ELSEVIER

The Spine Journal 10 (2010) 769–774

THE SPINE JOURNAL

Technical Report

Reliability assessment of Cobb angle measurements using manual and digital methods

Michelle C. Tanure, MD[a,*], Alan P. Pinheiro, MD[b,c], Anamaria S. Oliveira, PhD[a]

[a] Medical School, University of São Paulo, Ribeirão Preto, Brazil 14.049-900

[b] Department of Electrical Engineering, University of São Paulo, São Carlos, Brazil 13.566-590

[c] Biomedical Engineering Laboratory, Federal University of Uberlândia, Uberlândia, Brazil 38.400-902

Received 11 December 2009; accepted 18 February 2010

Abstract

BACKGROUND CONTEXT: The vertebral spine angle in the frontal plane is an important parameter in the assessment of scoliosis and may be obtained from panoramic X-ray images. Technological advances have allowed for an increased use of digital X-ray images in clinical practice.

PURPOSE: In this context, the objective of this study is to assess the reliability of computer-assisted Cobb angle measurements taken from digital X-ray images.

STUDY DESIGN/SETTING: Clinical investigation quantifying scoliotic deformity with Cobb method to evaluate the intra- and interobserver variability using manual and digital techniques.

PATIENT SAMPLE: Forty-nine patients diagnosed with idiopathic scoliosis were chosen based on convenience, without predilection for gender, age, type, location, or magnitude of the curvature.

OUTCOME MEASURES: Images were examined to evaluate Cobb angle variability, end plate selection, as well as intra- and interobserver errors.

METHODS: Specific software was developed to digitally reproduce the Cobb method and calculate semiautomatically the degree of scoliotic deformity. During the study, three observers estimated the Cobb angle using both the digital and the traditional manual methods.

RESULTS: The results showed that Cobb angle measurements may be reproduced in the computer as reliably as with the traditional manual method, in similar conditions to those found in clinical practice.

CONCLUSIONS: The computer-assisted method (digital method) is clinically advantageous and appropriate to assess the scoliotic curvature in the frontal plane using Cobb method.

Keywords: Scoliosis; Cobb method; Radiographic measurements; Computer-assisted; Digital measurements

Introduction

The Cobb angle [1] is commonly used for quantitative assessment of the lateral curvature of the spine in the frontal plane and is usually considered as the golden standard [2] for diagnosis and follow-up of patients with scoliosis. This measurement is also valuable in the planning of surgical procedures, monitoring and management of spine deformities, and determining the severity of the curvature [3].

The Cobb method has been traditionally adopted in clinical practice as a simple and well-known technique [4,5]. The calculation may be done manually, with the help of a pencil and a protractor. The observer draws lines on the X-ray film and calculates the angle formed by the most inclined vertebrae. Despite this simplicity, several factors may influence the calculation, causing measurement variability and impairing the accurate assessment of the patient [6]. These factors include the use of different protractors and markers, the correct identification of the vertebrae limiting the curvature and of the pedicles [4], and the level of experience of the observer.

Technological advances have allowed for an increased use of digital X-ray images in clinical practice. This technology offers many advantages, such as fast and efficient storage of images [7]; easy access for comparison and follow-up [8]; easy transfer between clinical sites; and the application of digital processing techniques capable of

FDA device/drug status: not applicable.

Author disclosures: none.

* Corresponding author. Av. Bandeirantes, 3900, Ribeirão Preto, Brazil. Tel./fax: (55) 16 3602-4413.

E-mail address: mitanure@usp.br (M.C. Tanure)

1529-9430/$ - see front matter
doi:10.1016/j.spinee.2010.02.020

improving the quality of X-ray images [9]. Another positive aspect of digital technology is the use of a systematic method of assessment, which may reduce the impact of errors related to human subjectivity. For these reasons, some authors [5,9] have reproduced the Cobb method in the computer, with the objective of assessing the contribution of digital technology to the analysis of digital X-ray images from patients with scoliosis.

Several authors have tried to verify the reliability of the estimates of Cobb angle and other scoliosis parameters using the manual versus the digital method. Wills et al. [10] compared the results obtained on traditional versus digitally acquired X-ray images. However, these authors used an in vitro model of the human spine to assess the precision of the digital method. Other studies investigated the intra- and interobserver variability of Cobb angle measurements, considering either the manual [11–13] or the digital [5,14] method. Other studies [7,12] compared directly the Cobb angle measurements using the manual versus the digital method, but the measured vertebrae were preselected. In their study, Ian et al. [15] assessed the reliability of computational algorithms for King classification and Cobb measurements. Kuklo et al. [16] used the digital method to assess several parameters commonly used to characterize adolescent idiopathic scoliosis, whereas Pinheiro et al. [17] calculated the reliability of the digital method in the measurement of vertebral axial rotation. Other authors, such as Scholten and Veldhuizen [18] chose to analyze the Cobb measurement variability using a mathematical model. Despite their important scientific contributions, a significant part of the studies that evaluated the reliability of the digital method in the calculation of the Cobb angle failed to consider some aspects that are relevant in clinical practice, such as the Cobb angle assessment in scoliotic curvatures without preselected end plates, in a wide range of curvature types and magnitudes, using images taken from actual patients with scoliosis instead of spine models.

Therefore, to demonstrate the clinical relevance of the digital method and its potential for use in clinical practice to measure the Cobb angle, the main objective of this study was to assess the variability and the reliability of the digital method versus the manual method, in conditions similar to those found in clinical practice. For this purpose, a software was developed that can semiautomatically reproduce the Cobb method. Three observers used the traditional (manual) method and the digital (software-based) method to assess X-ray images from 49 patients with scoliosis. The measurements obtained were compared and statistically analyzed.

Materials and methods

Data acquisition

Forty-nine panoramic X-rays from patients diagnosed with idiopathic scoliosis were used to assess the reliability of the digital method for the measurement of the Cobb angle. The patients were chosen among those seen at the Orthopedics Department of the University of São Paulo. The selection of patients was based on convenience, without predilection for gender, age, type, location, or magnitude of the curvature. Patients were invited to participate in the research study and to sign an informed consent, after which frontal plane X-ray images were obtained in posteroanterior view, with standardized focus distance, following the recommendations of the International Commission on Radiologic Protection concerning the guidelines for safeguarding the patient, the operator, and the environment, and ensuring the quality of the image. The study was approved by the local ethics committee. The study sample allowed the inclusion of all curvature types and ranges of magnitude found in the population to reproduce the characteristics of patients seen in clinical practice. Therefore, the study population included patients ranging from small (Cobb=12°) to large (Cobb=80°) curvatures. Concerning the position of the curvature along the spine, the study sample included simple and double thoracic, thoracic-lumbar, and simple and double lumbar curvatures. The 49 X-ray images were randomly identified and digitalized on a 300 dpi resolution scanner with mean dimension of 4,200×10,800 pixels (Vidar Systems, Diagnostic Pro, Herndon, VA, USA).

Manual and digital measurements

Three independent observers, spine surgeons familiar with the Cobb technique, performed two sets of analyses.

In the first set, the 49 X-ray images were assessed using the traditional manual method. To complete this task, the observers were instructed to use, for every measurement, their instruments, that is, pencil and protractor. Each of the 49 X-ray film was analyzed three times at a minimum interval of 1 week between repeated measurements, by each of the three observers, adding up to 441 manual assessments. The images were examined in random sequence. Each observer was blind to the measurements taken by the two others and to his/her own previous data of the same film. To maintain the blind and avoid scratching the films, we covered them with a transparent acetate sheet that allowed the observer to see the image clearly without compromising its quality. The acetate sheets with the measurements were filed and no marks were done on the X-ray films.

Before starting the second set, that is, the digital assessments, the observers were trained to use the software developed for the study. The digital procedure consisted of marking the digital X-ray images with the mouse, as follows: one dot on each extremity of the superior plateau of the first vertebra and one dot on each extremity of the inferior plateau of the last vertebral of the scoliotic curvature, that is, four dots, in total, for each curvature assessed (see Fig. 1). This was the only intervention from the observers—the remaining steps were performed automatically. The images used in this training were discarded,

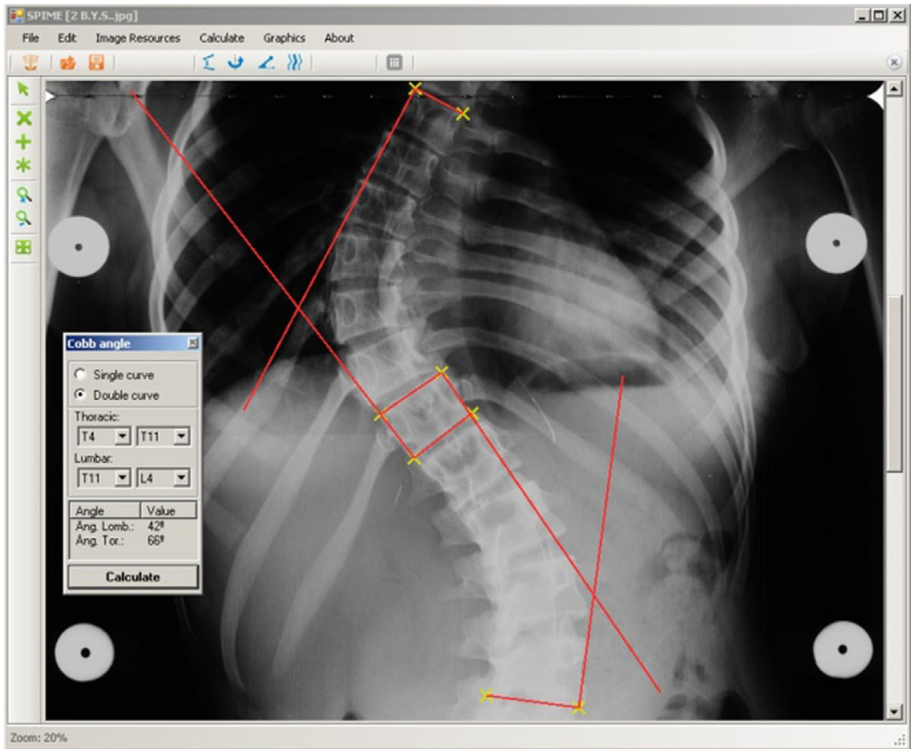

Fig. 1. Marks on the superior and inferior plateaus limiting two different curvatures. The yellow dots determine the position of the plateaus as manually defined by the user. The straight lines (red) were automatically projected by the software to calculate the Cobb angle based on entries made by the user.

and their results were not included in the study. The software offered several tools for improving the quality of the image, such as zoom, increased contrast, silhouette enhancement, and negative image effect.

After becoming familiar with the digital method, each observer received the 49 digital X-ray images. Each observer performed three repeated assessments with a minimum 1-week interval between them, totaling 441 digital analyses. These data were recorded and filed for further analysis.

In both sets, the observers could select the end plates based on their experience, that is, no curvature levels were preselected. The observers were also allowed to measure more than one curvature per examination, as required. However, the statistical calculations considered exclusively the common number of curvatures assessed by the three observers.

Statistical analysis

The reliability and variability of Cobb measurements using the manual and digital methods was assessed comparing intra- and interobserver differences.

The analysis of intraobserver variation, individually calculated for each observer, was expressed as mean absolute difference (MAD) between measurements, standard deviation (SD), and intraclass correlation coefficient (IaCC) of the measurements taken during the three assessments performed by each observer. Similarly, the interobserver variation was expressed as MAD, SD, and interclass correlation coefficient (IeCC) of the measurements taken during the nine assessments performed by the three observers. For both analyses, the confidence interval of intra- and interclass correlation coefficients was calculated to a level of significance of 95%. The MAD and SD values were averaged across the 49 patients.

The Student *t* test was used to assess the difference between the variability of manual versus digital measurements. The analysis of variance was applied to each observer, considering the three manual and the three digital assessments performed, which resulted in a set of six independent samples containing mutually independent observations. The analysis of variance function returns the p value under the null hypothesis that all samples are drawn from populations with the same mean. All statistical tests were calculated to a significance level of 95% using MatLab (MathWorks, Natick, MA, USA).

Results

The statistical results for the intraobserver analysis are shown in Table 1. The data in this table show that the MAD between measurements were less than 4°, and the IaCC showed strong correlation between measurements.

The analysis of variance p values estimated for the manual and digital measurements performed by each observer were $p=.94$ for Observer 1, $p=.90$ for Observer 2, and

Table 1
Statistical parameters of intraobserver analysis using manual and digital methods

	Observer 1		Observer 2		Observer 3	
Statistical parameters	Manual	Digital	Manual	Digital	Manual	Digital
MAD	2.69°	2.85°	3.25°	3.46°	3.18°	2.06°
SD	2.14°	2.25°	2.60°	2.73°	2.54°	1.69°
IaCC	0.97	0.97	0.96	0.95	0.94	0.98
CI of IaCC	0.94, 0.98	0.95, 0.98	0.92, 0.97	0.91, 0.97	0.89, 0.97	0.96, 0.99
Overall mean angle	39.17°	38.75°	37.10°	39.11°	41.20°	41.44°

MAD, mean absolute difference; SD, standard deviation; IaCC, intraclass correlation coefficient; CI, confidence interval.

$p=.93$ for Observer 3. These values indicate a high probability that the manual and digital measurements performed by each observer belong to the same population.

Table 2 illustrates the interobserver analyses and describes the main statistical differences between the manual and digital methods. The t test, performed at a 95% significance level, did not reveal statistically significant differences between manual and digital measurements ($t=0.51 >0.05$). The values shown in Table 2 confirm this result and indicate that the statistical indexes calculated for the two methods had similar results.

The individual analysis of Curvatures 1 and 2 also showed similar statistical values for both methods. The charts in Fig. 2 illustrate the difference between the three measurements taken by the observers and the dispersion of these measurements.

Discussion

Traditionally, the assessment of patients with scoliosis and the treatment decisions are based on the degree of spine curvature measured by the Cobb method. Usually, a 5-degree variation between measurements is acceptable in many cases [1]. Previous studies [6,10,13,15,19–22] reported mean errors ranging from 1.7° to 6.5° considering both manual and digital methods. In this study, the mean error values were 3.8° for the manual method and 3.6° for the digital method. The IaCC and IeCC values estimated in this study indicate excellent levels of intraobserver and interobserver reliability for the Cobb measurements. However, before making direct comparisons with previous studies, it is worth mentioning that each study has used different X-ray images, statistical analyses, and procedures for assessment.

Some studies [6,16] reported that the digital method contributed to increase the reliability of the Cobb angle measurements, while other authors [7,9,10] did not find significant differences in reliability between the two methods. These different conclusions may be related to the diverse methodologies used in the studies, some of which have imposed limitations on the observers (eg, preselection of end vertebrae). As pointed out by Gstoettner et al. [7], the selection of small scoliotic curves may also influence the results.

In this study, to reproduce the conditions found in clinical practice, the observers were allowed to select the curvature end plates according to their personal experience, that is, there was no preselection of curvature degrees. The samples investigated in this study ranged from 12° to 80°. The results revealed excellent levels of agreement between measurements taken using the digital method, with a similar performance to that seen with the manual method. Despite that, with both methods, there were cases where the difference between the two measurements was more than 10°. One of the factors contributing to these discrepancies is supposedly the selection of different vertebrae and issues concerning the quality of the images, which may have induced an inaccurate marking of the end plates. Some authors [23] believe that the protractor and the marking pencil may also contribute to measurement error with the manual method.

The analysis of the charts in Fig. 2 reveals that the digital method produced fewer outliers than the manual method, which resulted in a slight reduction of the SD of digital measurements. Possible reasons for this result may be the more limited user intervention in the digital method and the accurate calculation, by the digital procedure, of some geometrical operators used in the Cobb method. In addition, the digital technology allows the manipulation of the images using tools such as increased contrast, border enhancement and zoom, which may help observers in the identification and marking of anatomical structures. Another feature of the digital technology that might contribute to an effective assessment is its great capacity for data storage, and the direct comparison between images because the markings performed by the observer to calculate the

Table 2
Statistical parameters of interobserver analysis using manual and digital methods

Statistical parameters	Manual	Digital
MAD	3.85°	3.61°
SD	3.45°	3.18°
IeCC	0.95	0.96
CI of IeCC	0.91, 0.97	0.92, 0.97
Overall mean angle	39.16°	39.77°

MAD, mean absolute difference; SD, standard deviation; IeCC, interclass correlation coefficient; CI, confidence interval.

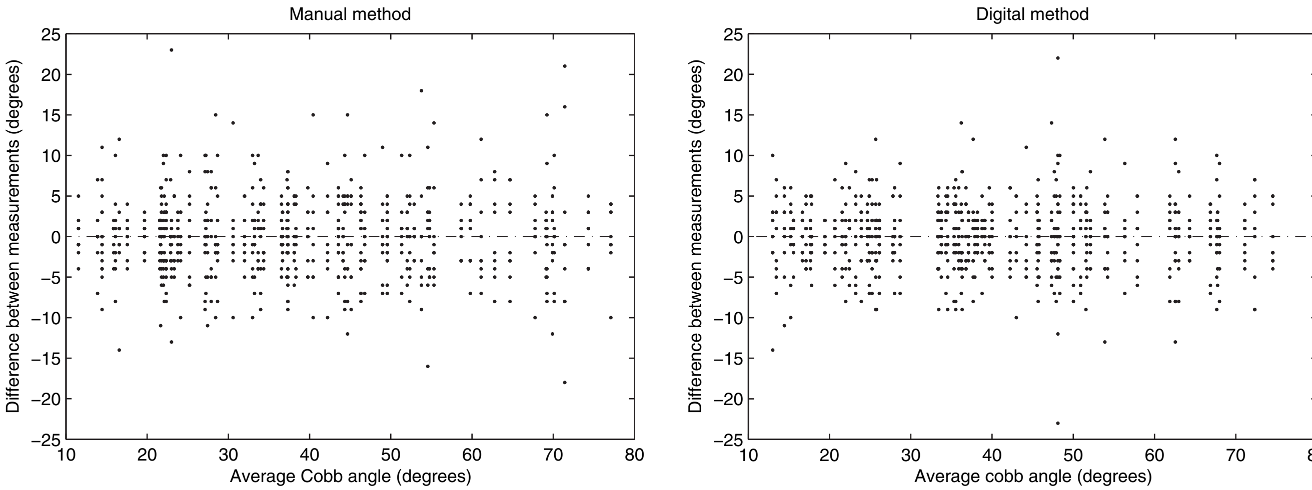

Fig. 2. Variability of measurements taken using the (Left) manual and (Right) digital methods. These charts were based on the combined difference between the three measurements of each assessment performed by the observers. The x-axis represents the mean value of each curvature assessed. This mean value was calculated based on the arithmetic mean of the measurements performed. The y-axis represents the differences between the first and second, second and third, and first and third measurements of each curvature assessed by an observer. The charts show the measurements from the three observers.

Cobb angle may be filed and compared with previous X-ray images, thereby reducing the discrepancies between assessments.

The relevance of these results is not limited to the comparative reliability of the digital versus manual methods but represents a step further in the sense of validating and consolidating the digital method, leading to the future development of new techniques for assessment of scoliotic curvatures, based on more complex mathematical models. Some authors [24] have emphasized that the Cobb angle predominantly reflects end plate tilt and end plate architecture, not revealing regional curvature changes. Based on these assumptions, some researchers [25] have proposed new mathematical methods, using the calculation capabilities of digital technology, to better characterize the spine curvatures. Another important field for potential contribution of the digital technology is the development of computer-aided diagnostic systems [26]. However, the full potential of the digital method can only be tackled after assessment of its reliability as compared with the golden standard method of Cobb.

Conclusion and future studies

The results showed that Cobb angle measurements may be reproduced in the computer as reliably as with the traditional (manual) method, in similar conditions to those found in clinical practice, suggesting that the digital method is clinically advantageous and appropriate to assess the scoliotic curvature in the frontal plane.

The remarkable calculation power of the digital method is an important driver for the development of new analytical techniques focusing the quantitative assessment of the spine curvature. Future studies involving the use of polynomial functions to characterize the spine curvature and to automatically detect vertebrae should further contribute to the assessment of spine curvatures.

Acknowledgments

This project was financially supported by grants from São Paulo State Research Support Fund (FAPESP, under process nr. 2007/58120-0) and Brazilian Scientific Research Advisory Board (CNPq, under process nr. 143.453/2008-4).

References

[1] Cobb J. Outline for the study of scoliosis. AAOS Instr Course Lect 1948;5:261–75.
[2] Vrtovec T, Pernus F, Likar B. A review of methods for quantitative evaluation of spinal curvature. Eur Spine J 2009;18:593–607.
[3] Oestreich A, Young L, Poussaint T. Scoliosis circa 2000: radiologic imaging perspective. Skeletal Radiol 1998;27:591–605.
[4] Chockalingam N, Dangerfield PH, Giakas G, et al. Computer-assisted Cobb measurement of scoliosis. Eur Spine J 2002;11:353–7.
[5] Champain S, Benchikh K, Nogier A, et al. Validation of the new clinical quantitative analysis software applicable in spine orthopedic studies. Eur Spine J 2006;15:982–91.
[6] Shea KG, Stevens PM, Nelson M, et al. A comparison of manual versus computer-assisted radiographic measurement: intraobserver measurement variability for Cobb angles. Spine 1998;23:551–5.
[7] Gstoettner M, Sekyra K, Walochnik N, et al. Inter- and intraobserver reliability assessment of the Cobb angle: manual versus digital measurement tools. Eur Spine J 2007;16:1587–92.
[8] Kushner DC, Cleveland RH, Herman TE, et al. Radiation dose reduction in the evaluation of scoliosis: an application of digital radiography. Radiology 1986;61:175–81.
[9] Allen S, Parent E, Khorasani M, et al. Validity and reliability of active shape models for the estimation of Cobb angle in patients with adolescent idiopathic scoliosis. J Digit Imaging 2007;123:1–11.
[10] Wills BPD, Auerbach JD, Zhu X, et al. Comparison of Cobb angle measurement of scoliosis radiographs with preselected end vertebrae: traditional versus digital acquisition. Spine 2007;32:98–105.

[11] Kuklo TR, Potter BK, Polly DW, et al. Reliability analysis for manual adolescent idiopathic scoliosis measurements. Spine 2005;30:444–54.
[12] Loder RT, Spiegel D, Gutknecht S, et al. The assessment of intraobserver and interobserver error in the measurement of noncongenital scoliosis in children <10 years of age. Spine 2004;29:2548–53.
[13] Carvalho AD, Vialle R, Thomsen L, et al. Reliability analysis for manual measurement of coronal plane deformity in adolescent scoliosis. Are 30 × 90 cm plain films better than digitized small films? Eur Spine J 2007;16:1615–20.
[14] Cheung J, Wever DJ, Veldhuizen AG, et al. The reliability of quantitative analysis on digital images of the scoliotic spine. Eur Spine J 2002;11:535–42.
[15] Ian A, Stokes F, Aronsson D. Computer-assisted algorithms improve reliability of King classification and Cobb angle measurement of scoliosis. Spine 2006;31:665–70.
[16] Kuklo TR, Potter BK, Schroeder TM, O'Brien MF. Comparison of manual and digital measurements in adolescent idiopathic scoliosis. Spine 2006;31:1240–6.
[17] Pinheiro AP, Tanure MC, Oliveira AS. Validity and reliability of a computer method to estimate vertebral axial rotation from digital radiographs. Eur Spine J 2010;19:415–20.
[18] Scholten P, Veldhuizen A. Analysis of Cobb angle measurements in scoliosis. Clin Biomech 1987;2:7–13.
[19] Dutton K, Jones T, Slinger B, et al. Reliability of the Cobb angle index derived by traditional and computer assisted methods. Australas Phys Eng Sci Med 1989;12:16–23.
[20] Jeffries B, Tarlton M, Smet AD, et al. Computerized measurement and analysis of scoliosis: a more accurate representation of the shape of the curve. Radiology 1980;134:381–5.
[21] Tang F, Chan L, Lau H, et al. Computer-generated index for evaluation of idiopathic scoliosis in digital chest images: a comparison with digital measurement. J Digit Imaging 2008;21:S113–20.
[22] Adam C, Izatt M, Harvey J, Askin G. Variability in Cobb angle measurements using reformatted computerized tomography scans. Spine 2005;30:1664–9.
[23] Morrissy R, Goldsmith G, Hall E. Measurement of the Cobb angle on radiographs of patients who have scoliosis: evaluation of intrinsic error. J Bone Joint Surg Am 1990;72:320–7.
[24] Polly D, Kilkelly F, McHale K, et al. Measurement of lumbar lordosis: evaluation of intraobserver, interobserver, and technique variability. Spine 1996;21:1530–5.
[25] Berthonnaud E, Dimnet J. Analysis of structural features of deformed spines in frontal and sagittal projections. Comput Med Imaging Graph 2007;31:9–16.
[26] Pietka E, Gertych A, Witko K. Informatics infrastructure of CAD system. Comput Med Imaging Graph 2005;29:157–69.