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Use of the smartphone for end vertebra selection in scoliosis

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ABSTRACT

Objectives: The aim of our study was to develop a smartphone-aided end vertebra selection method and to investigate its effectiveness in Cobb angle measurement.
Methods: Twenty-nine adolescent idiopathic scoliosis patients' pre-operative posteroanterior scoliosis radiographs were used for end vertebra selection and Cobb angle measurement by standard method and smartphone-aided method. Measurements were performed by 7 examiners. The intraclass correlation coefficient was used to analyze selection and measurement reliability. Summary statistics of variance calculations were used to provide 95% prediction limits for the error in Cobb angle measurements. A paired 2-tailed t test was used to analyze end vertebra selection differences.
Results: Mean absolute Cobb angle difference was 3.6° for the manual method and 1.9° for the smartphone-aided method. Both intraobserver and interobserver reliability were found excellent in manual and smartphone set for Cobb angle measurement. Both intraobserver and interobserver reliability were found excellent in manual and smartphone set for end vertebra selection. But reliability values of manual set were lower than smartphone. Two observers selected significantly different end vertebra in their repeated selections for manual method.
Conclusion: Smartphone-aided method for end vertebra selection and Cobb angle measurement showed excellent reliability. We can expect a reduction in measurement error rates with the widespread use of this method in clinical practice.
Level of evidence: Level III, Diagnostic study

Introduction

The Cobb technique is still the most important method for assessment of spinal deformity severity, progression risk and treatment plan.[1,2] Especially, it is the gold standard measurement method in the diagnosis and monitoring of scoliosis patients. It is usually measured by using a protractor and pencil or picture archiving and communication systems (PACS) or smartphone applications on standing posteroanterior radiographs.[3,4] Smartphone applications have become popular in orthopedic clinics parallel to the widespread use.[5] Cobb angle measurement with smartphone-aided method has become feasible because of its simple, fast and portable applicability.[6] Although many measurement techniques are defined, intra- and interobserver reliability is still controversial.[6–8] End vertebra selection, the deviation of the endplate lines and the use of different measuring instruments are among the reasons for differences in measurement.[9] It is known that end vertebra determination is the main source of measurement error.[8] Surgeons usually prefer visual selection to define the end vertebra on printed or digital radiographs. Zhang et al[9] developed a computer-aided system for end vertebra selection by using Fussy Hough transform technique.[10,11] They reported excellent intra- and interobserver reliability but this technique require software installation and can not be used on printed radiographs.

The purpose of this study was to develop a smartphone-aided end vertebra selection method to reduce the variability of Cobb angle measurement and investigate if this method is user friendly and sensitive.

Patients and methods

Twenty-nine posteroanterior radiographs of adolescent idiopathic scoliosis (AIS) patients were randomly selected from our

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hospital spinal deformity archive. Selection criteria required that patients were between 10 and 18 years of age, Cobb angle at least 20° degrees, and had no other neuromusculoskeletal disorders or surgery. Images area ranged from occiput to the hip joints. Damaged or unclear images were excluded. Each radiograph was printed onto A3 sized paper with multiple copies and all identifying information was masked by plaster and numbered to avoid remembering radiographs by the examiners. Measurements were performed by using smartphone and traditional manual method with 7 examiners (2 spinal surgeons, 3 orthopedist and 2 senior residents in orthopedic surgery) who are interested in scoliosis. Surgeons had no training period for the manual set because they had familiar measurement method. For the manual set, examiners selected upper and lower end vertebra visually and measured Cobb angle with the same narrow-lead (0.5 mm) pencil and the same protractor.

All smartphone measurements were performed using an Apple iPhone 5 (Apple incorporation, Cupertino, USA) running the iSetSquare application. For the smartphone set, examiners received a training period with 5 radiographs (not used in statistical analyze). In the smartphone-aided end vertebra selection technique, at first apical vertebra of spinal curve is detected. And then smartphone is placed horizontal on apical vertebral endplate and application indicator reset the angle to zero by pressing center of the screen of smartphone (Fig. 1B). Afterwards, smartphone is moved through next proximal vertebral endplates and the software automatically displays the angle (Fig. 1B–E). Phone is moved next upper vertebra endplate again and this is continued until the detect vertebra that highest angle is measured with smartphone and is determined upper most tilted vertebra (Fig. 1F). The same procedure is applied for the detection of lower most tilted vertebra. After upper and lower end vertebrae were determined, smartphone aligned to the both endplates sequentially and Cobb angle is calculated automatically.

For both methods, examiners measured the printed radiographs to put on the table. All examiners carried out the measurements independently for two times in each setting (manual and smartphone sets), with one week interval between each session. All data were recorded bye one blinded researcher.

We analyzed intraobserver and interobserver reliability in end vertebra selection and Cobb angle for both measurement methods. Intra- and interobserver reliability were calculated by intraclass correlation coefficient (ICC, 2-way mixed model on absolute agreement). ICC values may vary between 0 and 1, higher values indicate better reliability. The Fleiss criteria[12] for ICC values were adopted: 0.75 to 1.00: excellent reliability, 0.60 to 0.74: good reliability, 0.40 to 0.59: fair reliability, <0.40: poor reliability. We used ICC method because it provides more truly estimate reliability by giving high degree only when variance between trials for a special subject is small.[13,14] However, it doesn't distinguish different means between groups so we used paired 2-tailed Student *t* test to confirm if there is significant intraobserver differences in magnitude with a positivity threshold of $p < 0.05$. In addition, we calculated Cobb angle variability for each methods using to provide 95% prediction limits for the error in measurements. Statistical analyses were performed using SPSS 20.0 software (SPSS Inc., Chicago, IL).

Results

The study group includes 22 females and 7 males had a diagnosis of AIS. The mean age of the patients was 12.76 ± 2.8 years (range: 10–17). Eight of the major curves were thoracic and twenty-one were thoracolumbar.

The mean Cobb angle was 42.2° (range, 20°–81°) in the manual method and 45.5° (range, 23°–82°) in the smartphone-aided method. The 95% prediction limit of the Cobb angle variability was 3.6° (range, 2.6–4.9°) in the manual set and 1.9° (range, 1.1–2.4°) in the smartphone set.

The overall intraobserver ICC was 0.946 and interobserver ICC was 0.910 for the manual set, whereas the intraobserver ICC was 0.985 and interobserver ICC was 0.967 for the smartphone set (Table 1). Both intraobserver and interobserver ICCs were excellent in 2 methods but values of ICC were better in the smartphone set than manual set.

While the overall intraobserver ICC of upper end vertebra selection was 0.982 in the manual method, 0.991 in smartphone technique and overall interobserver ICC of upper end vertebra selection was 0.956 in the manual method, 0.966 in smartphone technique. Intraobserver ICC of lower end vertebra selection in the manual method was 0.973, in smartphone technique was 0.987 and interobserver ICC of lower end vertebra selection in the manual method was 0.914, in smartphone technique was 0.967 (Table 2). Both method provide excellent reliability in upper and lower end vertebra selection, however, smartphone set was better than manual set in all trials. When we analyze if there is significant intraexaminer end vertebra selection differences between sets, 2 of 5 observers selected significant different end vertebra between their first and second sets in manual method ($p < 0,05$, paired t-

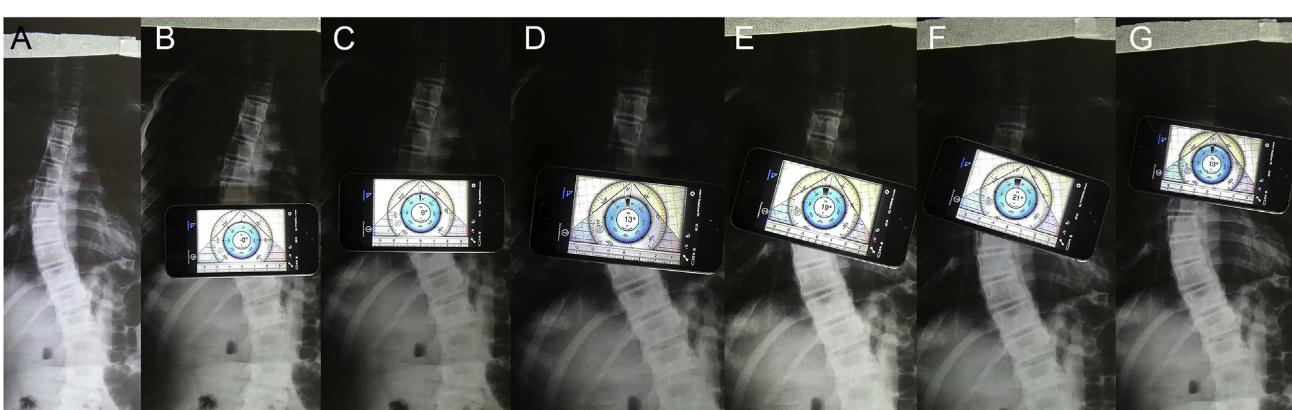

Fig. 1. Upper end vertebra selection technique by smartphone application. 1A shows posteroanterior scoliosis radiograph. 1B (0°): Smartphone is placed on apical vertebral endplate and angle is reset by pressing the center of screen. 1C (6°), 1D (13°), 1E (19°): Application automatically displays the angle while smartphone is placed on vertebral endplates proximally. 1F (21°): Upper end vertebra is defined when highest angle is derived. 1G (13°): Note that if procedure continues after end vertebra is found, angle start to decrease.

Table 1
Interclass correlation coefficients in manual and smartphone Cobb angle measurements.

	Manual	Smartphone
	Mean (range)	Mean (range)
Intraobserver 1	0.974 (0.944–0.988)	0.987 (0.973–0.994)
Intraobserver 2	0.914 (0.818–0.960)	0.985 (0.968–0.993)
Intraobserver 3	0.907 (0.801–0.956)	0.983 (0.964–0.992)
Intraobserver 4	0.976 (0.948–0.989)	0.995 (0.990–0.998)
Intraobserver 5	0.919 (0.827–0.962)	0.978 (0.952–0.989)
Intraobserver 6	0.973 (0.942–0.987)	0.989 (0.977–0.995)
Intraobserver 7	0.963 (0.922–0.983)	0.983 (0.964–0.992)
Overall intraobserver	0.946 (0.907–0.976)	0.985 (0.978–0.995)
Interobserver	0.910 (0.857–0.950)	0.967 (0.946–0.982)

test). However, there were no significant end vertebra selection differences in smartphone set.

Discussion

Therapeutic decisions in scoliosis patients depend on the severity and progression of the deformity.[15] Cobb angle is used in measurements of deformity and plays an important role not only in diagnosis but also in the follow-up of treatment. Therefore, in terms of reliability between measurements is crucial. End vertebra selection differences, poor quality radiographs, varying wide-diameter pencils and the use of inaccurate protractors are among the factors that affect measurement negatively.[4,7,16] A protractor that has rough edges or has not clearly inscribed lines causes measurement error. It is hard to determine endplate edges on poor quality images and use of varied pencils/markers on repetitive measures cause different results. The major intrinsic error factor of Cobb angle measurement is definition of end vertebra.[8,17] End vertebra is defined as the vertebra which is most tilted from the horizontal apical vertebra.[1] When the end vertebra selection variability was eliminated, measurement error between the examiners was relatively small.[18] Most studies showed a positive measurement effect was evident if the preselected end vertebrae were used.[7,18,19] Morrissy et al[18] studied on fifty scoliosis radiographs with four orthopedist to quantitate the intrinsic Cobb angle measurement error and found intra-and interobserver variability were lower in preselected end vertebra group than non preselected group. In addition, end vertebrae are usually selected visually in clinical practice. Computer assisted end vertebra selection method was developed by Zhang et al[9] by using Fussy Hough transform technique.[10,11] In this method, users click on the vertebra and a rectangle size is created as a region of interest (ROI). Then it is adjusted to ROI to fit the vertebra. After select and adjust the ROI, software automatically define the end vertebrae and calculate the Cobb angle. Both the intra- and interobserver reliability analyses concluded excellent for the Cobb angle. In our study we used the smartphone application to define the end vertebra and calculate Cobb angle and found excellent reliability just similar to Zhang's study. In addition, computer assisted system requires software and hardware installation to personal computer, user skills and digital radiographs. These can be considered as disadvantages of this method. However, smartphone-aided system is portable, usable on printed or digital radiographs and users can download program from application stores for free. Recent studies compared smartphone-aided and manual method for Cobb angle measurement.[3,6] Shaw et al reported iPhone is an equivalent to the manual protractor for Cobb measurement but approximately 3 min faster than protractor.[3] In Shaw's study, 7 observers were free to select the end vertebra and there were good to excellent agreement between iPhone and protractor on level selection. However, we used reliability analyze to compare the end vertebra selection variability. Both smartphone-aided and manual method provided excellent intra- and interobserver reliability but higher values are obtained from smartphone than the manual method (Table 2). This value differences can be related with 2 observers, who selected statistically significant difference end vertebra in manual method between repeated sets. As with similar previous studies, intraobserver reliability was higher than interobserver reliability. Carman et al[7] emphasized that intraobserver reliability is more clinically important than interobserver because intraobserver errors can cause misdiagnosis in the following of curvature.

Range of 2.6–8.8° and 2.4–9.0° have been reported as a measurement error for the manual and computer method.[7,9,20,21] Kukla et al[22] compared manual and computer assisted methods for Cobb angle measurement and found no significant difference in measurement error, but Chockalingam et al[23] and Sardjono et al[24] found the reliability of the computer assisted technique was significantly better than traditional measurements. As to the smartphone-aided measurement, the variability of the measurement was 1.8–3.6°.[3,6] Qiao et al conducted a comparative study, reported intraobserver error of 3.5° for the manual measurement versus 2.2° for the smartphone measurement. Interobserver error was 5.4° for the manual measurement and 3.6° for the smartphone measurement.[6] Shea et al found intraobserver error was 3.3° for manual set and 2.6° for computer set.[4] In our study, intraobserver error was 3.6° for the manual measurement versus 1.9° for the smartphone measurement and interobserver error was 5.1° for the manual measurement and 2.7° for the smartphone measurement. Although Qiao and Shea used preselected and constant end vertebra, we obtained similar results with smartphone set. When we compare reliability analyze, Qiao reported intraobserver ICC was 0,955 and interobserver ICC was 0.936 in the manual method. In present study, intra- and interrater ICCs were similar to these results with

Table 2
Interclass correlation coefficients in manual and smartphone end vertebra selection.

	Manual		Smartphone	
	Upper end vertebra mean (range)	Lower end vertebra mean (range)	Upper end vertebra mean (range)	Lower end vertebra mean (range)
Intraobserver 1	0.984 (0.966–0.993)	0.986 (0.971–0.994)	0.991 (0.980–0.996)	0.980 (0.958–0.991)
Intraobserver 2	0.988 (0.975–0.994)	0.930 (0.852–0.967)	0.989 (0.976–0.995)	0.986 (0.971–0.994)
Intraobserver 3	0.983 (0.963–0.992)	0.973 (0.942–0.987)	0.993 (0.984–0.997)	0.985 (0.969–0.993)
Intraobserver 4	0.990 (0.978–0.995)	0.972 (0.941–0.987)	0.996 (0.991–0.998)	0.992 (0.983–0.996)
Intraobserver 5	0.980 (0.957–0.990)	0.987 (0.972–0.994)	0.990 (0.979–0.995)	0.989 (0.977–0.995)
Intraobserver 6	0.976 (0.949–0.989)	0.979 (0.970–0.993)	0.994 (0.987–0.997)	0.995 (0.990–0.998)
Intraobserver 7	0.979 (0.956–0.990)	0.986 (0.964–0.992)	0.983 (0.965–0.992)	0.983 (0.964–0.992)
Overall intraobserver	0.982 (0.972–0.993)	0.973 (0.965–0.981)	0.991 (0.985–0.997)	0.987 (0.979–0.995)
Interobserver	0.956 (0.928–0.976)	0.914 (0.862–0.953)	0.966 (0.944–0.982)	0.967 (0.945–0.982)

lower reliability for manual method (Table 1). This could be related with our study observers were free to select end vertebra in manual method. But in smartphone set Qiao reported excellent reliability with intrarater ICC was 0.985 and interobserver ICC was 0.956. And we reported intrarater ICC was 0.985 and interrater ICC was 0.967 in smartphone set. Almost same excellent reliability results derived from this two study even though we don't use preselected end vertebra.

The main limitation of this study was the absence of measurement time data. If we could obtain data, we would be able to make a more comparable conclusion between methods. Nevertheless, this is the first study reporting the existence of smartphone technique to select end vertebra. This can be considered as one of the strengths of the study.

As a result, smartphone-aided method reduced Cobb angle measurement error by increasing the reliability of end vertebrae selection with practical usage advantage. We recommend using smartphone both end vertebrae selection and Cobb angle measurement.

Conflict of interest

The authors declare no conflict of interest. None of the authors have any commercial relationship with Apple or with the producers of the iSetsquare software mentioned in this article.

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