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TECHNICAL NOTE

Computer-assisted Cobb measurement of scoliosis

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Abstract This study was devised to develop a simple computerised method for measuring and quantifying the magnitude of spinal curvatures. A digitally scanned antero-posterior radiographic image was used. The vertebral column was defined as a line that can be subdivided into a number of segments, rather than into the exact number of vertebrae. The technique developed allows an observer to measure the spinal curvature with a high resolution and accuracy. One important advantage of the technique is that the assessor does not need to be skilled or experienced in measurement of a spinal curvature.

Keywords Cobb method · Spine deformity

Introduction

The Cobb method [3] remains the standard clinical measurement employed for the assessment and appraisal of scoliosis [6]. It is widely used to determine the magnitude of deformity in cases of scoliosis. However, its measurement is dependent upon various subjective factors, the most important of which is correct identification of the end vertebrae of a curvature and of the vertebral pedicles. Thereafter, the observer has to construct a number of lines manually on the radiograph – some of them perpendicular to others – prior to actual measurement. Finally, the Cobb angle is measured using a protractor. All these operations can contribute to high inter- and intra-observer variability in quantifying the curvature.

The variability of the Cobb method has previously been reported [4, 6, 7, 9], with varying estimates. Average intra-observer standard deviation (SD) has been reported as approximating 3.5° [2, 4, 9], while reports on the inter-observer SD range from 2.8° to 7.2° [4, 9]. High levels of variability have also been reported when the end vertebrae of the curve are preselected. Morrissy et al. [4] reported an intra-subject variability of 2.8° and an inter-subject variability of 6.3° under conditions of preselection. Stokes et al. found the greatest range of manual Cobb-angle measurements on any film to be 8° (pooled SD=1.3°), even when the apex and end vertebrae were pre-marked and held constant [7]. A 5° increase in Cobb angle measurements between two follow-up visits can suggest a curvature progression for many clinicians, and this may lead to changes in the treatment plan [1]. Therefore, if a Cobb angle is to be used clinically, it is important that its estimation be highly reliable.

The concept of the Cobb technique remains simple, well known and established among clinicians. Thus, it can be argued that it is undesirable to change such a measure to an alternative method. Therefore, the development of a computerised technique that is based on the Cobb method, but which reduces the variability of the measurements, could be valuable. Hence, the purpose of this study was to develop an application that would improve the accuracy of the Cobb-angle measurement by employing simple computer techniques.

Method

A series of standard, digitally acquired anonymous radiographs, obtained from the regional spinal unit in Liverpool, were used for the study. A computer programme was developed using MATLAB (The MathWorks Inc., Mass., USA), which was applied to the assessment of the spinal curve. This programme permits the operator to select an appropriate area of the spine for measurement. The radiograph is viewed horizontally, and two points are selected using a pointing device, such as a computer mouse at the top left- and top right-hand sides of the radiograph. The programme then divides the spine into eight equidistant segments, by the construction of a series of parallel lines at right-angles to the spinal axis on the image, in a left to right sequence (Fig. 1). The size of these segments is dependent on the dimensions of the radiographic image, and thus is independent of the actual vertebral sizes and spinal length of the subject.

The observer identifies two points on each line where the anatomical medial and lateral edges of the vertebra intersect the line. These are digitised using the mouse (Fig. 2). Once these edges are defined and digitised for all the parallel lines, the computer programme determines the mid-point of each of these two points. Connecting all these midpoints defines the spinal midline (Fig. 3). Accuracy of this midline reconstruction increases as the number of elements into which the spine is divided rises. All possible angles between the midpoints are determined using simple mathematical functions. The programme calculates the largest of these angles; this defines the Cobb angle criterion.

Angles were estimated on nine scoliotic X-ray images in order to examine the validity of the system. Ten observers, including experienced clinicians, radiographers and novice volunteers, evaluated the radiographs in a random order. Spinal angle estimation

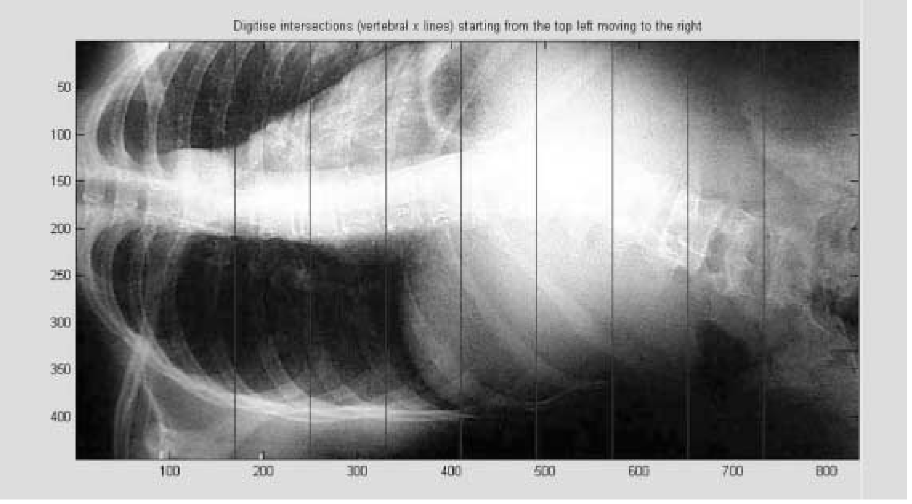

Fig. 1 Choosing limits and dividing the spinal image into sections

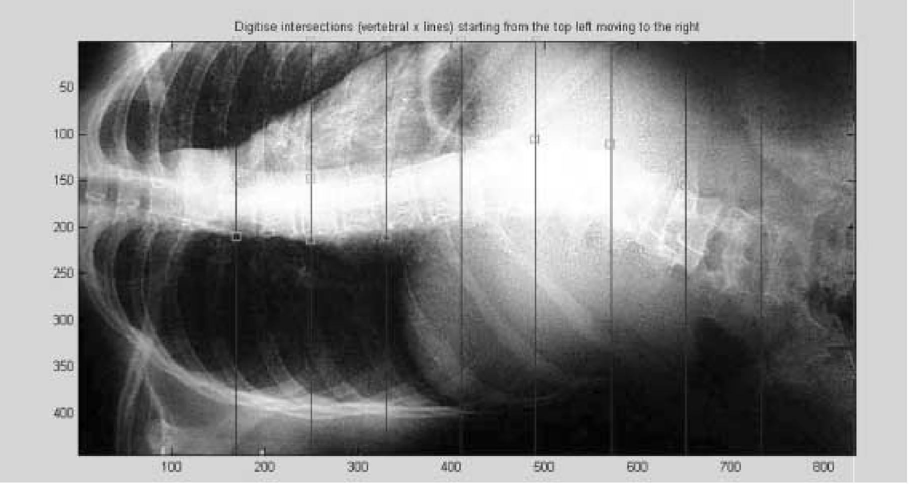

Fig. 2 Digitising edges of the spinal image

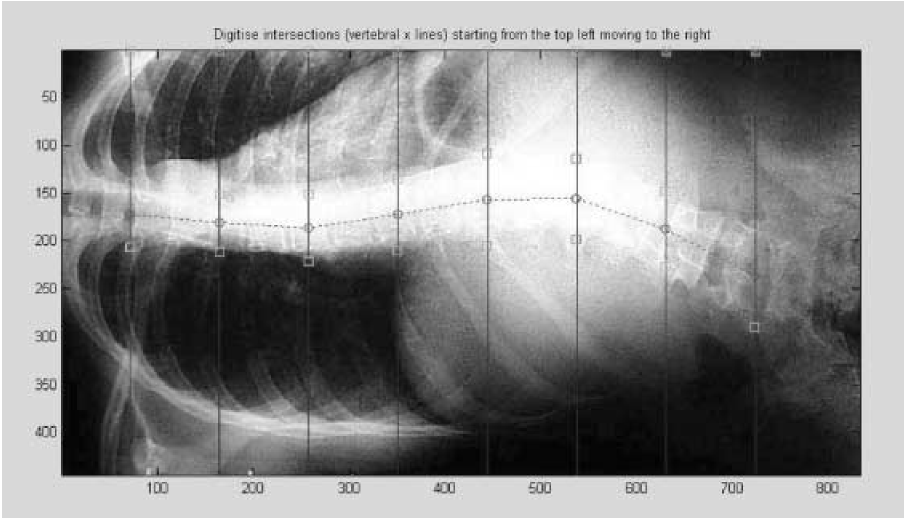

Fig. 3 Spinal midline

was carried out three times over a period of a week. Intra- and inter-observer errors of measurement were calculated using standard methods reported in the literature [5, 8].

The technical error of measurement (TEM) or the measurement error standard deviation was estimated using the following formula:

$$\sqrt{\frac{\sum_{1}^{N}\left[\sum_{1}^{K} \mathrm{M}\,(\mathrm{n})^{2}-\frac{\left(\sum_{1}^{K} \mathrm{M}(\mathrm{n})\right)^{2}}{\mathrm{K}}\right]}{\mathrm{N}\,(\mathrm{K}-1)}}$$

where, N is the number of subjects, M(n) is the nth replicate of measurement and K is the number of determinations. This formula provides an estimate of measurement error in the units of measurement of the variable; in this case in degrees.

The reliability coefficient (R), which is not expressed in degrees, is estimated using the following formula:

$$\mathrm{R}=1-\left[(\mathrm{TEM})^{2} / (\mathrm{SD})^{2}\right]$$

This coefficient (R) ranges on a scale from 0–1, and will give an estimation of error in inter-subject variance. If the reliability coefficient is 0.8, then the data are 80% error free. Cobb angle measurements were also undertaken manually by three observers on the same radiographs in order to compare the results.

Results

Mean angle estimations and the standard deviation for individual observers are presented in Table 1.

The intra-observer technical error of measurement (TEM) between the first two measurements for individual observers is presented in Table 2, and the angle estimations from manual Cobb angle measurement are given in Table 3.

Mean intra-observer TEM was estimated at 0.739°, and the mean coefficient of reliability was 0.985, indicating that the measurements are 98% error free. Inter-observer TEM was estimated as 1.22°, and the mean coefficient of reliability was 0.988. Although this reliability measure is mainly used with anthropometric measurements, and there are no recommended values for R in the literature [8], the reliability coefficients estimated for intra- and inter-observer error are high, at 0.98, and thus acceptable. Manual measurement of the Cobb angle produced similar results for the average spinal curve angle with an inter-observer TEM of 1.855° and a mean coefficient of reliability of 0.781, which are comparable to the previously reported variability limits.

Discussion

A semi-automated computerised technique that can measure the Cobb angle accurately has been developed in this study. The measuring criterion (angle) of the Cobb method was closely adhered to because of its widespread use and simplicity. The only subjective stage of this method arises when the observer determines the upper and lower limits of the curve on the spinal image and when the medial and lateral edges of each vertebra are defined. These are the only sources of variability, since all the other operations are automatic. The mean intra- and inter-observer errors in measurement were considerably lower compared with previously published reports. Other measurements, for example the offset distance, can also be calculated, provided details of the two-dimensional calibration of the film are available. The technique can also be applied to other spinal images, such as a lateral view, for the measurement of kyphosis or lordosis.

Analysis time for each radiograph was also measured. The mean analysis time was about 2.3 min in total, from starting digitisation to obtaining the spinal angle. This is not much longer than the time that an experienced surgeon would need to evaluate a radiograph using the con-

Table 1 Estimated angles (degrees): mean and standard deviation

Radio-graph no.	Observer 1				Observer 2				Observer 3				Observer 4				Observer 5			
	Trial 1	Trial 2	Trial 3	Mean (SD)	Trial 1	Trial 2	Trial 3	Mean (SD)	Trial 1	Trial 2	Trial 3	Mean (SD)	Trial 1	Trial 2	Trial 3	Mean (SD)	Trial 1	Trial 2	Trial 3	Mean (SD)
1.00	39.88	36.12	39.10	38.37 (1.98)	43.34	43.01	42.94	43.10 (0.21)	42.88	42.79	43.00	42.89 (0.11)	40.36	42.68	41.92	41.65 (1.18)	42.11	42.71	41.94	42.25 (0.40)
2.00	28.83	29.11	29.47	29.14 (0.32)	30.21	30.10	29.87	30.06 (0.17)	31.60	31.11	30.96	31.22 (0.33)	32.00	31.88	32.64	32.17 (0.41)	29.15	29.39	30.00	29.51 (0.44)
3.00	24.72	25.01	26.10	25.28 (0.73)	24.61	25.05	25.12	24.93 (0.28)	23.91	24.27	24.64	24.27 (0.37)	25.11	26.32	25.83	25.75 (0.61)	24.21	24.83	24.66	24.57 (0.32)
4.00	30.86	31.21	30.73	30.93 (0.25)	30.23	29.71	29.52	29.82 (0.37)	31.12	31.44	30.92	31.16 (0.26)	29.23	29.80	29.37	29.47 (0.30)	30.18	28.92	29.60	29.57 (0.63)
5.00	22.55	22.75	22.94	22.75 (0.20)	20.91	21.34	21.14	21.13 (0.22)	22.73	22.69	22.18	22.53 (0.31)	20.34	20.98	21.03	20.78 (0.38)	22.41	22.76	22.29	22.49 (0.24)
6.00	23.27	23.26	22.49	23.01 (0.45)	21.90	22.23	22.35	22.16 (0.23)	23.40	23.32	21.95	22.89 (0.82)	19.82	20.14	19.79	19.92 (0.19)	22.20	22.34	22.99	22.51 (0.42)
7.00	25.70	23.74	23.29	24.24 (1.28)	23.20	23.01	22.81	23.01 (0.20)	24.65	24.35	24.10	24.37 (0.28)	23.20	23.68	22.49	23.12 (0.60)	23.87	24.40	24.32	24.20 (0.29)
8.00	33.28	32.86	31.84	32.66 (0.74)	31.62	32.15	31.22	31.66 (0.47)	31.60	32.21	31.86	31.89 (0.31)	32.68	31.45	31.73	31.95 (0.64)	31.84	31.88	30.70	31.47 (0.67)
9.00	31.48	30.75	32.04	31.42 (0.65)	32.88	32.52	33.09	32.83 (0.29)	32.20	33.41	33.19	32.93 (0.64)	32.66	32.91	33.09	32.89 (0.22)	32.19	33.00	33.40	32.86 (0.62)

Radio-graph no.	Observer 6				Observer 7				Observer 8				Observer 9				Observer 10			
	Trial 1	Trial 2	Trial 3	Mean (SD)	Trial 1	Trial 2	Trial 3	Mean (SD)	Trial 1	Trial 2	Trial 3	Mean (SD)	Trial 1	Trial 2	Trial 3	Mean (SD)	Trial 1	Trial 2	Trial 3	Mean (SD)
1.00	42.31	43.90	43.40	43.20 (0.81)	41.91	42.05	43.31	42.42 (0.77)	39.10	38.90	40.14	39.38 (0.67)	42.34	41.61	43.09	42.35 (0.74)	42.01	42.55	41.90	42.15 (0.35)
2.00	31.13	33.10	32.62	32.28 (1.03)	28.22	29.45	28.67	28.78 (0.62)	32.80	31.92	30.11	31.61 (1.37)	31.27	31.00	30.22	30.83 (0.55)	28.36	28.95	28.01	28.44 (0.48)
3.00	26.18	25.98	25.32	25.83 (0.45)	24.11	24.93	25.62	24.89 (0.76)	22.24	22.01	24.87	23.04 (1.59)	26.10	25.47	25.00	25.52 (0.55)	24.12	24.87	25.43	24.81 (0.66)
4.00	31.43	31.10	30.30	30.94 (0.58)	30.50	29.19	29.83	29.84 (0.66)	30.93	32.19	31.33	31.48 (0.64)	30.30	31.86	32.43	31.53 (1.10)	29.20	30.87	30.10	30.06 (0.84)
5.00	22.81	23.60	21.09	22.50 (1.28)	22.63	22.10	21.43	22.05 (0.60)	20.11	22.14	20.98	21.08 (1.02)	22.40	20.31	20.67	21.13 (1.12)	23.60	22.19	24.00	23.26 (0.95)
6.00	23.01	22.66	23.19	22.95 (0.27)	20.28	23.43	21.90	21.87 (1.58)	21.28	22.21	23.14	22.21 (0.93)	20.50	20.12	21.77	20.80 (0.86)	21.60	23.53	20.11	21.75 (1.71)
7.00	26.19	28.53	25.08	26.60 (1.76)	25.10	26.26	24.87	25.41 (0.75)	26.10	27.39	26.88	26.79 (0.65)	25.23	24.88	25.27	25.13 (0.21)	24.21	25.33	26.04	25.19 (0.92)
8.00	33.55	32.16	33.04	32.92 (0.70)	31.76	32.14	32.86	32.25 (0.56)	34.54	32.76	34.18	33.83 (0.94)	32.71	33.38	33.03	33.04 (0.34)	31.54	31.29	32.99	31.94 (0.92)
9.00	35.00	34.87	35.18	35.02 (0.16)	33.12	36.20	34.29	34.54 (1.55)	32.76	33.63	34.00	33.46 (0.64)	33.10	34.92	34.14	34.05 (0.91)	33.07	30.12	33.78	32.32 (1.94)

Table 2 Intra-subject technical error of measurement (TEM) and the coefficient of reliability (*R*)

Subject no.	TEM (degrees)	*R*
1	0.91	0.98
2	0.28	0.99
3	0.43	0.98
4	0.58	0.98
5	0.47	0.99
6	0.92	0.98
7	0.95	0.99
8	0.99	0.99
9	0.77	0.99
10	1.09	0.98

Table 3 Manual Cobb measurements

Radiograph no.	Average Cobb angle (degrees)			Mean
	Observer 1	Observer 2	Observer 3	
1	41	42	41	41.33
2	29	27	32	29.33
3	28	24	27	26.33
4	33	30	34	32.33
5	24	22	24	22.66
6	24	21	20	21.66
7	28	25	26	26.33
8	35	30	32	32.33
9	35	35	33	34.33

ventional method. Analysis time was noted to decrease as the observer became more familiar with the procedure. Furthermore, since the procedure is dependent upon the number of segments within the area of deformity defined on the image, any remaining areas on the image can be skipped. By reducing the number of segments analysed, there is a consequent reduction in digitisation time. Although the number of parallel divisions is normally preset at eight, the programme can ask for an input from the operator, which can range from three to any reasonably high number. Eight was considered optimal to achieve acceptable digitisation time and high accuracy.

Further improvements to the process could be achieved by the application of special computerised optical techniques, which would fully automate the procedure. Digital radiographs were used for this study, since these are routinely used in the hospital. However, it is also possible to scan and use conventional radiographs. The system is easily adaptable for use in clinics, since its hardware requirements are a basic Pentium or similar personal computer (PC), with an added math co-processor. A scanner or camera is required to digitise the radiographic images. This equipment should be available on most units, and allows an easy access to the clinician.

The software was written using MATLAB, which is a standard scientific programming language. However, the programme is flexible, and could be re-written in any language such as C++. The overall cost of the whole package is regarded as minimal.

The new technique is considered to be of value for the accurate clinical appraisal of cases of scoliosis, especially in the follow-up stages. It also would find application in any investigation that requires an accurate quantification of the scoliosis angle; for example, if a longitudinal series of images are analysed.

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