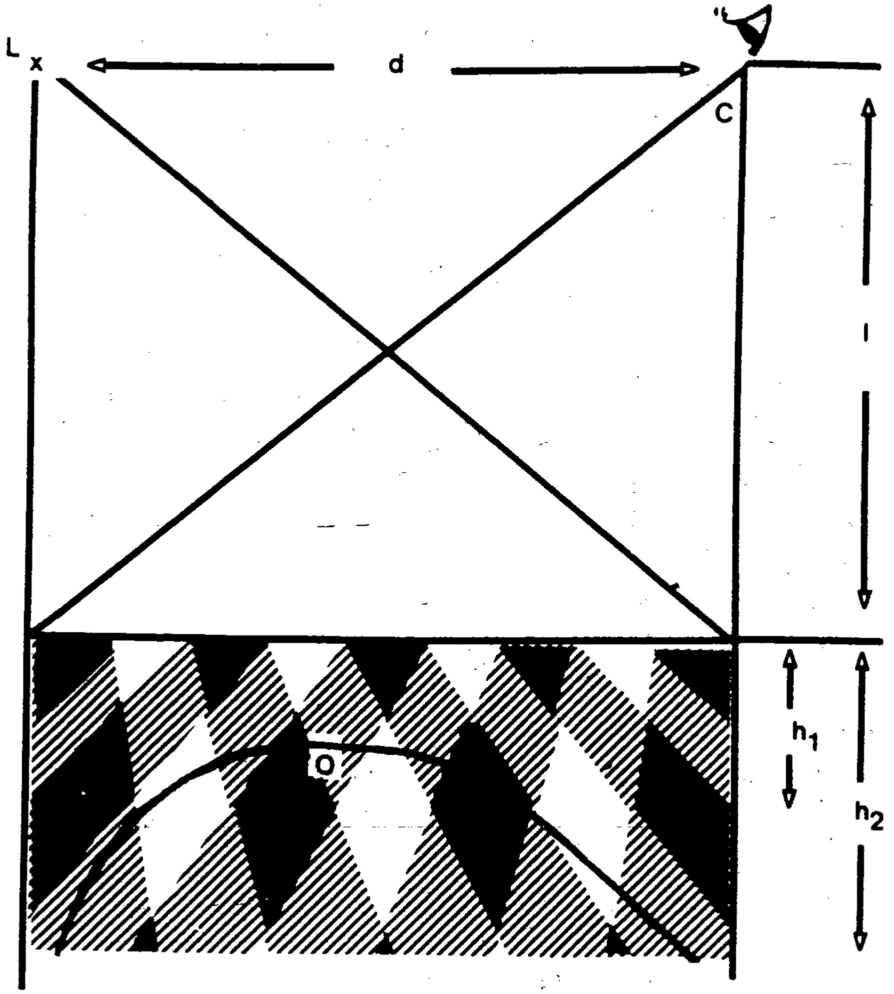


Figure V Illustration of the principle of the formation of fringes (Takasaki 1981).

A curved object is illuminated by a point source of light, L. It is observed from point C. The region illuminated by the light source through the grating and the region which can be observed from point C through the grating are shown by sets of lines fanning out from points L and C. The two sets of stripes project two sets of curved lines on the object's surface. The intersection points of these two sets are seen from C as bright spots. These spots form a set of Moire fringes which look like contour lines (Takasaki, 1981).

Other Moire techniques include a projection techniques developed by the Fujinon Corporation and the projection method which is based on that of Miles and Speight (1975).

The Fujinon FM40 is a grating projection system which is set at a 5 mm fringe interval. It uses a 650 watt Halogen light source, and Fuji MA 35X camera. Adaptations can be made to attach an instamatic camera. These units have been used widely in Japanese school screening programs.

The projection system described by Miles & Speight (1975) involves photographing a specially prepared grid which is projected onto a flat reference screen. Each patient is then photographed with the grid projected on their back. The reference grid and patient grid are then printed onto lithographic film. On aligning the reference grid ordinary Moire contour fringes are produced.

In addition to Moire topography techniques there is rasterstereography, holography and stereophotogrammetry (Heirholzer, Frobin 1981; Windischbauer 1981).

There are problems with the Moire method. These shortcomings include:

- the necessity for precision of the geometry of the system
- noise created by two types of fringe diffusion
- changing fringe interval with increasing fringe number
- problems with measuring a living "squirming" body
- identification of convexity and concavity is not possible without prior knowledge of the shape (Moire Fringe Topography and Spinal Deformity - Proceedings of an International Symposium 1981).

Medical Application

The examination of new techniques, and the refinement of old techniques to describe spinal deformities continues to be done. In my opinion this is an indication that techniques currently used either do not give a true picture of a three dimensional spinal deformity or are too complex to use clinically.

Shadow Moire Topography is a non-invasive technique which has been investigated for the clinical analysis of spinal deformities.

When using Shadow Moire Topography for the measurement of a human shape there are two procedural problems which exist. The first and simplest problem to deal with is orienting the Moire screen or projection to the patient. The second, and more difficult problem is duplicating the patient's posture. In order to use Moire Topographs for comparative studies, the Topographs must be taken so that the patient's posture can be reproduced. The three methods of patient positioning which have been examined are currently being used by researchers in the field of Shadow Moire Topography and the study of spinal deformities.

Illustrations of the three methods of positioning are included in Appendix I which includes the standard instructions given to each patient regarding positioning.

THE STUDY

It was proposed that Shadow Moire Topography is a useful technique for assessing changes in shape of the back which occur with progressive scoliosis.

Hypotheses

Three hypotheses were tested:

1. Topographic measurements of repeated Shadow Moire Topographs are repeatable to within ± 1.25 mm.
2. Changes seen in topographic measurements are positively related to curve classification.
3. Patient positioning affects the variance of shape measurements of live subjects by Shadow Moire Topography.

Equipment

Accuracy of the Clinical Shape Monitor (CSM) was determined by the Department of Physics of the National Research Council of Canada (NRC). The NRC test model, designed to evaluate the performance of moire instruments, was used to produce test photographs with the MERU-CSM. The test model consisted of various sloping surfaces and a number of control points with known XYZ coordinates. The photographs were taken while the outside reference surface of the test model was parallel to the MERU-CSM and practically in contact with it. The calculated values of the control points were compared with the known coordinates of the control points to evaluate the performance of the CSM.

The Clinical Shape Monitor (CSM), Nikon FE 35mm camera and Vivitar flash (light diffuser removed), and Kodak PX 135 black & white film were used for data collection.

Five by seven inch photographs were digitized using a Summagraphics Bit Pad One digitizing tablet and Part I of the Shape Analysis Package (SAPI).

Part II of the Shape Analysis Package (SAPII) was used to analyze the raw data. Programs were written in Pascal and run on an IMS 8000 microcomputer.

Method

This study was conducted in two stages.

Stage I

In Stage I two things were determined. First, the variability of measurements due to the operator's error in digitizing the Moire Topographs was determined. Second, the variability of measurements due to the positioning procedure was determined.

A randomized block design was the experimental model used to determine the variability due to the positioning procedure used. The three positioning methods chosen were free standing, entire body inclined (to 10 degrees), and seated. Three skeletally mature adults with no known spinal deformities were studied. Each subject was photographed using each of the three positioning methods. A total of 30 Moire Topographs were taken of each patient. Ten Topographs were taken with the patient in each of the three positions. The 30 Topographs were taken in a randomized order within the span of one hour.

Data Collection

Analysis of the data was a semi-automated procedure. Five by seven Moire topographs were manually digitized using the SAPI. Four horizontal sections were digitized (at premarked locations on the body). These locations are illustrated in Figure VI. The data for each subject was collected during a single session. Marker placement was maintained for the duration of the repositioning study.

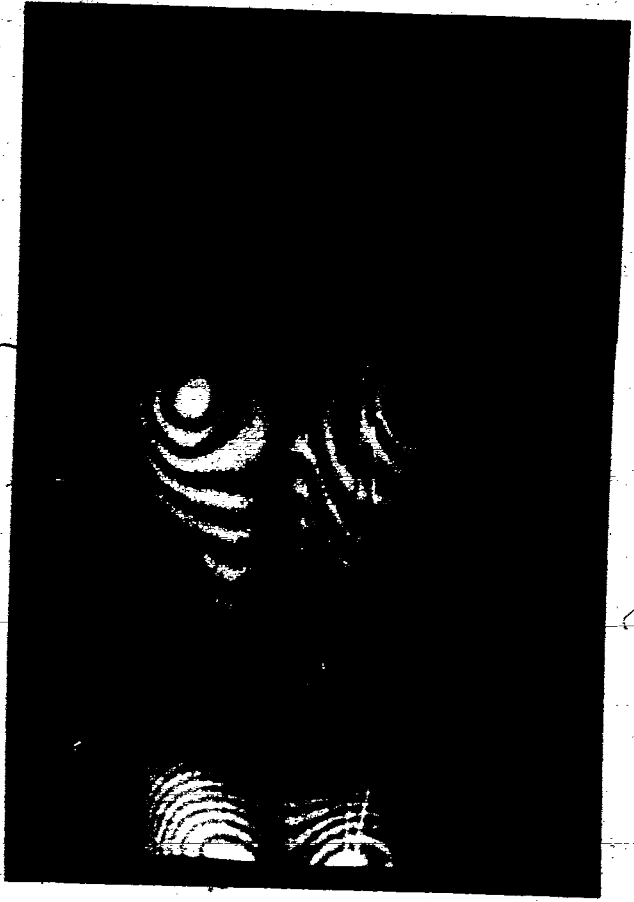


Figure VI Illustration of the placement of body surface markers

Data Analysis

The Shape Analysis Package (SAPII) was used to analyze the raw data. The SAPII was a pascal program which calculated topographic variables from the raw data. For each of the premarked locations, a sectional contour line was defined.

The topographic variables calculated for each horizontal contour were as follows:

1. hump height - the "h" height difference of the two peaks .

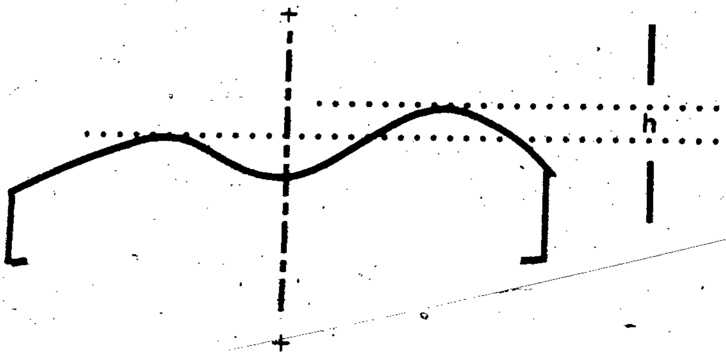


Figure VII A cross-sectional view of the back surface where "h" represents the hump height.

2. hump angle - the angle formed by the line linking the two peaks and a horizontal line

hump angle = ARCTAN (h/(a+b))

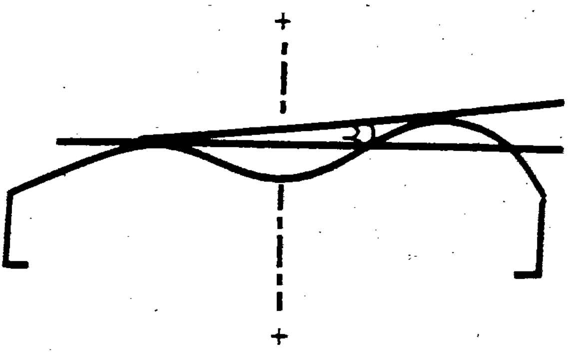


Figure VIII A cross-sectional view of the back surface where "α" represents the hump angle.

3. lateral deviation - the distance from the centreline to the midpoint of the line linking the two peaks

   lateral deviation = $(a-b)/2$

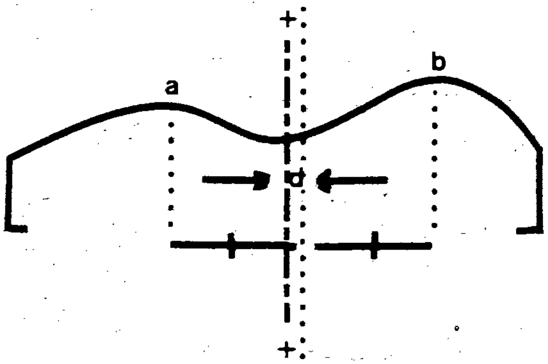


Figure IX A cross-sectional view of the back surface where "d" is the lateral deviation.

When a peak existed on both the right and the left sides of the back, a calculation of the lateral deviation of the spine was done. The centreline was defined as the line between seventh cervical vertebra (C7) and the gluteal fold. The distance between the peak and the centreline was called "a", and the distance between the peak and the right side of the centerline was called "b". The height difference of the two peaks was calculated and called "h". When only 1 peak was detected on either the left or right side, the difference of height of the peak and a point in equal distance from the centreline on the opposite side of the back was calculated and called "h". However, sometimes two peaks were selected on one side. In this case, the peak which was near the centreline was automatically detected and made to be the true hump for use in calculation.

4. rib hump index - measure of trunk rotation

rib hump index = (h/trunk width) * 100

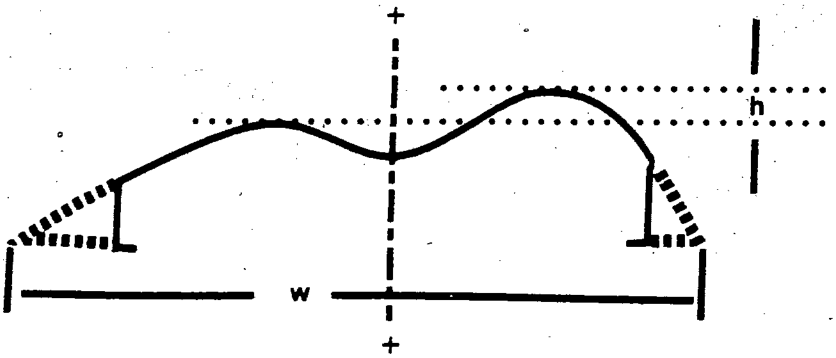


Figure X A cross-sectional view of the surface of the back where "h" is the hump height and "w" is the trunk width.

5. arclength - i) length of the contour line to the left of the centre
ii) length of the contour line to the right of the centre
iii) quotient of the length of the left side and right side of the contour line.

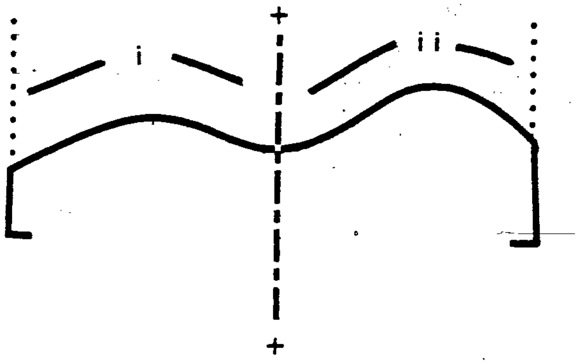


Figure XI A cross-sectional view of the back surface where "i" is the length of the left side of the surface of the back and "ii" is the length of the right side of the surface of the back.

Two tables containing the patient's I.D., date, name and all the topographic measurements were produced with each analysis. A contour drawing ilustrating the cross-sections digitized was also produced.

Normality of the Data

The normal-scores correlation test for normality was used to check the normality of the study data. Standard deviation, as a measure of variability, depends on the normality of the data. The correlations of study scores to normal scores were used to determine the level of significance of normality of the study data.

Identification of Sources of Error

Digitizing Variability

The digitizing variability was determined from repeated digitizations of a single Moire topograph. Two specified sections were digitized ten times. This test was repeated on three separate days. The mean and standard deviation of the repeated measures of each topographic parameter were calculated (Quenouille 1966).

Variability Due to Positioning Procedure Used

The standard deviation was calculated for each subject (3) in each of the positions (3) for each of the measurement variables (5). The maximum value of each measurement variable, representing the maximum deformity of the four cross-sections digitized, was used to determine the standard deviation of the measurement.

Subsequently, the coefficients of variation for each variable for each person and each position were calculated.

$$\text{Coefficient of Variation (CV)} = 100\% \, (s/\bar{x})$$

where s = standard deviation $\bar{x}$ = mean value

The coefficient of variation is used to compare the variation of different samples, each with different arithmetic means (Fundamentals of Biostatistics 1982).

Stage II

Variability Due to Positioning Procedure Used on a Scoliotic Patient

The procedure for determining the variability due to positioning described on the previous page was followed using a subject with a scoliosis.

Case Study

A clinical case study was carried out. Four assessments of one patient were done over a period of 1.42 years. Moire measurements were coupled with the Cobb angle measured from a radiograph taken at the same assessment. Moire measurements previously described (hump height, hump angle, rib hump index, lateral deviation, arclength ratio) were calculated from each Moire Topograph.

The viability of using surface shape measurements to predict changes of spinal curvature was examined. The variables were recorded as increased, decreased or unchanged. A concomitant change of three of the five measurement parameters must have occurred for a prediction to be made.

Results

Clinical Shape Monitor Performance

The Clinical Shape Monitor's accuracy was assessed by the National Research Council. The following results were obtained:

> For an average fringe depth of 5.4 mm., "Points on the vertical surfaces, inclined towards the light source could only be read with difficulty. Errors are generally within 5.4 mm. (1 fringe) for 12 observed points ... Two sets of test photographs were made approximately two weeks apart. Comparison of corresponding photographs indicated that the results were repeatable to within one fringe. It should be noted that extreme care has to be taken to install the camera and light and orientations with respect to the screen. We feel that a more positive setting of the camera and the light source is essential to obtain the necessary repeatability (M.C. van Wijk, Photogrammetric Research, Division of Physics, National Research Council 1983)".

A copy of this report has been included in Appendix III of the thesis.

Digitizing Variability

The digitizing variability was determined from repeated digitizations of a single Moire Topograph. The means and standard deviations, seen in Table I were calculated for five Moire variables.

Table I Summary of the variability of calculated variables due to digitizing errors

	CALCULATED VARIABLES				
	lateral deviation (cm)	arclength ratio	hump height (cm)	rotation index	hump angle (degrees)
Mean	1.510	1.238	0.570	1.672	3.178
Std.Dev.	±0.081	±0.004	±0.000	±0.017	±0.028

In summary, the standard deviation incurred in repeated measurements of Moire photographs was ±0.081 cm (Std. dev. of the lateral deviation measurement).

Normality of the Data

The normality of the repositioning data was tested using the normal scores correlation test (Cryer, 1986). The correlation levels are presented in Table II. In twenty-eight of the forty-five correlations normality of the distribution could not be rejected. Therefore there were seventeen which were not normally distributed.

Table II Normal-Scores correlation test for normality of lateral deviation, arclength ratio, hump height, rib hump index and hump angle for each subject in each position

	Subject 1	Subject 2	Subject 3
Lateral Deviation			
Position 1	0.971	0.944	0.973
Position 2	0.963	0.851 ***	0.927
Position 3	0.942	0.970	0.924
Arclength Ratio			
Position 1	0.946	0.949	0.966
Position 2	0.958	1.000	0.988
Position 3	1.000	0.918 **	1.000
Hump Height			
Position 1	0.974	0.950	0.975
Position 2	0.974	0.865 ***	0.862 ***
Position 3	0.873 ***	0.796 ***	0.897 **
Rib Hump Index			
Position 1	0.964	0.954	0.983
Position 2	0.905 **	0.922	0.868 ***
Position 3	0.878 ***	0.795 ***	0.912 **
Hump Angle			
Position 1	0.865 ***	0.919	0.988
Position 2	0.893 **	0.904 **	0.957
Position 3	0.892 **	0.751 ***	0.965

Note :
*** normality rejected at $p < 0.01$
** normality rejected at $p < 0.05$
(Cryer, 1986)

Position 1 = seated; Position 2 = standing; Position 3 = inclined

Variability of Repositioning Normal Subjects

The normal subjects were three male volunteers. They had no prior history of severe back pain or familial spinal disorders. The subjects' mean age was 29.1 years (range 25 - 32 years). Their mean height was 180.7 cm (range 174 - 188 cm); mean mass was 79.5 kg. (range 74 - 88 kg.).

The Nature of the Data

The nature of the data created two problems for the statistical analysis. First, the measurement of lateral deviation depended on the presence of a prominence on both sides of the midline of the back. If two prominences were not found the variable could not be calculated and a value of zero was assigned. Therefore when zero occurred it may have been an assigned value rather than a measurement of the back's symmetry. Second, the variables hump height, rotation index and hump angle relied on the presence of right/left asymmmetry. If the right and left sides were symmetrical there was no rib hump and all these variables were equal to zero. In 46% of the cases the hump height, rotation index and hump angle measurements were zero with the patient using the seated positioning procedure. These two problems limited the use of some statistical treatments (e.g. log X transformation).

The percentage of occasions in which it was possible to calculate a measurement for each variable is presented in Table III. The seated position was the only one for which there was missing data. Missing data was common to all subjects.

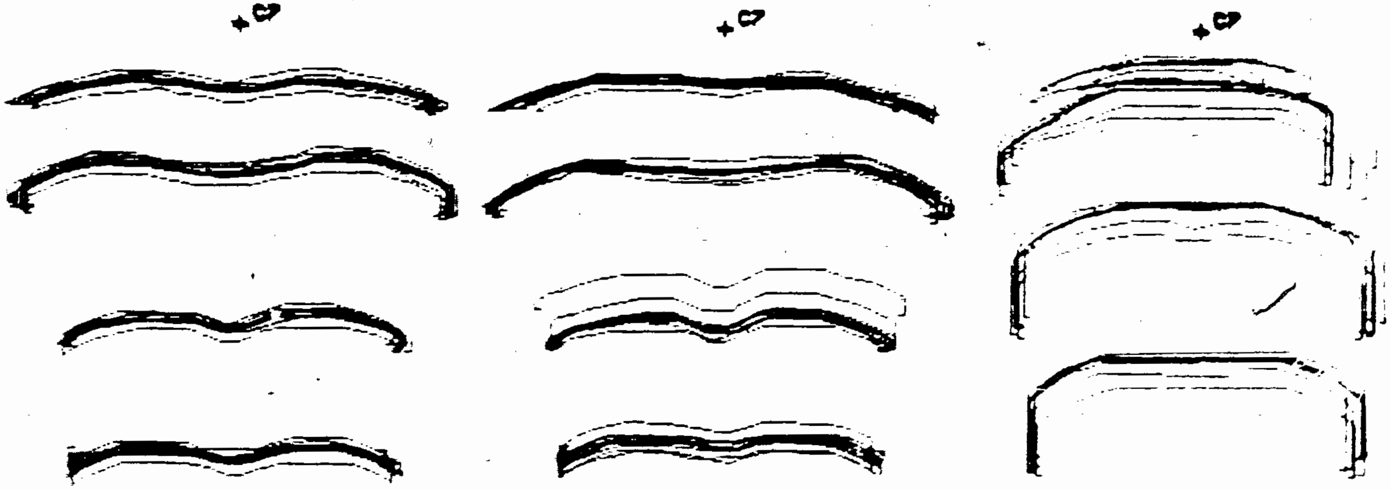
The test for normality of the data revealed that seventeen of the data sets were not normally distributed thus eliminating them from further analysis. The consequence of this was that the positioning procedures were not rated on the basis of average coefficient of variation. The non-normal data sets eliminated resulted in an unequal number of coefficients of variation calculated for each positioning procedure. Comparison of the average coefficients of variation based on unequal numbers of observations could have been misleading.

Table III Percentage of occasions in which it was possible to calculate a value for lateral deviation, arclength ratio, hump height, rib hump index and hump angle (based on 90 Moire Topographs of three normal subjects).

POSITION VARIABLE\	standing (%)	inclined (%)	seated (%)
lateral deviation	100	100	67
arclength ratio	100	100	100
hump height	100	100	100
rotation index	100	100	100
hump angle	100	100	100

Visual Inspection of the Cross-Sectional Profiles

Overlays of each patient's cross-sectional profiles are presented in the following pages. Qualitatively the profiles, of standing compared to inclined compared to seated positioning, appear to be different. Standing and inclined positioning appear to be less variable than the seated positioning profiles.



a b c

Figure XII Subject BJ a) standing; b) inclined; c) seated position

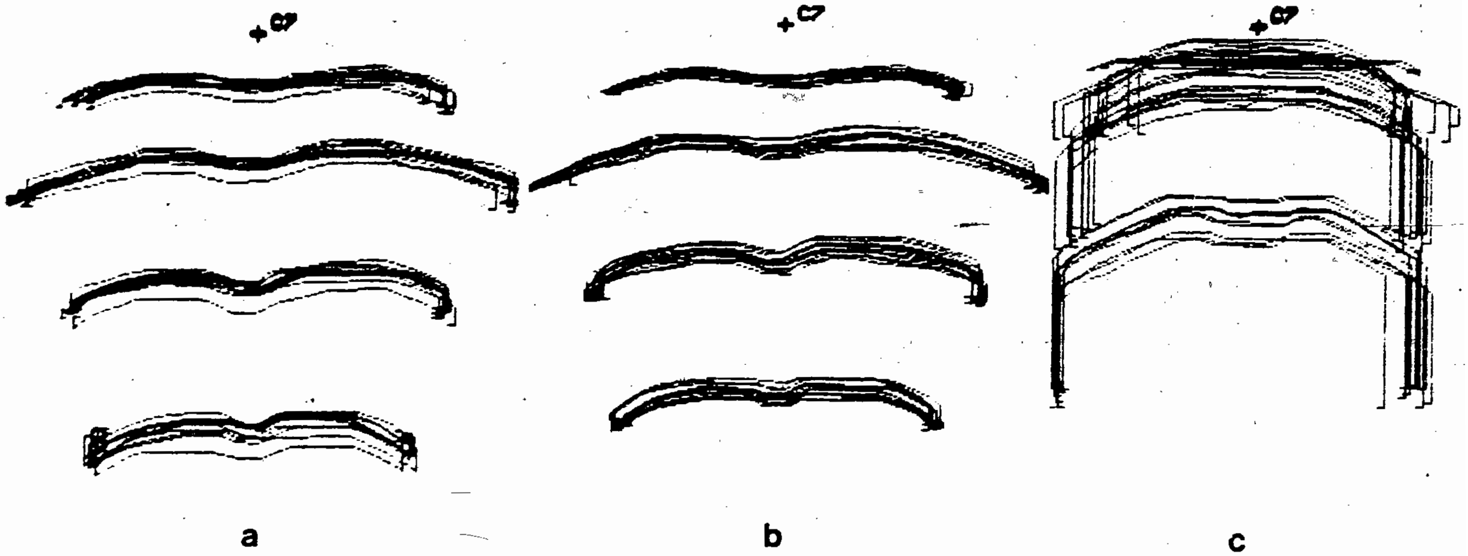


Figure XIII Subject CS a) standing; b) inclined; c) seated position

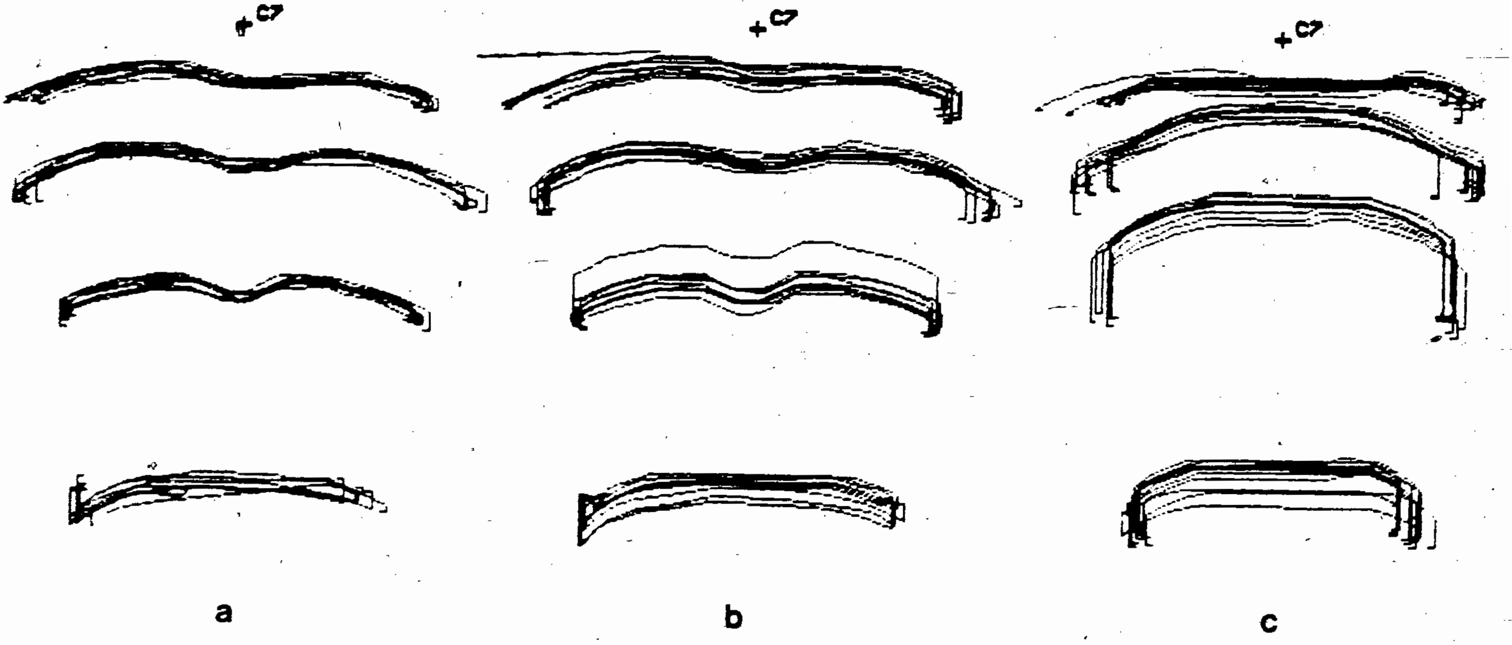


Figure XIV Subject DC a) standing; b) inclined; c) seated postion

Coefficient of Variation Findings

The standard deviation and mean of each variable for each person in each position is reported in Appendix II. In order to compare the variability of different variables, each with different arithmetic means, the coefficient of variation has been calculated for each variable for each subject in each position. The coefficient of variation and its standard deviation have been summarized in Table IV.

Table IV Coefficient of variation (CV) and its standard deviation for each variable for each subject in each position (each CV value has been presented as a ratio of standard deviation divided by the mean value in the following table rather than expressed as a percentage).

	Subject 1		Subject 2		Subject 3	
	CV	Std. Dev.	CV	Std. Dev.	CV	Std. Dev.
Lateral Deviation						
Position 1	1.460 ±	0.749	6.130 ±	11.970	0.646 ±	0.196
Position 2	3.590 ±	4.150	***		0.287 ±	0.069
Position 3	0.808 ±	0.274	3.700 ±	4.400	0.248 ±	0.059
Arclength Ratio						
Position 1	0.010 ±	0.002	0.019 ±	0.004	0.009 ±	0.002
Position 2	0.020 ±	0.004	0.005 ±	0.001	0.011 ±	0.002
Position 3	0.007 ±	0.002	***		0.007 ±	0.002
Hump Height						
Position 1	0.814 ±	0.280	0.636 ±	0.191	2.980 ±	2.890
Position 2	2.760 ±	2.480	***		***	
Position 3	***		***		***	
Rotation Index						
Position 1	0.792 ±	0.266	2.140 ±	1.530	3.250 ±	3.420
Position 2	***		0.286 ±	0.069	***	
Position 3	***		***		***	
Hump Angle						
Position 1	***		5.670 ±	10.260	2.959 ±	2.850
Position 2	***		***		0.330 ±	0.082
Position 3	***		***		0.194 ±	0.045

*** data not normally distributed

Position 1 = seated; Position 2 = standing; Position 3 = inclined

It was not possible to calculate the sum of the coefficients of variation (CV) for the three subjects in each position. Seventeen of forty-five data sets were not normally distributed, thus excluding them from further analysis. It is of note that nine of the data sets which were not normally distributed were collected using the inclined positioning procedure, seven the free standing procedure and one the seated procedure.

The coefficients of variation of the normally distributed data sets were ranked from lowest to highest. The graphs which follow illustrate the spread of the ranking of the coefficients of variation by positioning procedure, variables measured and by subject.

There was no positioning procedure which was clearly less variable than the others tested. The ranking of the coefficients of variation by subject showed that variability existed within the measurements made on each subject. That is none represented the extremes of the variability possible. The ranking clearly showed that arclength ratio was the least variable parameter studied.

Legend for Figure XV on following page

Pos'n 1 = seated
Pos'n 2 = standing
Pos'n 3 = inclined

Sub. 1 = subject 1
Sub. 2 = subject 2
Sub. 3 = subject 3

L. Dev = lateral deviation
ACR = arclength ratio
HH = hump height
RI = rotation index
HA = hump angle

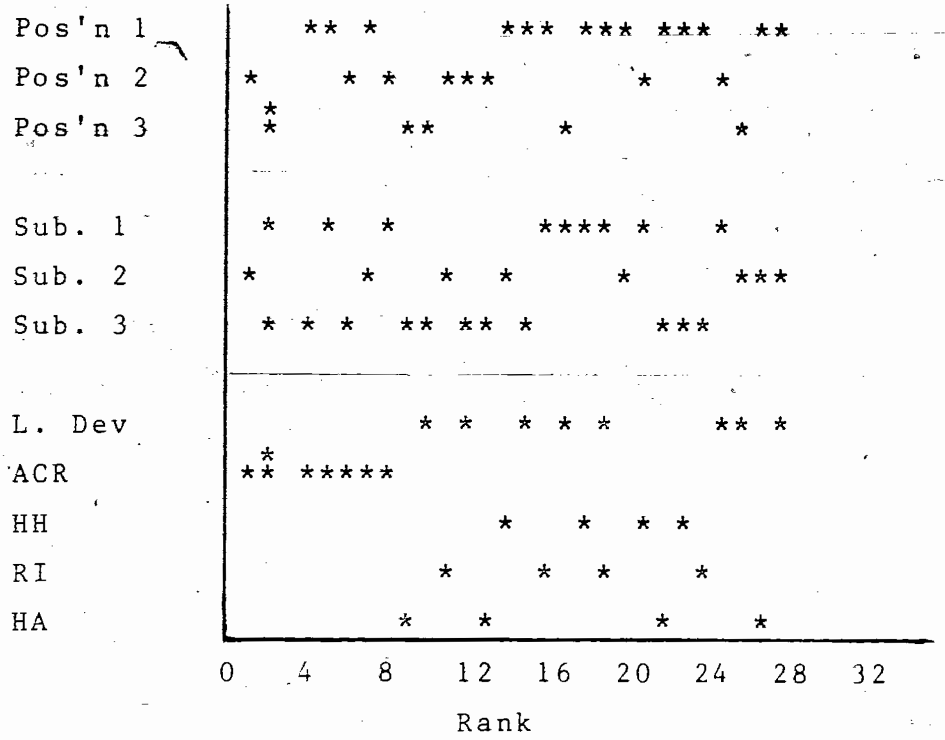


Figure XV Ranking of the coefficients of variation by positioning procedure, variable and subject (normal subjects)

Summary of the Variability of Repositioning Normal Subjects

In summary, in twenty-eight of forty-five cases, the data represented normal distributions. The observation, from visual inspection of the data, that standing and inclined positioning profiles were less variable than seated positioning profiles could not be confirmed statistically. Arclength ratio exhibited the lowest variability of the parameters included in this study.

Variability of Repositioning Scoliotic Patient

The patient was 16.4 years of age, 162.5 cm tall, weighed 50 kg. and had a history of familial spinal deformity. She was diagnosed as having idiopathic scoliosis in May 1984. She had a right thoracic scoliosis (from T6-10) and a left thoracolumbar scoliosis (from T11-L3) with the curves measuring 14 and 17 degrees. The thoracolumbar curve was diagnosed as the primary curve and had an associated Grade I rotation.

The Nature of the Data

Once again, as with the observations of normal subjects there were certain conditions in which a measurement could not be made. In this case, missing lateral deviation values occurred in seven of ten observations with the patient in the seated position. Therefore the standard deviation was calculated for each variable for the scoliotic subject in each position. Table V summarizes the findings.

Normality of the Data

Normality of the repositioning data was tested using the normal-scores correlation test (Cryer, 1986). The correlation levels are presented in Table V on page 40. Eleven of the fifteen correlations, of the scoliotic patient's data, correlated at at least the 0.05 level of significance with the normal scores.

Visual Inspection of Cross-Sectional Profiles

Overlays of the cross-sectional profiles were drawn for the scoliosis patient. Qualitatively, standing and inclined positioning profiles appear to be less variable than seated positioning profiles.

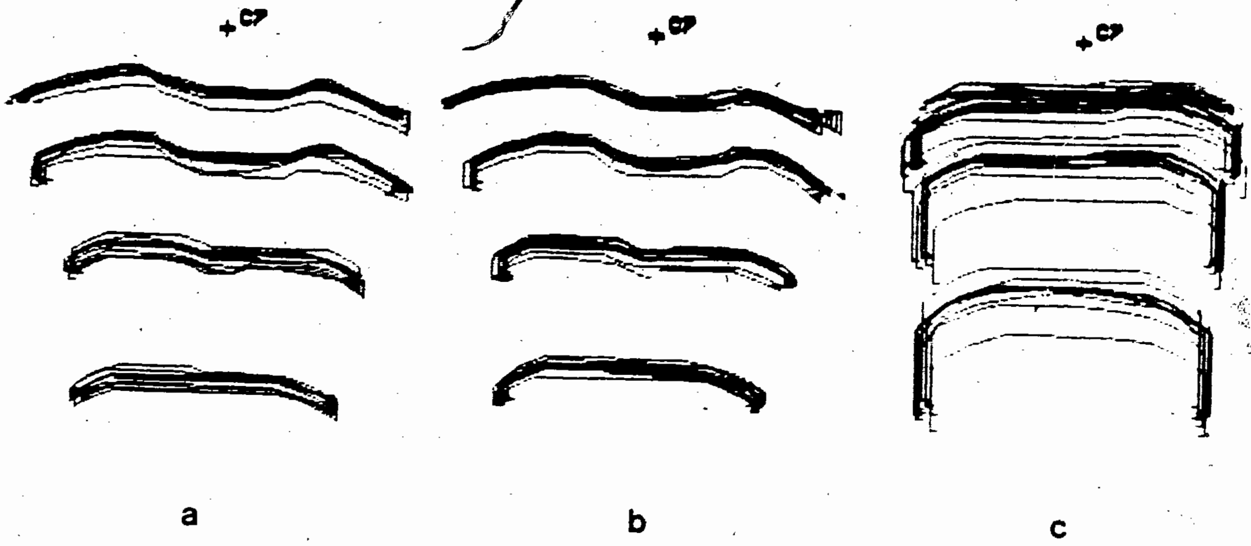


Figure XV Scoliosis subject KL a) standing; b) inclined; c) seated position

Coefficient of Variation Findings

The coefficients of variation were calculated for each variable for each position for the scoliotic patient. The average of the coefficients of variation of the data sets which were normally distributed were used to rate the variability of each positioning procedure. An unequal number of measurements were normally distributed the different positions. The averages must therefore be viewed critically. Standing was rated as the best method (CVaverage/100 = 0.043, n = 4) while inclined positioning was rated second (CVaverage/100 = 0.250, n = 3) and seated positioning was rated third

(CVaverage/100 = 3.538, n = 4). Table V presents the test of normality results as well as the standard deviation of the original variable and coefficent of variation for each measurement taken in each position for the scoliotic patient.

Table V Std. deviation of the original variable, coefficient of variation and normal-scores correlation of each item for the patient in each position

	Std. Deviation	Coeff. of Var.	N-score Correlation
Position 1			
l. dev.	± 0.16	2.01	0.94
arclength	± 0.01	0.01	1.00
hump height	**	**	0.86 **
rib h. index	± 2.18	7.26	0.93
hump angle	± 4.58	4.87	0.97
Position 2			
l. dev.	**	**	0.91 **
arclength	± 0.01	0.00	0.96
hump height	± 0.01	0.01	0.99
rib h. index	± 0.4[illegible]	0.11	0.94
hump angle	± 0.22	0.05	0.98
Position 3			
l.dev.	± 1.10	0.50	0.93
arclength	± 0.01	0.01	1.00
hump height	**	**	0.91 **
rib h. index	***	***	0.87 ***
hump angle	± 1.25	0.24	0.98

Note:
*** normality rejected at the $p < 0.01$ level
** normality rejected at the $p < 0.05$ level
(Cryer, 1986)

Position 1 = seated; Position 2 = standing; Position 3 = inclined

In addition, the coefficients of variation were ranked from lowest to highest. The graphs which follow illustrate the spread of the ranking of the coefficients of variation by positioning procedure and by variables measured. The observation, from visual inspection of the data, that standing and inclined positioning profiles were less variable than seated positioning profiles concurred with the observation of the normal profiles. These observations could not be confirmed statistically. Arclength ratio exhibited the lowest variability of the parameters included in this study for the scoliotic patient as it did for the study of normal subjects.

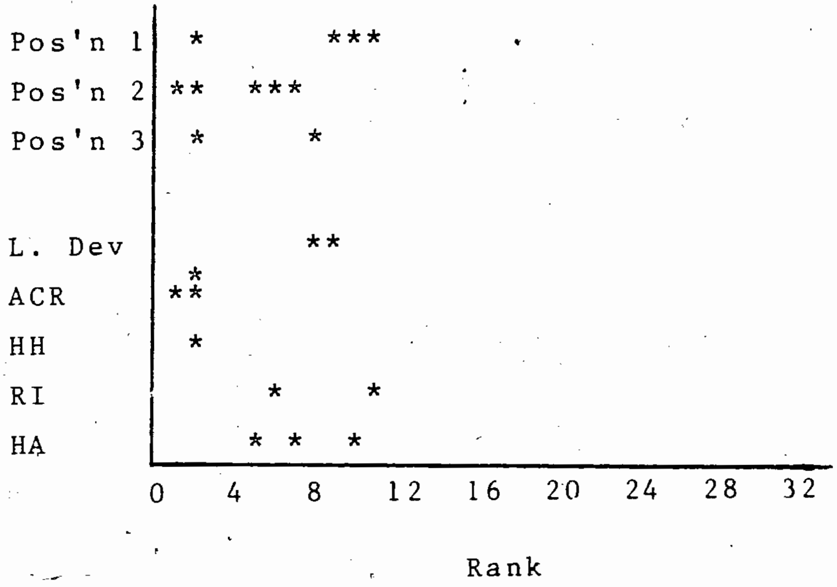


Figure XVII Ranking of the coefficients of variation by positioning procedure and variable (patient studied)

Summary of the Variability of Repositioning a Scoliotic Subject

In summary, in eleven of fifteen cases, data represented normal distributions. The observation from visual inspection of the data that standing and inclined positioning profiles were less variable than seated positioning profiles was confirmed by the determination of the average coefficient of variation for each method. Due to the unequal number of coefficients of variation for each procedure the results of this method of ranking of procedures should be viewed critically.

Ranking the coefficients of variation illustrated that no one positioning procedure was clearly superior to another. It did show that arclength ratio was the least variable of the parameters included in this study.

Recommendations for a Clinical Procedure

Of the three methods of positioning studied, one positioning procedure could not be recommended over another on the basis of the findings of this study.

If lateral deviation is regarded as an important clinical indicator of spinal curve status the standing or inclined methods of positioning would be superior to the seated positioning procedure. Absence of a lateral deviation value in 67% of the observations would make this variable unacceptable for clinical decision making purposes.

The arclength ratio was the least variable parameter used in this study. Arclength ratio appears to be independent of the positioning procedure used. It would be worthwhile to investigate the relevance of this variable for the study of scoliosis.

Case Study

The subject was 12.3 years of age at the onset of the study. Her curve was a left thoracolumbar curve of 32 degrees, as measured by Cobb's method, extending from T10 to L3. Her height was 137 centimetres. Onset of menarche had been 0.5 years previous to the initial visit. She was monitored and treated over a period of 1.42 years. During this time she was treated with both a thoracolumarsacral orthose (TLSO) and a Milwaukee brace (MB) before her curvature required surgery to arrest the curve progression. During this same period her curve progressed from 15 degrees to more than 44 degrees. Table VI summarizes the measurements made during observation of the patient.

Table VI Summary of the maximum topographic measurements of the patient's back as calculated from Moire topographs.

	CALCULATED VARIABLES						
Date d/m/yr	Cobb Angle (degrees)	Lateral Deviation (cm)	Arclength Ratio (--)	Hump Height (cm)	Rotation Index (--)	Hump Angle (degrees)	Treatment
29/9/82	15	2.3	0.9	3.4	16.8	15	
21/2/83	33	1.3	0.9	3.7	13.9	13	TLSO
16/5/83	33	1.9	2.4	4.7	16.7	17	TLSO
20/2/84	44	2.5	2.3	4.7	17.3	17	MB
--/6/84	Surgery - Harrington Rod Instrumentation						

Prediction of Curvature Increases from Surface Topography Calculations

A significant change in spinal curvature was predicted if a concomitant change in three of the five topographic parameters occurred.

There were no correct predictions made using surface topography calculations during the study of this patient. The lack of prediction may result from either or both of two phenoma. First, the inherently large coefficients of variation of some variables as seen in normal subjects may preclude accurate prediction. Second, skeletal changes may not be reflected in changes of topography. The second question can not be confirmed unless the variability of topographical measurement can be reduced. Table VII details the predictions made and the corresponding Cobb angle measurements.

Table VII Summary of the Cobb angle changes and increase/decrease predictions from surface topography calculations.

	Predicted Increase			Actual Cobb Angle (degrees)	Prescription
	Yes	No	Same		
27/9/82	-	-	-	15	Observation
21/2/83		x		33	TLSO brace
16/5/83	x			33	TLSO brace
20/2/84		x		44	Milwaukee brace

DISCUSSION

Topographic measurements of normal male subjects are affected by repositioning. The pathological case studied reflected the same results.

Normality of the data was tested. In twenty-eight of the forty-five correlations normality of the distribution could not be rejected. Of the seventeen cases which were not normally distributed, the correlation levels were high.

The coefficients of variation differed for each variable and each method of positioning for the normal subjects studied. Determination of the best procedure could not be done statistically because of the non-normality of seventeen data sets.

Ranking of the coefficients of variation by procedure showed no dominance of any one positioning procedure.

Ranking by measurement parameter did show that arclength ratio was the least variable parameter for both the normal group and the scoliotic patient tested. The question remains if it is a useful measurement of surface shape changes. Further examination of how the measurement would be affected by surface shape changes is necessary.

These findings have implications for future work in this field. Further basic studies into understanding positioning procedures is required. Positioning is important not only to the study of scoliosis but to all imaging based data collection systems. Knowledge of the errors introduced by positioning is essential so that they can be accounted for and data can be interpreted correctly.

Of the three procedures, free standing appeared to be the least controlled positioning procedure. However, it may take advantage of a habituated posture and the body's righting response. The other positioning procedures are subject to the patient's conscious attempt to follow instructions, with fewer cues from habituated patterns. The one scoliotic patient's measurements did concur with the normal group's results. Once again no one method of positioning was clearly superior. In addition the parameter arclength ratio demonstrated low measurement variability. It has been conjectured by Sahlstrand (1978) that scoliosis is due to a defect of patients' balance or righting response. In light of Sahlstrand's research, a scoliotic group should be studied to determine if the variability measures are actually the same for this group.

In 67% of the repositioning photographs lateral deviation could not be measured. Calculation of the lateral deviation depended on the presence of a prominenece on both sides of the midline of the back. The measurement would be of limited value for clinical studies if it can not be measured.

Three sources of error were identified in this study. First, error due to the accuracy of the equipment (±2.7 mm.) was quantified by the National Research Council. Second, Stage I of this study determined the variability of repeated digitizations by a single operator (standard deviation was ±0.81 mm). This is well within the precision to which the Clinical Shape Monitor is capable of. Efforts to improve the accuracy of the measurement of surface shape therefore lay in collection of the data rather than its analysis. Finally, the error due to repositioning subjects was addressed. Since digitizing error was negligible, variablity of the measurements of more than ±2.7 mm. should have been due to changes of the back shape when the subject was repositioned.

The variability due to repositioning differed from subject to subject for each procedure. For example, for the measure of lateral deviation of subject

1 in the seated position the coefficient of variation was 1.42, while for subject 2 it was 5.75 and for subject 3 it was 0.65. These differences are notable. In future studies it may be of interest to examine the differences between subjects. It would be useful to have a method to choose the appropriate method of positioning for individual patients.

Because of the predominance of females, as compared to males, who have curvature of the spine future studies should include female subjects.

The clinical assessment showed that whereas Cobb angle can show skeletal changes, these are not necessarily reflected in changes of topography which relate to the cosmetic aspect of the condition. The accuracy of predicting spinal curve increases and decreases in the case study was 0.0 %. However, in the clinical situation the influences of uncontrolled variables warrant examination. These influences include changing spinal curvature and changing treatment. The subject of this clinical case study changed treatment three times, from observation to a Thoracolumbar sacral orthosis to a Milwaukee brace. Each change of treatment occurred before the combined radiographic and topographic assessment. In the second and third examinations treatment had been maintained. The increase in curvature which had occurred on the second examination was then identified on the third examination. The question, "Do patients accomodate to imposed treatments?", could be asked. If so, would prediction of curve changes be possible after accomodation to treatment had occurred?

The subject studied in this thesis was an example of both initiating and changing treatment as increases of spinal curvature occurred. She represented a complex case under which to make spinal curvature progression predictions from surface topography measurements.

CONCLUSIONS

The hypotheses tested to examine Shadow Moire Topography as a useful technique for assessing the shape changes of the back which occur with scoliosis can now be answered.

First, topographical measurements obtained by means of the Clinical Shape Monitor are repeatable to within ± 2.7 mm as determined by the National Research Council.

Second, curve changes of the patient studied could not be related to the calculations made from Moire topographs in the longitudinal case study of this thesis. Whereas Cobb angle can show skeletal changes, these are not necessarily reflected in changes of the surface topography.

Third, a statistically significant difference could not be calculated for the patient positioning procedures. Ranking of the coefficients of variation by positioning procedure revealed no clear difference between procedures.

RECOMMENDATIONS

The following recommendations can be made to investigators in the field of Moire Topography and Spinal Deformity:

1) investigations should be pursued to examine the reasons for the lack of normality of repeated measurements;

2) the measurement problem of assigned values and missing values should be resolved before further studies are done;

3) useful variables which are independent of differences due to positioning should be sought.

APPENDIX I

Patient Positioning Instructions

General Information

The equipment which you see is used to create a contour map on your back. In the same way as a geographical contour map cites the elevation of a landscape a black and white photograph of your back will record the shape and allow us to determine the height of the prominences on your back.

While you stand in each of the positioning devices, which I will instruct you how to use later, the Clinical Shape Monitor (CSM) will be moved quite close to the surface of your back. This is important so that the darkest possible contour lines will be created.

In order to record your back shape your back must be bare from the neck to the mid-buttocks region and its width. A total of 30 photographs will be taken, 10 photographs using each of the three methods of positioning will be taken.

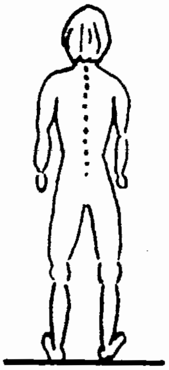
Special Instructions for the use of each Positioning Device:

1. Standing - Two photographs will be taken with your heels on that line in a comfortable standing position. When you are standing there allow your arms to hang loosely at your sides, look straight ahead and breath normally. I will remind you of these things when the pictures are taken to ensure that the correct position is assumed.

2. Inclined - Notice that this positioner is not attached to the wall. It leans on the wall. To position your feet, place them between the upright bars so that you can feel the horizontal bar at the bottom touch the front of your ankles. Now lean forward against the upright bars. You should feel your hip bones rest against the upright bars and if possible your shoulders as well. Let your arms hang loosely at your sides, look straight ahead, and breath normally.

3. Seated - Sit on the edge of the chair with your feet apart and knees bent. Bend forward with your arms hanging. Now press your palms and fingers together. Line your fingers up with the line on the floor and also look at the line. Breath normally (Harada et. al 1981).

1



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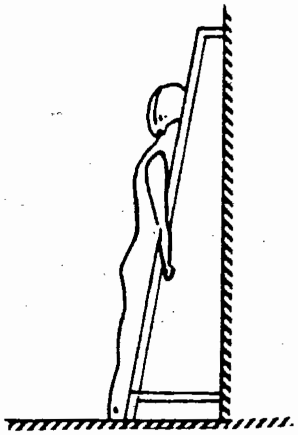

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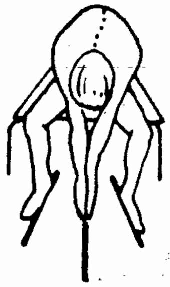

APPENDIX II

Standard Deviation (s) and mean ($\bar{X}$) values of each variable for each subject in each position

Lateral Deviation (cm)

	Subject 1		Subject 2		Subject 3	
	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$
Position 1	±0.219	-0.15	±0.184	-0.03	±0.323	0.50
Position 2	±0.682	-0.19	±0.470	0.42	±0.342	-1.19
Position 3	±0.646	-0.80	±0.924	0.25	±0.228	-0.92

Arclength Ratio

	Subject 1		Subject 2		Subject 3	
	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$
Position 1	±0.010	1.02	±0.018	0.97	±0.009	0.96
Position 2	±0.020	1.01	±0.005	0.98	±0.011	1.02
Position 3	±0.007	1.03	±0.017	0.98	±0.007	1.02

Hump Height (cm)

	Subject 1		Subject 2		Subject 3	
	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$
Position 1	±0.448	-0.55	±0.356	-0.56	±0.328	-0.11
Position 2	±1.020	0.37	±0.262	-0.84	±0.589	-0.94
Position 3	±0.810	0.11	±0.577	-0.47	±0.557	-0.42

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Standard Deviation (s) and mean ($\overline{X}$) values of each variable for each subject in each position continued ...

Rotation Index (—-)

	Subject 1		Subject 2		Subject 3	
	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$
Position 1	±1.220	-1.54	±1.200	-0.56	±0.975	-0.30
Position 2	±3.300	0.77	±0.771	-2.70	±1.790	-2.71
Position 3	±2.310	-0.53	±1.630	-1.65	±0.293	-1.85

Hump Angle (degrees)

	Subject 1		Subject 2		Subject 3	
Position 1	±3.120	-2.49	±2.610	-0.46	±2.160	-0.73
Position 2	±4.650	1.33	±1.110	-3.52	±1.390	-4.20
Position 3	±3.910	-1.03	±2.500	-2.21	±0.659	-3.39

APPENDIX III

CSM Accuracy Report - NRC

MERU Shadow Moiré Clinical Shape Monitor (MERU-CSM)

The NRC test model, designed to evaluate the performance of moiré instruments, was used to produce test photographs with the MERU-CSM. The test model consists of various sloping surfaces and a number of control points with known XYZ coordinates. The layout of the control points and their XYZ coordinates are shown on the attached sketch representing one quart of the model surface. The same coordinate values are applicable to the corresponding points on the other three sections of the model.

The photographs were taken while the outside reference surface of the test model was parallel to the MERU-CSM screen and practically in contact with it. A Contax RTS camera with a 50mm Zeiss lens was used. The camera was focussed at 3m and a lens opening f:8 was used. The following distances were set between the camera lens and the light source:

photo #1	d = 392.1mm
#2	457.2mm
#3	548.3mm
#4	685.0mm
#5	912.8mm

In order to increase the depth over which the fringes could be identified, a slit, approximately 10mm wide, was placed in front of the electronic flash. The use of the slit increased the distance, over which a satisfactory fringe image quality was obtained, to more than 30cm which was adequate to cover the entire depth of the test model. Without the slit, fringes could only be identified over a distance of about 20cm from the screen.

The fringe number, estimated to one tenth of the fringe interval was read on the different photographs for twelve symmetrically located targets of the test object (see photo #1). For targets with the same Z-coordinate the readings were averaged in order to minimize the effect of a possible lack of parallelism of the screen with respect to the test object reference surface. The averaged fringe values were used to calculate the distance between the screen and the targets using the equation:

$$h_N = \frac{N\ell s}{d - Ns}$$

with the given values for d, ℓ and s and the average recorded fringe value N. The calculated values h_N were compared with the corresponding Z-coordinates of the test object. The following results were obtained:

photo #1 (d = 392.1mm)	A satisfactory moiré pattern was obtained over the entire depth of the test object (300mm). The errors are generally within 2.4mm ($\frac{1}{3}$ fringe) for 12 observed points.
photo #2 (d = 457.2mm)	A satisfactory moiré pattern was obtained over the entire depth of the test object, although some difficulty was

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	experienced to read points on the vertical surface which is inclined towards the light source. Errors are generally within 4.3mm ($\frac{2}{3}$ fringe) for 12 observed points.
photo #3 (d = 548.3mm)	Points on the vertical surface, inclined towards the light source could only be read with difficulty. Errors are generally within 5.4mm (1 fringe) for 12 observed points.
photo #4 (d = 685.0mm)	The image quality of the fringes, on both vertical surfaces does not allow for a precise identification of the fringes. For the horizontal surfaces the errors are generally within 3.9mm (1 fringe) for 6 observed points.
photo #5 (d = 912.8mm)	The overall image quality does not permit a precise identification of the fringes.

Two sets of test photographs were made approximately two weeks apart. Comparison of corresponding photographs indicated that the results were repeatable within one fringe. It should be noted however that extreme care has to be taken to install the camera and the light in their correct positions and orientations with respect to the screen. We feel that a more positive setting of the camera and the lightsource is essential to obtain the necessary repeatability. This is particularly important when the instrument is to be used by different persons who not necessarily may have the capability to adjust the various components of the instrument with a sufficient degree of accuracy.

Ottawa, March 1983

M.C. van Wijk
Photogrammetric Research
Division of Physics
National Research Council

APPENDIX IV

Raw Data - the maximum value of each variable, representing the maximum deformity of the four cross-sections digitized, was used to determine the standard deviations. The maximum values are presented in the following table. See the author for the complete raw data files.

RAW DATA - NORMAL SUBJECTS

Subject 1 - seated position

Trial #	L. Dev.	Arclength	Hump Height	Rib Hump	Hump Angle
1	-0.15	1.04	-0.55	-1.53	-10.65
2	-0.45	1.03	-1.08	-2.89	- 3.04
3	0.00	1.02	-1.12	-3.01	- 2.77
4	0.00	1.02	0.00	0.00	0.00
5	0.00	1.02	0.00	0.00	0.00
6	0.00	1.04	0.00	0.00	0.00
7	0.00	0.98	-0.55	-2.05	-2.36
8	-0.43	1.02	-0.55	-1.51	-1.49
9	0.00	1.02	-0.55	-1.48	-1.53
10	-0.51	1.02	-1.09	-2.93	-3.10

Subject 1 - free standing position

1	-1.10	1.03	-1.63	-5.94	-7.19
2	-0.65	1.03	-0.52	-1.66	-2.73
3	-0.54	1.02	1.06	2.93	5.33
4	0.46	1.01	-0.53	-1.73	-2.70
5	-0.36	1.01	1.06	2.85	4.12
6	0.43	0.98	1.06	2.81	4.72
7	-0.42	1.03	-0.53	-1.69	-2.79
8	0.81	1.02	1.06	2.88	4.41
9	0.51	0.98	1.58	4.35	5.11
10	-0.99	1.03	1.06	2.87	4.97

Subject 1 - inclined position

1	-1.49	1.04	-0.53	-1.67	-2.72
2	-1.42	1.03	-0.52	-2.05	-4.01
3	-0.58	1.03	-1.04	-1.65	-2.71
4	-1.09	1.04	-1.04	-3.25	-5.50
5	-0.47	1.03	-0.52	-1.63	-2.76
6	-0.54	1.03	1.06	2.91	4.81
7	-0.60	1.03	-0.52	-1.65	-2.71
8	-1.54	1.02	-0.52	-1.63	-2.70
9	-0.90	1.04	1.03	2.60	5.09
10	0.61	1.02	1.04	2.71	3.79

RAW DATA - NORMAL SUBJECTS CONTINUED

Subject 2 - seated position

Trial #	L. Dev.	Arclength	Hump Height	Rib Hump	Hump Angle
1	0.00	0.98	-0.53	-1.88	-3.05
2	0.00	0.97	-0.52	-1.85	-2.31
3	0.00	0.98	-0.51	-1.77	-2.91
4	0.00	0.99	0.00	0.00	0.00
5	0.27	0.93	0.55	1.68	5.93
6	0.00	0.98	0.00	0.00	0.00
7	0.00	0.96	0.00	0.00	0.00
8	-0.11	0.95	-0.51	-1.77	-2.23
9	-0.48	0.98	0.00	0.00	0.00
10	0.00	0.98	0.00	0.00	0.00

Subject 2 - free standing position

1	0.56	0.98	-0.53	-1.81	-2.57
2	0.73	0.98	-0.53	-1.80	-2.49
3	-0.46	0.98	-1.05	-3.63	-5.17
4	-0.43	0.98	-1.02	-3.05	-3.34
5	0.39	0.98	-1.03	-2.97	-3.17
6	0.55	0.97	-1.06	-3.57	-4.95
7	0.70	0.98	-0.53	-1.81	-2.62
8	0.73	0.98	-0.54	-1.83	-2.54
9	0.78	0.98	-1.02	-2.90	-3.23
10	0.65	0.97	-1.05	-3.66	-5.08

Subject 2 - inclined position

1	-0.36	0.98	-1.04	-2.82	-2.87
2	-1.40	0.99	-0.52	-1.77	-2.64
3	-0.21	0.98	-0.53	-1.77	-2.83
4	1.53	0.97	-0.53	-1.78	-2.56
5	0.69	0.96	-1.05	-3.64	-5.39
6	0.95	0.97	-0.53	-1.88	-2.46
7	0.52	0.97	1.05	2.64	4.47
8	0.73	0.98	-0.53	-1.86	-2.61
9	-0.90	1.02	-0.54	-1.91	-2.66
10	0.90	0.97	-0.52	-1.79	-2.55

RAW DATA - NORMAL SUBJECTS CONTINUED

Subject 3 - seated position

Trial #	L. Dev.	Arclength	Hump Height	Rib Hump	Hump Angle
1	0.70	0.94	0.50	1.57	3.20
2	0.38	0.97	-0.55	-1.53	-4.07
3	0.35	0.96	0.00	0.00	0.00
4	0.47	0.96	0.00	0.00	0.00
5	0.38	0.96	0.00	0.00	0.00
6	-0.13	0.97	0.00	0.00	0.00
7	0.31	0.97	0.00	0.00	0.00
8	0.85	0.97	-0.51	-1.52	-3.23
9	1.02	0.96	0.00	0.00	0.00
10	0.63	0.96	-0.52	-1.53	-3.19

Subject 3 - free standing position

1	-1.51	1.02	-1.07	-3.34	-4.20
2	-0.95	1.01	-1.09	-3.50	-4.05
3	-1.47	1.04	-1.04	-3.24	-4.14
4	-1.36	1.01	-1.05	-3.28	-4.18
5	-1.34	1.04	-1.04	-3.25	-4.66
6	-1.06	1.03	-1.05	-2.20	-3.85
7	-0.63	1.01	-0.52	-1.63	-2.24
8	-1.50	1.02	-1.56	-5.07	-6.72
9	-1.42	1.02	-1.53	-3.27	-5.78
10	-0.66	0.97	0.52	1.71	-2.11

Subject 3 - inclined positioning

1	-0.95	1.01	-0.53	-1.63	-2.87
2	-0.86	1.02	-0.53	-1.59	-3.01
3	-0.86	1.03	-0.54	-1.63	-3.02
4	-0.80	1.02	-0.54	-1.93	-3.91
5	-0.77	1.02	-0.54	-1.69	-2.48
6	-0.76	0.96	-1.07	-2.36	-4.44
7	-0.64	1.02	0.55	-1.86	-3.33
8	-1.34	1.03	-0.53	-1.61	-2.95
9	-1.30	1.02	-1.06	-2.36	-4.36
10	-0.91	1.02	0.55	-1.86	-3.54

RAW DATA - SCOLIOTIC PATIENT

Scoliotic Patient - seated position

Trial #	L. Dev.	Arclength	Hump Height	Rib Hump	Hump Angle
1	0.29	0.97	-0.54	-1.68	-2.04
2	0.45	0.94	-0.53	1.96	3.96
3	0.00	0.95	0.57	2.03	6.77
4	0.05	0.95	-0.52	-1.97	-2.52
5	0.00	0.94	-0.55	2.06	3.71
6	0.00	0.93	-0.57	-2.07	-2.50
7	0.00	0.95	-0.58	-1.99	-2.79
8	0.00	0.96	-1.09	-3.46	-7.18
9	0.00	0.93	-0.56	2.09	-6.78
10	0.00	0.96	0.00	0.00	0.00

Scoliotic Subject - free standing positioning

1	1.07	0.96	1.09	3.62	4.04
2	-0.48	0.96	1.09	4.44	4.34
3	-0.20	0.96	1.10	4.55	4.27
4	1.11	0.96	1.08	3.58	4.06
5	1.49	0.94	1.10	3.24	4.37
6	1.34	0.97	1.10	3.94	4.50
7	-0.30	0.96	1.07	4.35	4.52
8	1.03	0.96	1.07	3.63	4.11
9	-0.36	0.96	1.10	4.49	4.72
10	-0.39	0.96	1.10	4.43	4.28

Scoliotic Patient - inclined position

1	-0.53	0.96	1.08	4.39	4.26
2	2.16	0.97	1.61	4.80	6.41
3	1.83	0.94	1.63	4.90	6.41
4	-0.61	0.96	1.10	4.43	4.44
5	-0.41	0.95	1.08	4.33	4.56
6	0.59	0.93	1.62	6.97	7.04
7	1.77	0.95	1.10	4.70	5.67
8	-0.39	0.94	1.10	4.44	4.49
9	0.95	0.95	0.55	2.27	2.96
10	-0.32	0.95	1.09	4.80	5.47

REFERENCES

Aaro S, Burgstrom R, Dahlborn M; The Derotating Effect of the Boston Brace - A Comparison Between Computer Tomography and a Conventional Method; Spine, Vol. 6, Number 5: 477-482, 1981.

Aaro S, Dahlborn M; The Longitudinal Axis Rotation of the Apical Vertebra, the Vertebral, Spinal and Rib Cage Deformity in Idiopathic Scoliosis Studied by Computer Tomography; Spine, Vol. 6, Number 6: 567-572, 1981.

American Academy of Orthopaedic Surgeons; Atlas of Orthotics - Biomechanical Principles and Application; The C. V. Mosby Company, Saint Louis, 1975.

Armstrong G, Livermore N, Suzuki N, Armstrong J; Nonstandard Vertebral Rotation in Scoliosis Screening Patients. Its Prevalence and Relation to the Clinical Deformity; Spine, Number 7: 50-54, 1982.

Axelgaard J, Brown J; Lateral Electrical Surface Stimulation for the Treatment of Progressive Idiopathic Scoliosis; Spine, Vol. 8, Number 3: 242-260, 1983.

Bannon M, Tredwell S; Clinical Decision Making - The Role of Relative Moire Measurements; Proceedings of the Symposium on Surface Topography and Spinal Deformity, 1984.

Berg U, Aaro S; Long-Term Effect of Boston Brace Treatment on Renal Function in Patients with Idiopathic Scoliosis; Clinical Orthopaedics and Related Research, Number 180: 169-172, 1983.

Blount W, Moe J; The Milwaukee Brace - Second Edition; Williams & Wilkins Company, Baltimore, 1980.

Bobechko W; Electrical Stimulation in Scoliosis, Functional Neuromuscular Stimulation; Washington, D. C., National Academy of Sciences, pp 145, 1972.

Bunnell W; A Study of the Natural History of Idiopathic Scoliosis; Orthopaedic Transactions Number 7: 6, 1983.

Cobb J; Outline for the Study of Scoliosis; Am. Acad. Orthop. Surg. Lect., Number 5: 261-275, 1948.

Cochran T, Nachemson A; Long-Term Anatomic and Functional Changes in Patients with Adolescent Idiopathic Scoliosis Treated with the Milwaukee Brace; Spine, Vol. 10, Number 2: 127-133, 1985.

Cryer J; Time-Series Analysis - Data Processing; Duxbury Press, 1986.

Dorland's Illustrated Medical Dictionary - Twenty-sixth Edition; W. B. Sanders Company, Toronto, 1981.

Enneking W, Harrington P; Pathological Changes in Scoliosis; Journal of Bone and Joint Surgery, Vol. 51-A, Number 1: 165-184, 1969.

Haderspeck K, Schultz A; Progression of Idiopathic Scoliosis - An Analysis of Muscle Actions and Body Weight Influences; Spine, Vol..6, Number 5: 447-455, 1981.

Harada Y, Takemitsu Y, Imai M; The Role of Contour Line Photogaphy Using Light Cutting Method and Moire Topography In School Screening For Scoliosis; Moire Fringe Topography and Spinal Deformity, Proceedings of an International Symposium; Pergamon Press, Toronto, pp. 113-121, 1981.

Heirholzer E, Frobin W; Rastersterographic Measurement and Curvature Analysis of Body Surface of Patients With Spinal Deformities; Moire Fringe Topography and Spinal Deformity, Proceedings of an International Symposium; Pergamon Press, Toronto, pp. 267-276, 1981.

Jonasson-Rajala E, Josefsson E, Lundberg B, Nilsson H; Boston Thoracic Brace in the Treatment of Idiopathic Scoliosis - Initial Correction; Clinical Orthopaedics and Related Research, Number 183: 37-41, 1984.

Kahanovitz N, Snow B, Pinter I; The Comparative Results of Psychological Testing in Scoliosis Patients With Electrical Stimulation or Bracing; Spine, Vol. 9, Number 5: 442-444, 1984.

Klugh, H; Statistics: The Essentials for Research - Second Edition; John Wiley & Sons, Inc., New York, 1974.

Laurnen E, Tupper J, Mullen M; The Boston Brace in Thoracic Scoliosis - A Preliminary Report; Spine, Vol. 8, Number 4: 388-395, 1983.

Lonstein J, Carlson J; The Prediction of Curve Progression in Untreated Idiopathic Scoliosis during Growth; Journal of Bone and Joint Surgery, Vol. 66-A, Number 7: 1067-1071, 1984.

McDormand C; Children's Hospital Radiography Department; Personal Communication, 1985.

McDormand C, Pel T; Scoliosis Radiography - Let's Reduce Patient Exposure; submitted to the Canadian Journal of Radiography, Radiotherapy and Nuclear Medicine, 1985.

Miles C, Speight B; Recording the Shape of Animals by a Moire Method; Journal of Phys. E.: Scientific Instruments, Vol. 8, 1975.

Miller JAA, Nachemson AL, Schultz AB; Effectiveness of Braces in Mild Idiopathic Scoliosis; Spine, Vol. 9, Number 6: 632-635, 1984.

Moe J, Winter R, Bradford D, Lonstein J; Scoliosis and Other Spinal Deformities; W. B. Saunders Company, Toronto, 1978.

Moe J, Kharrat K, Winter R, Cummine J; Harrington Instrumentation Without Fusion Plus External Orthotic Support for the Treatment of Difficult Curvature Problems in Young Children; Clinical Orthopaedics and Related Research, Number 185: 35-45, 1984.

Munster, Germany 1983; Proceedings of the Second International Symposium on Moire Fringe Topography and Spinal Deformity; September 13-15 1982.

Nash C, Moe J; A Study of Vertebral Rotation; Journal of Bone and Joint Surgery, Number 51-A: 223-224, 1969.

Nordvall A; Studies in Idiopathic Scoliosis. Relevant Etiology, Conservative and Operative Treatment; Acta Orthop. Scan. (Suppl) Number 150: 91-94, 1973.

Nottage W, Waugh T, McMaster W; Radiation Exposure During Scoliosis Screening Radiography; Spine, Vol. 6, Number 5: 456-459, 1981.

Ohtsuka Y, Shinota A, Inoue S; Application of Moire Topography and Low-Dose X-Ray Imaging to School Screening Program of Scoliosis; Moire Fringe Topography and Spinal Deformity, Proceedings of an International Symposium, Pergamon Press, pp. 102-112, 1981.

Quenouille M; Introductory Statistics; Pergamon Press, Oxford, 1966.

Risser J; Clinical Evaluation of Scoliosis; The Journal of the American Medical Association, Vol. 164: 134-136, 1957.

Risser J; Scoliosis: Past and Present; The Journal of Bone and Joint Surgery; Vol. 46-A, Number 1: 167-199, 1964.

Roger R, Stokes I, Harris J, Turner-Smith A; Monitoring Scoliosis with Serial Measurements of Three-Dimensional Back Shape - The Use of Moire Photography and Computer Shape-Matching Techniques; Moire Fringe Topography and Spinal Deformity - Proceedings of an International Symposium, Pergamon Press, Toronto, pp. 258-266, 1981.

Rudicel S, Renshaw T; The Effect of the Milwaukee Brace on Spinal Decompensation in Idiopathic Scoliosis; Spine, Vol. 8, Number 4: 385-387, 1983.

Sahlstrand T, Ortengren R, Nachemson A; Postural Equilibrium In Adolescent Idiopathic Scoliosis; Acta Orthop. Scand., Vol. 49, Number 4: 354-365, 1978.

Schultz A, Haderspeck K, Takeshima S; Correction of Scoliosis by Muscle Stimulation - Biomechanical Analysis; Spine, Vol. 6, Number 5: 468-476, 1981.

Shinoto A, Ohtsuka Y, Inoue S; Quantitative Analysis of Scoliosis and Kyphosis Deformity By Moire Method; Moire Fringe Topography and Spinal Deformity, Proceedings of an International Symposium; pp. 206-224, Pergamon Press, Toronto, 1981.

Takasaki H; Moire Topography and its Application to Human Body; Moire Fringe Topography and Spinal Deformity, Proceedings of an International Symposium; pp. 1-17, Pergamon Press, Toronto, 1981.

Takasaki H; Moire Topography and Its Birth to Practical Application; Optics and Lasers in Engineering 3, Applied Science Publishers Ltd., England, 1982.

Tredwell S; University of British Columbia, Department of Orthopaedics; Personal Communication, 1980.

Tredwell S, Bannon M; Use of Shadow Moire Topography in Predicting Clinical Changes in Scoliosis; Scoliosis Research Society Proceedings, San Diego, 1985.

Tuckman B; Conducting Educational Research; Harcourt Brace Jovanovich, Inc., New York, 1972.

Uden A, Willner S, Pettersson H; Initial Correction With the Boston Thoracic Brace; Acta Orthop. Scan., Vol. 53: 907-912, 1982.

Vermont, U.S.A. 1980; Proceedings of an International Symposium on Moire Fringe Topography and Spinal Deformity; September 22-24 1980.

Willner S; Effect of the Boston Thoracic Brace on the Frontal and Sagittal Curves of the Spine; Acta Orthop. Scan., Vol. 55: 457-460, 1984.

Windischbauer G; Moire-Contourography - Recommendations for Standardization Criteria Based on Computer Aided Modelling; Moire Fringe Topography and Spinal Deformity, Proceedings of an International Symposium; pp. 244-248, Pergamon Press, Toronto, 1981.

Zorab P (ed.); Scoliosis and Growth, Proceedings of a Third Symposium held at the Institute of Diseases of the Chest, Brompton Hospital, London, November 13, 1970. London, Churchill Livingston, 1971.