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MATHEMATICAL MODELING OF SCOLIOSIS INDICATORS IN GROWING CHILDREN[¶]

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ABSTRACT

Scoliosis is a disease, which distorts body shape and is associated with many complications if left untreated. Idiopathic scoliosis, generally, becomes evident around the age of 8 *years*. A two-minute-unclothed examination of primary school students may alert the pediatric orthopedist to early-warning signals, which are expressed as a mathematical index, named as 'Normalized-Scoliosis-Risk Weightage' (NSRW). NSRW is a modification of index proposed earlier, 'Cumulative-Scoliosis-Risk Weightage' (CSRW) and is expressed as a percentage. This new index is insensitive to number of tests included to compute its value and hence could be compared for different sessions, having a varying number of tests. Both NSRW and CSRW are based on family history, age, statuses of being tall and/or wasted, forward bending tests, non-alignment of plumb-line, shoulder drooping, uneven scapulae, back-midline shape, unequal body triangles, uneven spinal dimples and positive moiré/dotted-raster. A high NSRW calls for a through physical examination ruling out scoliosis-like conditions, *e. g.*, leg-length inequality and hip weakness, before sending the child for X rays. This is necessary to reduce unwarranted X rays, which are harmful to bone marrow of growing youngsters. A mathematical model is proposed and tested on 7- and 8-*year* old students of a local school to separate scoliosis-like conditions from true scoliosis (lateral curvatures and rotations of the spinal column), 'Differential-Spinal-Function Testing' (DSFT) was conducted, consisting of four tests, visual (standing), visual (sitting), forward bending (standing) and forward bending (sitting). This paper reports effectiveness of NSRW in predicting lateral curvatures and spinal rotations.

Keywords: Spinal-deformity modeling, Cumulative-Scoliosis-Risk Weightage (CSRW), Normalized-Scoliosis-Risk Weightage (NSRW), Differential-Spinal-Function Testing (DSFT)

LIST OF ABBREVIATIONS

AP: **A**ntero**p**osterior
CSRW: **C**umulative-**S**coliosis-**R**isk **W**eightage
DSFT: **D**ifferential-**S**pinal-**F**unction **T**esting
NGDS: **N**ational **G**rowth and **D**evelopmental **S**tandards for the Pakistani Children
NSRW: **N**ormalized-**S**coliosis-**R**isk **W**eightage
SF: The **S**yed **F**irdous Growth-and-Imaging Laboratory, University of Karachi
SGPP: **S**ibling **G**rowth **P**ilot **P**roject — a subproject of the NGDS Pilot Project

INTRODUCTION

One could observe primary-school children going to their schools any morning. Heavy school bags, sometimes worn on one shoulder only, lack of outdoor exercise depriving their bodies from fresh air and sunshine, consumption of snacks and junk food instead of healthy food, all contributing towards scoliosis, a condition defined as lateral curvatures and rotations of the spinal column. If untreated, this condition, severely, affects quality of life, causing morbidity and, in severe cases, mortality.

Anthromathematics (mathematics of body sizes, forms, proportions and structures) of the human spinal column is going to be one of the most active areas of research in this century, which should involve mathematical-computer modeling of the scoliotic spine, so that one understands better the etiology and the prognosis of scoliosis, which is defined as lateral curvatures and rotations of the spinal column.

This paper describes a scoliosis-screening program implemented in a local school during 2011-2013. A number of tests were conducted and mathematical modeling done to come up with a criterion indicating risk for acquiring scoliosis. This criterion is not sensitive to the number of tests performed. Hence, the results obtained could be compared for tests conducted during different sessions, in which the number of tests available is different. In this work, the authors give a threshold value of this criterion. The students, having a value larger than this threshold, should be subjected to further thorough examination and kept under observation till the end of their growth periods.

[¶]Main contribution of PhD dissertation of the second author, registered from Department of Mathematics, University of Karachi

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Fig. 1*a*-*f*. Visual examinations (*a*-*c*) and forward-bending tests (*d*-*f*) for scoliosis case finding

MONITORING THE SCOLIOTIC CURVE

Scoliosis, a potentially body-disfiguring condition, needs to be detected through screening and case finding (Labelle *et al.*, 2013). Once detected, the condition needs to be documented through photographs, quantified through X rays and a suitable management strategy decided by a team of orthopedic surgeons, which should include observation and follow up, exercises (Negrini *et al.*, 2015) as well as brace treatment and, in severe cases, surgical correction. A thorough neuro-orthopedic evaluation should be performed prior to deciding treatment options (Cottalorda *et al.*, 2012). Adobor *et al.* (2012) describe scoliosis detection, patient characteristics, referral patterns and treatment in the absence of a screening program in Norway. In a later work, they evaluate health economics of screening and treatment in patients with adolescent idiopathic scoliosis (Adobor *et al.*, 2014). During the last few years interest has increased in early onset scoliosis (Bialek, 2015; Tis *et al.*, 2012). At times, it appears in combination with other conditions (Persson-Bunke *et al.*, 2012). It is suggested to visualize spinal deformity in the wider context of trunk deformity (Carlson *et al.*, 2013).

The Power of Inspection: *Visual Examinations and Forward-Bending Tests*

Eighty percent of physical examination consists of inspection. This method does not require any special equipment and arrangement. The only requirements are good natural light, appropriate body exposure and expertise of screener. For scoliosis case finding, the unclad student should be subjected to visual examinations and forward-bending tests (Figures 1*a*-*f*). These checks, however, generate a large number of false positives and other methods have been employed to detect and document the curve.

Cobb Method of Documenting the Curve

Although Ferguson and Tideström methods have been reported in the literature, Scoliosis Research Society recommends to work only with the Cobb method, also called 'end-of-the-curve method'. Cobb suggested that the curvature angle be determined by lines drawn parallel to top border of the upper vertebral body of the primary curve. However, the major disadvantages of this approach are that the method does not specify the location of curve (a thoracic curve or a lumbar curve), length of the curve (a short curvature of congenital scoliosis is different from a long stretched curvature an idiopathic scoliosis), form of the curve (an S curve or a C curve; same angle may be exhibited by different forms) as well as rotation and torsion. This led to the need for modeling at the vertebral level. Some of the attempts are given in the next section.

Historical Methods

Measuring methods for monitoring the scoliotic curve include 3-D-laser scanning (V3D I/800/medical video-laser system — body digitizer), AP-X rays, deformed grating, graph screen, height-difference-measuring method (formulator body contour), inclinometer, ISIS (Integrated-Surface-Imaging System), multi-light-cutting method, the Newcastle Ultrasound Imaging System, ocular inspection and palpation, pantograph, phase-measuring profilometry and modal analysis, silhoutter, stereophotogrammtery and TAUSS (Tel-Aviv University Stereometry System).

Drawbacks of Some Traditional Methods

AP-X rays of backbone show the entire spinal column from external auditory meatus to hip joint (patient in the attention position). Although, still considered as confirmatory test, there are concerns about the harmful effects of

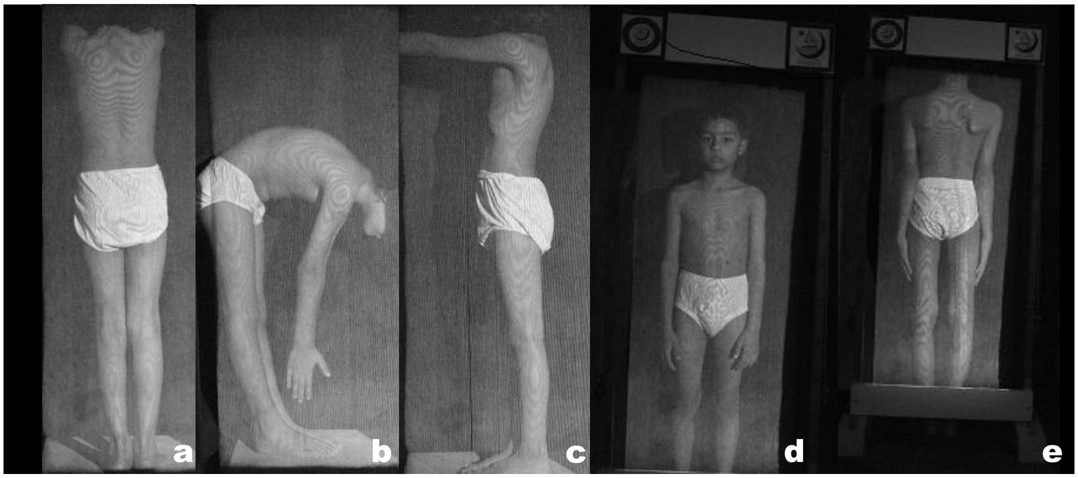

Fig. 2*a-e*. Moiré topography in various postures to document scoliosis

radiation on the delicate bone marrow of growing children. Other methods have shortcoming that they distort the condition one wants to observe, *e. g.*, pantograph may alter the curve by tactile stimulation. More and more interest is developing in non-destructive, non-invasive and non-contact systems, which could provide a permanent record, preferably, in three dimensions.

Moiré Fringe Topography

Moiré fringe topography is such an optical technique that produces shadow patterns (fringes), which can be arranged to provide a map of three-dimensional surfaces by generating contours, which are curves of constant distance from the moiré grid. When a family of curves is superposed on another family of curves a new family appears, the moiré pattern. To produce the effect, the overlapping lines should intersect at an angle of less than 45^0. Unlike contouring with holographic techniques, stability is not required. The resolution moiré contouring systems can be varied continuously. The moiré pattern on the back of a student in attention position alerts the screener to asymmetry about the sagittal plane as well as rotations of the spinal column (Figures 2*a-e*). Hence, it becomes useful in screening and case finding for scoliosis (Kamal *et al.*, 2013*c*).

Rasterstereography

Rasterstereography is similar to stereophotography. One of the cameras is replaced by a multimedia projector and a raster is projected on the body, which is distorted because of the curvatures of the body. Information about the curvatures of human body may be obtained from special algorithms (Figures 3*a-d*). Unlike moiré fringe topography, where the set-up requires special arrangement, rastersteregraphy set-up is simple. On the other hand, interpretation of moiré fringes is simple, whereas analysis and interpretation of rasterstereography information requires complex algorithms (Kamal *et al.*, 2013*a*).

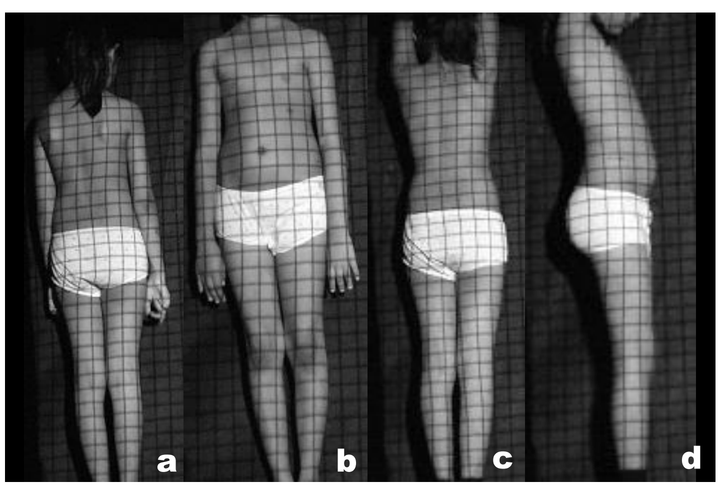

Fig. 3*a-d*. Rasterstereography in various positions to document scoliosis

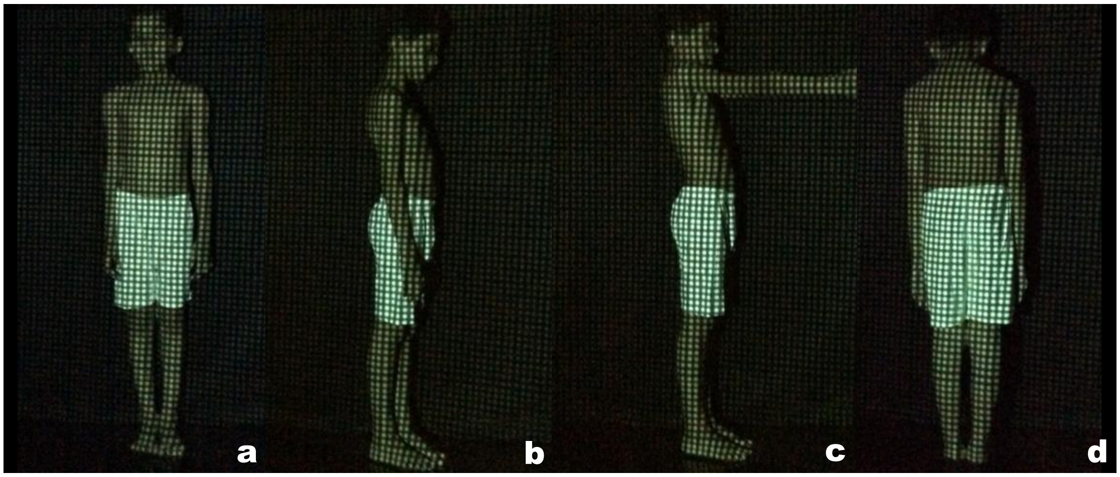

Fig. 4*a*-*d*. Dotted-rasterstereography in various positions to document scoliosis

Dotted-Rasterstereography

The noise effect in rasterstereography (square grid projected on body) was minimized (broken lines; features not extractable) by using dotted-raster, consisting of green dots (Wasim *et al.*, 2013). The positions of dots were easily located, which helped extraction of body curvatures (Figures 4*a*-*d*).

REVIEW OF MODELS OF THE HUMAN SPINAL COLUMN

In order to understand nature of scoliosis and devise effective intervention strategies, it is necessary to understand thoroughly the human spinal column. In this section, we, briefly, describe anatomy of the spinal column and some attempts of modeling this structure.

The human spinal column consists of 33 vertebrae. Out of these 33, top 7 lie in the cervical region, next 12 form the thoracic region, another next 5 constitute the lumbar region and the last 9 make up the sacral region.

Two-Dimensional Models

2-D models generate frontal view from spinal projections obtained from AP-X rays or moiré topographs of back, both in the attention position (Oxborrow, 2000). There were attempts to obtain Cobb angles from back moiré pictures (Kamal, 1982*b*; El-Sayyad and Kamal, 1981).

Three-Dimensional Models

Spinal column is such a structure, which exists in three-dimensional space. AP-X-ray pictures are, therefore, not capable of properly visualizing kyphosis or lordosis. 3-D-spinal-column models synthesize full view from spinal projections in the sagittal and the frontal planes, generated from lateral and AP-X-ray pictures. However, only one back moiré topograph in the attention position was able to generate both views (Kamal 1982*a*). Recently, Bella *et al.* (2014) have tried to define shape of spine using moiré method.

3-D-static models were developed simultaneously in Germany (Hierholzer and Lüxmann, 1982) and in United States (Kamal, 1982*b*; 1983*a*; *b*). Natural curvatures of the spine, visible in lateral projection, were included later (Kamal, 1987). 9 *years* later, a comprehensive model was presented (Kamal, 1996*a*). From X-ray or moiré measurements, a parabolic curve was generated, relating *x*, *y* and *z* where

(1*a*-*c*) $$x = x(\xi), y = y(\xi), z = z(\xi)$$

which was a best fit to discrete measurements performed at different locations represented by the parameters, ξ_{i}; i = 1,…,33; corresponding to 33 vertebrae of the spinal column. The parameters ξ_{i} were visualized as lengths measured along spinal column with origin at the level of external auditory meatus, the length increasing towards hip joint. In the neighborhood of any point on the spinal column, this curve was represented by

(2) $$x = f(y,z) = \frac{1}{2}ay^2 + byz + \frac{1}{2}cz^2$$

where $a = a(\xi_{\mathrm{i}}), b = b(\xi_{\mathrm{i}}), c = c(\xi_{\mathrm{i}}),$ values of these parameters were found by solving simultaneous equations generated using equation (2) for three neighboring values of (*x*, *y*, *z*). For this purpose, equation (2) was written as

(3*a*-*c*) $$x(\delta_i) = \frac{1}{2} a(\xi_i) y^2(\delta_i) + b(\xi_i) y(\delta_i) z(\delta_i) + \frac{1}{2} c(\xi_i) z^2(\delta_i)$$

where $\delta_i = \xi_i - \Delta$ in equation (3*a*), $\delta_i = \xi_i$ in equation (3*b*) and $\delta_i = \xi_i + \Delta$ in equation (3*c*), $\Delta << \xi_i$, assuming that values of *a*, *b* and *c* were same for these closely-located points. The cross term (yz) vanished, when the coördinate mesh (the word 'mesh' is used in the spirit that the three unit vectors along the *x* axis, the *y* axis and the *z* axis, respectively, are related through the orthonormality conditions) was rotated clockwise about the *x* axis through an angle α

(4*a*, *b*) $$y = y_{rot} \cos\alpha + z_{rot} \sin\alpha, z = -y_{rot} \sin\alpha + z_{rot} \cos\alpha$$

where

(5) $$\alpha = \frac{1}{2} \tan^{-1} \frac{2b}{c-a}$$

The curvatures were obtained from the coefficients of squares of rotated coördinates, *i. e.*, ${y_{rot}}^2$ and ${z_{rot}}^2$

(6) $$x = f_{rot}(y_{rot}, z_{rot}) = \frac{1}{2} \kappa_{1i} {y_{rot}}^2 + \frac{1}{2} \kappa_{2i} {z_{rot}}^2$$

where

(7*a*, *b*) $$\kappa_{1i} = a + c - \frac{2b^2}{4b^2 + (c-a)^2}, \kappa_{2i} = a + c + \frac{2b^2}{4b^2 + (c-a)^2}$$

The natural curvatures in a normal child (matched by age and gender, who does not have any spinal deformity) were expressed as

(8) $$x = F_{rot}(y_{rot}, z_{rot}) = \frac{1}{2} K_{1i} {y_{rot}}^2 + \frac{1}{2} K_{2i} {z_{rot}}^2$$

where K_{1i} and K_{2i} denoted natural curvatures of a normal child. Next, the child was instructed to hang freely from a bar and improvement in the deformity observed. The curvatures were, again, determined after guarded graduated passive correction κ'_{1i} and κ'_{2i}. If K'_{1i} and K'_{2i} represented curvatures of the normal child in the hanging position, 'Degree of Correction of Spinal Deformity', *D*, was defined as

(9) $$D = \frac{50}{n} \sum_{i=1}^{33} \left[\frac{(\kappa_{1i} - \kappa'_{1i})^2}{(\kappa_{1i} - K'_{1i})^2} + \frac{(\kappa_{2i} - \kappa'_{2i})^2}{(\kappa_{2i} - K'_{2i})^2} \right] \%$$

Geometrically, if $\kappa_{1i} = \kappa'_{1i}$ and $\kappa_{2i} = \kappa'_{2i}$, there is no correction and $D = 0$. On the other hand, if $\kappa'_{1i} = K'_{1i}$ and $\kappa'_{2i} = K'_{2i}$, the deformity is completely corrected and $D = 100\%$. Table 1 shows classification of *D* as 'severe', 'intermediate' and 'mild' and lists recommended treatment in each category. This 3-D-static model was found to be useful in the study of posture of children.

The 3-D-dynamic model was a generalization of the 3-D-static model, to study movement of the human spinal column during a gait cycle (Kamal, 1996*b*).

Crystal-Structure-Based Model

Crystal-structure analogy was applied to the human spinal column, which is a collection of vertebrae in the

Table 1. Severity of 'Degree of Correction of Spinal Deformity' (*D*) and recommended treatment

Range of Degree of Correction of Spinal Deformity (*D*)	*Severity Level*	*Recommended Treatment*
$0 \le D < \frac{100}{3}\%$	Severe	Surgery
$\frac{100}{3}\% \le D < \frac{200}{3}\%$	Intermediate	To be decided by orthopedic surgeon[£]
$\frac{200}{3}\% \le D \le 100\%$	Mild	Combination of exercises and brace

[£]The decision should depend on the location and the progression of scoliotic curve as well as the numerical value of *D* — how close the value is to 33.33% (inclination towards surgical treatment) or 66.66% (inclination towards a combination of exercises and brace)

Fig. 5*a*, *b*. Matrix representing sensitivity and specificity in the context of clinical setting as well as significance of values of alpha (probability of wrong decision**:** false positive) and beta (probability of wrong decision**:** false negative)

cervical, the thoracic, the lumbar and the sacral regions, located at certain distances from each other. The center-of-mass of each vertebra was described in terms of positional coördinates (x, y, z) in the body-coördinate system. From the crystallography point-of-view, this could be visualized as 'form factor'. Adding rotational (in terms of Euler angles) and inter-vertebral-spacing information, the analysis takes the form of 'structure factor', used in solid-state physics to interpret crystal structure (Kamal *et al.*, 2012).

UNDER-TREATMENT AND OVER-TREATMENT

Under-treatment (missed diagnoses/false negatives) and over-treatment (false positives) are some of the issues, which determine efficiency (timely processing of patients) and effectiveness (screening resulting in isolation of statistically-significant cases for follow-up/treatment) of a screening program.

Theoretical Considerations

Kamal *et al.* (2013*b*) defined 'sensitivity' and 'specificity' as well as introduced two new terms, 'relative sensitivity' and 'relative specificity'. These are, briefly, described here and illustrated in Figures 5*a*, *b*. Sensitivity measures the proportion of actual positives, identified correctly. Consider a person having a certain disease. A test, conducted to find out this condition, gives positive result, then right-decision (true positive) probability may be expressed as (1–β), a measure of sensitivity. The wrong-decision probability is represented as β. This is the situation in which the disease was present, but the relevant test performed, gave negative result. This is termed as false negative (missed diagnosis), the consequence of which may be essential-medical-care denial. Such a situation could have tragic consequences, when early intervention may have provided better treatment options, *e. g.*, early detection of scoliosis may prevent a lot of suffering for a teenager. A smaller value of β increases test sensitivity, which has higher performance. However, in such a situation reliability decreases. Missed diagnoses result, when β is close to unity. In this situation, there is a high false-negative rate and the test is less sensitive, generating a mistaken perception of acceptability, which is an issue of safety. Specificity gives the proportion of actual negatives, identified correctly. Let us take the example of a person not having a disease. However, a test, conducted to find out this condition generates negative result, then right-decision (true negative) probability may be represented by (1–α), a measure of specificity. The wrong-decision probability is expressed as α, a situation in which the disease is not present, but the relevant test conducted gives positive result. This is termed as false positive, which may become cause of over-treatment. Such a situation could inflict economic burden and distress in patient life. For example, scoliosis surgery carries risk of paralysis. An unnecessary surgery may expose the patient to such risks. A smaller value of α increases test specificity, which has higher reliability. However, it decreases performance. An α close to unity results in a high false-positive rate and the test becomes less specific. Hence, it creates mistaken perception of unacceptability, which is a performance issue. The terms 'relative sensitivity' and 'relative specificity' were used, when probabilities of a freshly introduced test were computed on the basis of agreed-upon standards. The definitions of sensitivity and specificity given in Figures 5*a*, *b* became definitions of relative quantities, if disease present (absent) were replaced by positive (negative) result of a clinically accepted test (agreed-upon standard). The verdict of a presence or absence of a disease seems to be too large a claim to be made by mortals. Results of various examinations (physical, biochemical and radiological) are put together and interpreted with the help of a clinical model to decide about presence of a disease.

Multi-Level Screening for Scoliosis

Kamal *et al.* (1996) proposed 'Integrated-Trunk-Deformities-Screening Protocol' consisting of multiple-level screening of primary-school students. The checks located at the top level were designed to be highly sensitive and could be performed in a semi-private setting. The checks located at the bottom level were chosen to be highly specific. These involved moiré fringe topography of back in the attention position to cover the entire spinal column from external auditory meatus to hip joint as well as moiré analysis for asymmetry of shoe soles and footprint molds. These were compared with the standard forward-bending test. The goal was to minimize X-ray exposure to children, while identifying at-risk cases for orthopedic referral. Although very enthusiastic, the number of tests involved and the special environment needed did not make this protocol suitable for mass screening.

QUANTIFICATION OF RISK OF ACQUIRING SCOLIOSIS

Orthopedic surgeons feel a strong need to look into factors associated with scoliosis in school children (Baroni *et al.*, 2015). Power of mathematics should be employed to develop an index, which could indicate risk of scoliosis in preteen children. Such an index should include more factors than simple positive moiré and could be useful in deciding which child should be put under observation. Being highly sensitive, moiré examinations generate a large number of cases to be followed up, which saturates the health-care resources, resulting in denial of essential medical surveillance to those in real need.

Cumulative-Scoliosis-Risk Weightage (CSRW)

A mathematical index, CSRW, was introduced by our group (Kamal *et al.*, 2013*d*), which associated a weight to each early-warning signal These included, family history (scoliosis in father, mother, brother or sister increases the risk), age slot, degree of tallness, degree of wasting (lesser mass-for-height), positive forward-bending tests, non-alignment of plumb-line, positive indicators in visual examination of back (drooping shoulders, uneven scapulae, curved shape of midline of back, unequal body triangles, uneven spinal dimples) and positive moiré (front and back), with the weightage increasing if the condition existed for more than one checkup. Various tests to examine spinal column are described in detail in a previous publication (Kamal *et al.*, 2015).

Drawbacks of CSRW: Need for Refining

The drawback of CSRW comes from the fact that if some test results are not available for certain students (*e. g.*, history information), this index cannot be compared with other students of the same class. There is a need to refine this definition to take care of missing information or additional information on hand by addition of extra tests in a subsequent session, so that the modified index may be compared for data collected in different years.

Normalized-Scoliosis-Risk Weightage (NSRW)

'Normalized-Scoliosis-Risk Weightage', NSRW, is expressed as a percentage and may be computed using the expression

$$NSRW = 100\frac{CSRW}{\sum score_{\max}}\% \tag{10}$$

where $score_{\max}$ is the maximum value of score of an individual item (01-26), corresponding to a certain checkup.

Table 2[∀]. Weights assigned for computation of 'Cumulative-Scoliosis-Risk Weightage' (CSRW) and 'Normalized-Scoliosis-Risk Weightage' (NSRW)[§]

Scoliosis-Risk Weightage	*A*[϶]	*B*[∈]	*C*[∃]
01. Family history	2.0	2.0	2.0
02. Age [3, 6.5)[⊃] *years*	0.5	0.5	0.5
03. Age [6.5, 7.5)[⊃] *years*	1.0	1.0	1.0
04. Age [7.5, 8.5)[⊃] *years*	1.5	1.5	1.5
05. Age [8.5, 11)[⊃] *years*	2.0	2.0	2.0
06. Tall (above 50^{P})[#]	1.0	1.5	2.0
07. Tall (above 75^{P})[#]	1.5	2.0	2.5
08. Tall (above 97^{P})[#]	2.0	2.5	3.0
09. Wasted (more than 10%)[#]	1.0	1.5	2.0
10. Wasted (more than 20%)[#]	1.5	2.0	2.5
11. Wasted (more than 30%)[#]	2.0	2.5	3.0
12. FBT_{F} (lumbar asymmetry)	1.0/1.5[⊂]	1.5/2.0[⊂]	2.0/2.5[⊂]
13. FBT_{B} (thoracic asymmetry)	1.0/1.5[⊂]	1.5/2.0[⊂]	2.0/2.5[⊂]
14. Plumb-line non-alignment	1.0	1.5	2.0
15. Shoulder drooping	0.5	1.0	1.5
16. Uneven scapulae	0.5	1.0	1.5
17. Midline of back C-shaped	0.5/1.0[¥]	1.0/1.5[¥]	1.5/2.0[¥]
18. Midline of back S-shaped	1.0/1.5[¥]	1.5/2.0[¥]	2.0/2.5[¥]
19. Unequal body triangles	0.5	1.0	1.5
20. Uneven spinal dimples	0.5	1.0	1.5
21. Positive moiré (back)	1.0	1.5	2.0
22. Positive moiré (front)	0.5	1.0	1.5
23. Positive dotted-rater (back)	1.0	1.5	2.0
24. Positive dotted-raster (front)	0.5	1.0	1.5
25. Limp	1.0	1.5	2.0
26. Spastic gait	0.5	1.0	1.5

[∀]This is an extension of Table 1 appearing in Kamal *et al.* (2015), with additional entries 23-26.

[§]The student should be subjected to differential-spinal-function testing (DSFT) if CSRW is equal to or more than 5.5 after the first examination, 6.5 after the second examination and 7.5 after the third examination, as per recommendations given in Kamal *et al.* (2015).

[϶]This value is applicable if the condition appears only during any single examination — 1st examination or 2nd examination or 3rd examination.

[∈]This value is applicable if the condition appears during any two examinations — (1st + 2nd) examinations or (2nd + 3rd) examinations or (1st + 3rd) examinations.

[∃]This value is applicable if the condition appears during all the three examinations — (1st + 2nd + 3rd) examinations.

[⊃][*x*, *y*) means *x* (3 *years* in the first entry) is included, but *y* (6.5 *years*) is not. Hence, a 6.5-*year* old student is rated according to criterion 03.

[#]The superscript P denotes percentile.

[⊂]Second value is applicable, if the front and the back asymmetries are on opposite sides.

[¥]Second value is applicable, if the deformity is not corrected upon asking the child to assume mild-stretching posture.

Table 2 lists weights assigned for a single examination or multiple examinations, in order to compute CSRW and NSRW.

PREVENTING OVER-TREATMENT

A compulsory two-minute-unclothed-scoliosis screening, which may include moiré and dotted-raster examination of spinal column, for primary-school students in the age group 7-10 *years* combined with observation of at-risk cases and follow-up of mid curves and rotations may prevent lifetime suffering (Horn, 2012; Luk *et al.*, 2010). In order to differentiate true curvatures and rotations from scoliosis-like conditions, 'Differential-Spinal-Function Testing' (DSFT) was devised and implemented on students studying in a local school (Kamal *et al.*, 2014*a*; 2015). It is briefly described below.

Differential-Spinal-Function Testing (DSFT)

The decision was made in two levels for the existence of lateral curvatures and rotations of the spinal column. In the first step, two tests were conducted and the results compared to suspect a possible condition. In the second step, a third test was administered to indicate that condition. The first-step tests were**:** visual (standing), visual (sitting), forward bending (standing) and forward bending (sitting) — postural problem suspected through positive visual examinations (standing and sitting), indicated through positive mild-stretching test (if mild-stretching test was negative, *i. e.*, the deformity was not corrected after mild stretching, it was indicative of lateral curvatures); leg-length inequality suspected though positive visual and forward-bending tests (both standing), indicated through uneven spinal dimples; hip weakness suspected though positive visual and forward-bending tests (both sitting), indicated through positive Tredelenburg sign; spinal rotation suspected through positive forward-bending tests (standing and sitting), indicated through either positive moiré/dotted-rater or positive forward-bending tests (back and front views) on opposite sides.

SUBJECTS AND METHODS

This work reports spinal examinations of the 68 boys and 65 girls during 2011-2013, enrolled while studying in KG and followed up till they passed class 2.

Study Design

The study was organized under the banner of the NGDS Pilot Project (http://ngds-ku.org), National Growth and Developmental Standards for the Pakistani Children, carried out since 1998.

*Purpose of the Study***:** The following objectives were considered for design and conduct of this study**:**

- To devise a criterion to select students for DSFT, which is not sensitive to missing tests
- To determine threshold values for this new criterion after the first examination, the second examination and the third examination

*Study Type***:** This study was longitudinal-observational study.

*Sampling***:** The sampling procedure was convenience sampling. Data reported in this work were obtained on civilian-school students, who belong to middle-class locality of Karachi, Pakistan.

Institutional Review Process and Informed Consent: Study protocols were designed after considering prevailing human-right and ethical standards applicable in our region and approved by 'Institutional Review Board' of University of Karachi. Opt-in policy was selected and parents filled in and sent to school 'Informed Consent Form' (http://www.ngds-ku.org/BLA/Form_BLA.pdf). Prior to examination, student's verbal consent was obtained.

*Inclusion/Exclusion Criteria***:** Students, who could be administered DSFT, were included. One boy, who had multiple musculoskeletal deformities and could not stand unaided, was excluded at the data-processing stage.

Organization of the Study

A dedicated room was used, furnished according to the needs of examination. The room provided acoustic as well as visual privacy for these gender-segregated examinations. During girls' examinations, a female assistant was, always, present.

Conduct of the Study

For the checkup the students removed their school uniforms, shoes and socks, retaining only short underpants. Heights were measured using setsquares by mounting engineering tape on wall (Figures 6*a*, *b*) and masses measured

Fig. 6*a, b*. Measurement of height of a male and a female student in SF-Growth-and-Imaging Laboratory — (*a*) first appeared in Kamal and Jamil (2012) and (*b*) in Kamal and Jamil (2014)

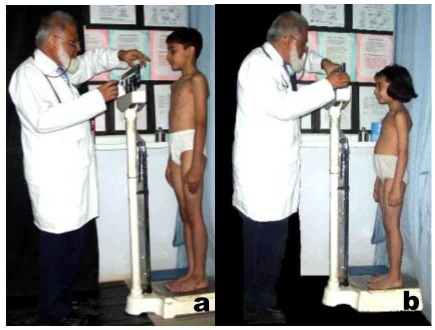

Fig. 7*a, b*. Measurement of mass of a male and a female student in SF-Growth-and-Imaging Laboratory — (*a*) first appeared in Kamal and Jamil (2012) and (*b*) in Kamal and Jamil (2014)

using beam scale (Figures 7*a, b*) each year according to the procedures given elsewhere (Kamal, 2006). A detailed back examination was conducted in class 2. Visual and forward bending tests were conducted in both sitting and standing positions. Details of back examination are given in Kamal *et al.* (2015). Those requiring moiré examinations were called in SF-Growth-and-Imaging Laboratory after filling 'The SGPP Participation Form' (http://www.ngds-ku.org/SGPP/SGPP_Form.pdf). Sibling Growth Pilot Project (SGPP) is a family-centered project, in which all siblings are monitored to look into their growth patterns. If one of the brothers or the sisters has scoliosis, this increases risk of scoliosis in the student.

A **:**	set of students, in whom lateral curvatures of spinal column were indicated
B **:**	set of students, in whom rotations of spinal column were indicated
$A \cap B$ **:**	set of students, in whom both lateral curvatures and rotations were indicated
$A - B$ **:**	set of students, in whom lateral curvatures were indicated, but rotations were not
$B - A$ **:**	set of students, in whom rotations were indicated, but lateral curvature were not

Fig. 8. Inclusion criteria for elements of intersection and difference sets

Data Collection and Analysis

Data were collected on weekdays (Monday to Friday) in the morning hours. They were analyzed by first computing Growth-and-Obesity Profile (Kamal *et al.*, 2011) of each student to determine tallness and wasting needed to compute CSRW and NSRW. Each student was subjected to DSFT to figure out threshold for selecting students for scoliosis surveillance. We would like to study correlation of those cases in which lateral curvatures, spinal rotations or both were indicated with mean NSRW. Let *A* denote set of students, in whom lateral curvatures of spinal column were indicated and *B* the set, in whom rotations of spinal column were indicated. Figure 8 lists elements of intersection and difference sets. Figure 9 represents the same in Venn-diagrammmic representation. A pi-

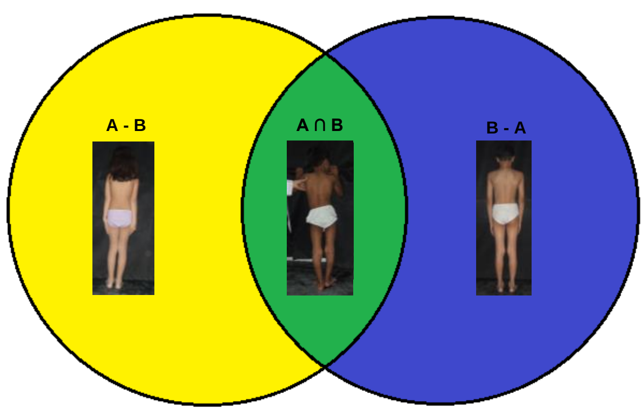

Fig. 9.Venn-diagrammic representation of intersection and difference sets

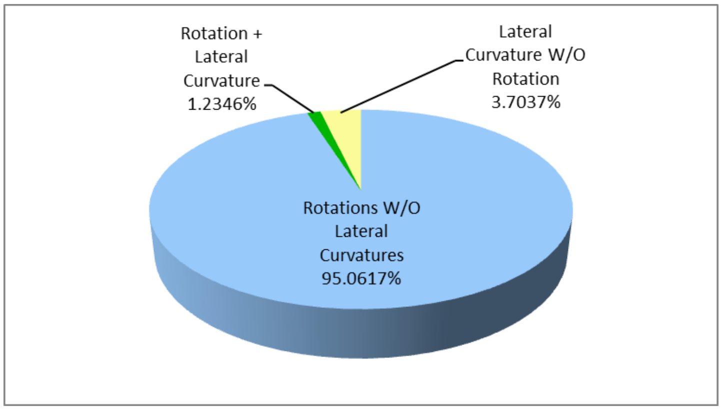

Fig. 10. Pi-chart representation of percentages of lateral curvatures without rotations $(A-B)$, rotations without lateral curvatures $(B-A)$ and both present simultaneously $(A\bigcap B)$

chart representation of percentages of lateral curvatures without rotations, rotations without lateral curvatures and both present simultaneously in shown in Figure 10. From the above description, it could be easily concluded

(11*a*) $$A\bigcup B=(A-B)\bigcup(A\bigcap B)\bigcup(B-A)$$

(11*b*, *c*) $$A=(A\bigcap B)\bigcup(A-B);\ B=(A\bigcap B)\bigcup(B-A)$$

Arithmetic mean of NSRW was computed corresponding to elements of each set, A, B, $A\bigcup B$, $A-B$ and $B-A$.

Table 3. Mean Normalized-Scoliosis-Risk Weightage (NSRW) for students suspected of scoliosis[⊗]

Differential-Spinal-Function-Testing (DSFT) Results (Corresponding Set Representations)[⊗]	*Number of Boys*	*Number of Girls*	*Total*	*Mean NSRW*[¶]
Lateral curvatures indicated (A)	1	3	4	38.76%
Rotations indicated (B)	27	51	78	43.00%
Both lateral curvatures and rotations $(A\bigcap B)$	0	1	1	35.71%
Lateral curvatures indicated, no rotations $(A-B)$	1	2	3	59.56%
Rotations indicated, no lateral curvatures $(B-A)$	27	50	77	43.10%

[⊗]Color coding of rows as well as set representation according to Figure 8

[¶]Mean (Average) of individual NSRW scores of each student

RESULTS AND DISCUSSION

Table 3 gives the number of students, who indicated lateral curvatures or rotations and the corresponding mean NSRW (Normalized-Scoliosis-Risk Weightage). Table 4 lists the threshold value of NSRW suggested, which warrants DFST (Differential-Spinal-Function Testing). The authors recommend posture checks for boys and girls 4-7 *years* (Kamal and El-Sayyad, 1981) and examinations to detect scoliosis for children 7-10 *years* employing visual

Table 4. Threshold of Normalized-Scoliosis-Risk Weightage (NSRW)
for Differential-Spinal-Function Testing (DSFT)

25%	After the first examination
30%	After the second examination
35%	After the third examination

inspection, moiré fringe topography and dotted-rasterseterography. At-risk cases (NSRW above the threshold value) should be kept under observation till the end of their growth periods (An *et al.*, 2015; Schulte *et al.*, 2008). Those indicating lateral curvatures and rotations indicated by DSFT, should be followed up during their teenage years no matter how small the curvature or the rotation is. The students, in whom leg-length inequality or hip weakness is indicated, should be treated for these conditions.

FUTURE DIRECTIONS

An in-depth study of the physics (Kamal *et al.*, 1998) and the mathematics (Kurz *et al.*, 2015) of human spinal column shall open up new avenues for researcher of the third millennium.

Future work should be focused on developing a mathematical model, which should reduce degrees of freedom of spinal column from a total of 231 = (33)(3 + 3 + 1) to, possibly, one. The product (33)(3 + 3 + 1) comes from multiplying the number of vertebrae in the spinal column (33) with the sum of positional degrees-of-freedom (3), rotational degrees-of-freedom (3) and inter-vertebral-spacing degree-of-freedom (1). This may be accomplished by setting up problem closer to natural symmetries of the system (Kamal, 2004) by formulating a coördinate system, which should reduce the degrees-of-freedom of spinal column (Kamal *et al.*, 2012). The very first step should be to include rotations and inter-vertebral spacing in the static and dynamic models proposed earlier (Kamal, 1996*a*, *b*).

Relationship of leg-length inequality and hip weakness in inducing scoliosis is worth studying. In tall and wasted children, asymmetric force about the transverse plane may produce a torque, which may cause scoliosis. This factor is, already, included in NSRW, but needs to be further investigated from perspectives of mathematics and physics.

More work is needed to develop a system to combine moiré fringe topography, rasterstereography and dotted-rasterstereography with backscatter-X-ray-scanning technology for 3-D-spinal-column-surface analysis — height and curvature maps of the surface of spine (Kamal, 2013). Availability of this technique should pave the way to experimentally validate crystal-structure-based model (Kamal *et al.*, 2014*b*)

CONCLUSION

This paper introduced Normalized-Scoliosis-Risk Weightage (NSRW) and recommended threshold values of NSRW after the first, the second as well as the third examination, which should be considered as guidelines to conduct Differential-Spinal-Function Testing (DSFT). NSRW has been designed in such a way to make it insensitive to omitted tests or added tests in different sessions. Implementation of these protocols should allow pediatric orthopedic professionals utilize their time and resources more effectively in scoliosis case finding.

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NOTE (added after publication): Figures 2*a-c* and Figures 3*c*, *d* first appeared in Kamal and Khan (2015). The authors regret this omission.

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