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ORIGINAL ARTICLE

Use of the iPhone for Cobb angle measurement in scoliosis

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Abstract

Purpose The Cobb technique is the universally accepted method for measuring the severity of spinal deformities. Traditionally, Cobb angles have been measured using protractor and pencil on hardcopy radiographic films. The new generation of mobile 'smartphones' make accurate angle measurement possible using an integrated accelerometer, providing a potentially useful clinical tool for assessing Cobb angles. The purpose of this study was to compare Cobb angle measurements performed using a smartphone and traditional protractor in a series of 20 adolescent idiopathic scoliosis patients.

Methods Seven observers measured major Cobb angles on 20 pre-operative postero-anterior radiographs of Adolescent Idiopathic Scoliosis patients with both a standard protractor and using an Apple iPhone. Five of the observers repeated the measurements at least a week after the original measurements.

Results The mean absolute difference between pairs of smartphone/protractor measurements was 2.1°, with a small (1°) bias toward lower Cobb angles with the iPhone. 95% confidence intervals for intra-observer variability were ±3.3° for the protractor and ±3.9° for the iPhone. 95% confidence intervals for inter-observer variability were ±8.3° for the iPhone and ±7.1° for the protractor. Both of these confidence intervals were within the range of previously published Cobb measurement studies.

Conclusions We conclude that the iPhone is an equivalent Cobb measurement tool to the manual protractor, and measurement times are about 15% less. The widespread availability of inclinometer-equipped mobile phones and the ability to store measurements in later versions of the angle measurement software may make these new technologies attractive for clinical measurement applications.

Keywords Scoliosis · Cobb angle · Smartphone · iPhone · Measurement variability

Introduction

Measurement of Cobb angles from plane radiographs is routine practice to monitor the progression of spinal deformities in spinal clinics worldwide. The Cobb method [1] remains the most popular method for assessment of abnormal spinal curves in both coronal and sagittal planes since it was adopted by the Scoliosis Research Society in 1966. In 2008, Kotwicki [2] stated that classical radiography assessed with the Cobb Method is still the most important image-based method for assessment of scoliosis patients. The concept of inclinometer based Cobb angle measurement was first proposed by Whittle and Evans [3]. A recent review by Vrtovec et al. [4] evaluated over 100 studies of existing manual and computerized 2D and 3D methods for quantitative measurements of spinal curvature from medical images and concluded that many computerized methods remained too complex and were not appropriate for routine clinical use because of their variability.

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Increased adoption of picture archiving and communication (PACS) systems within hospitals has reduced the need for manual measurement of scoliosis Cobb angles in some cases, as spinal curves can be measured directly on digital radiographs using software tools built into the imaging viewing software. However, access to this technology is not universal, and software-based digital radiograph measurement tools are generally not portable or useful when the clinician is consulting with patients outside of the hospital or computer networked medical facility. For these reasons, scoliosis curve measurements using hard copy radiograph films or printed versions of digital radiographs are still widely performed.

The recent generation of mobile 'smartphones' often incorporate a micro-electro-mechanical-system (MEMS) accelerometer, which can accurately sense acceleration and inclination. The availability of various software applications for smartphones which read and display the accelerometer signal allow them to be used in a wide range of potential clinical applications, such as a goniometer for measuring peripheral joint ranges of motion, a scoliometer (Scoliosis Research Society, Milwaukee, WI) for rib hump assessment in scoliosis clinics, or as investigated in this study, for the measurement of Cobb angles on plain radiographs. The aim of this study was to quantify the measurement performance of the Apple iPhone compared with a standard protractor for the assessment of coronal Cobb angles on hardcopy radiographs.

Fig. 1 Full length postero-anterior radiograph of a patient in the study where the thoracic curve was pre-nominated for observers to measure as it was reasonable to expect that either the thoracic or lumbar curves of this patient may be chosen as the major curve

Materials and methods

Study cohort

Twenty adolescent idiopathic scoliosis (AIS) patients were randomly selected from the Paediatric Spine Research Group' spinal deformity patient database at the Mater Children's Hospital, Brisbane, Australia. The patient group represented a range of AIS curve classifications and severities. A single digital pre-operative full-length postero-anterior radiograph for each patient was retrieved. Each radiograph was de-identified of all patient information and multiple copies of the 20 radiographs were printed onto A3 sized paper. The general region (e.g., thoracic or lumbar) of the major scoliotic curve to be measured was nominated on each radiograph at the time of issuing measurement instructions, to ensure that all observers measured the same curve. This was necessary as a number of the chosen radiographs demonstrated a double scoliosis or large compensatory curve (Fig. 1). The observers were free to select which vertebral levels were included in the major curve for each patient according to the Cobb technique (i.e., between the most inclined endplates at the proximal and distal ends of the major curve) [1].

Radiographic measurements

Seven observers (two experienced spinal orthopaedic specialists, two spinal fellows, a specialist physiotherapist, an experienced spinal orthotist and a training grade registrar) measured the major Cobb angles of the 20 coronal plane radiographs using first a smartphone, and second a pencil and protractor using the traditional Cobb technique [1]. All smartphone measurements were performed using an Apple iPhone (Apple Inc, Cupertino, USA) running the Tiltmeter Pro software,[1] which was downloaded from the Apple iTunes store. The Tiltmeter software requires the radiograph or a printed version of a radiograph to be secured in the vertical plane similar to a transparent radiograph positioned on a backlit X-ray reader box.

The smartphone measurements of the 20 radiographs by a particular observer were performed in a block, followed by the manual protractor measurements of the same set of

[1] Measurement of Cobb angles using the iPhone involved measuring the angle of the inferior and superior vertebral endplates selected and then adding these numbers together to obtain the Cobb angle. Since performing this study, a newer version of the software application enables the addition of the two angles automatically thus avoiding a potential error in simple addition by the observer.

radiographs. The protractor measurements were always performed after the smartphone measurements because the protractor measurements involved marking the radiographs. Observers were not given any specific instruction on how to alter their Cobb angle measurement technique to account for the non-transparency of the smartphone as opposed to the traditional transparent protractor. Using this approach, the time between initial measurement of a particular radiograph using the smartphone and re-measurement of the same radiograph using the protractor was found to be approximately half an hour. Measurements using the two techniques were recorded on separate datasheets, so that when entering the protractor measurement results the prior smartphone measurement results were not visible on the same sheet. To assess inter and intra-observer variability associated with the two measurement techniques, five of the original seven observers performed a second set of measurements at least a week after their first set of measurements using fresh, unmarked hardcopy radiographs. To estimate the relative measurement time for the two techniques, two of the observers recorded the total time they took to perform each block of 20 measurements. During measurements, the observers recorded the upper and lower endplates selected for each curve.

Statistical analysis

The two Cobb measurement methods were compared using the approach described by Bland and Altman [5, 6]. Intra-observer variability was assessed by analysing the absolute difference between successive Cobb angle (α) measurements by the same observer using the same measurement tool,

$$\Delta\alpha = |\alpha_n - \alpha_{n+1}|$$

where n and $n + 1$ are successive measurements. 95% confidence intervals for intra-observer variability were calculated as ($1.96 \times SD_{intra}$) [5, 6] where SD_{intra} is the standard deviation of the intra-observer differences $\Delta\alpha$. The inter-observer variability (standard deviation of the difference between measurements by two different observers) was calculated as $\sqrt{2} \times SD_{inter}$ for a single measurement per observer, where SD_{inter} is the standard deviation of the inter-observer differences [5]. The 95% confidence intervals for inter-observer variability were calculated using $2.09 \times$ SD (t-distribution with 19 dof) [5].

Results

Demographics

The study group comprised 17 females and 3 males with a mean age of 14.4 ± 1.7 years (range 11.8–18.8). By selection, all patients had a clinical diagnosis of AIS. Eleven of the major curves were thoracic and convex to the right (Lenke 1 curves [7]) and nine were thoracolumbar curves and convex to the left (Lenke 5 curves [7]). Assessment of the 20 radiographs by seven observers, and repeat assessment by five of the observers, gave a total of 240 sets of measurements. One of these sets was excluded due to the observer not measuring the nominated major curve, leaving 239 pairs of protractor/iPhone measurements. The overall mean major Cobb angle for the group was 45° (range 15°–72°). The mean measurement time for an observer to measure the 20 Cobb angles was 19 min (range 15–23) for the smartphone compared with 22.5 min (range 18–27) for the protractor.

iPhone versus protractor comparison

Figure 2 shows all data points for both the iPhone and protractor measurements plotted versus the mean Cobb angle for each pair of measurements. Figure 3 shows a graph of signed measurement difference between pairs of iPhone/protractor measurements for the same radiograph, versus mean Cobb angle. The mean absolute difference between pairs of iPhone and protractor measurements was $2.1 \pm 1.7°$ (range 0 to 8°), and the mean signed difference was 1.0° (range $-8°$ to $+8°$), suggesting that there is a small measurement bias between iPhone and protractor techniques. The 95% confidence interval for differences between iPhone and protractor measurements on the same radiograph was $1.96 \times SD = \pm 3.3°$.

Intra-observer variability

Figure 4 shows the difference between pairs of successive measurements by the same observer for both the iPhone and protractor, plotted versus mean Cobb angle. The mean

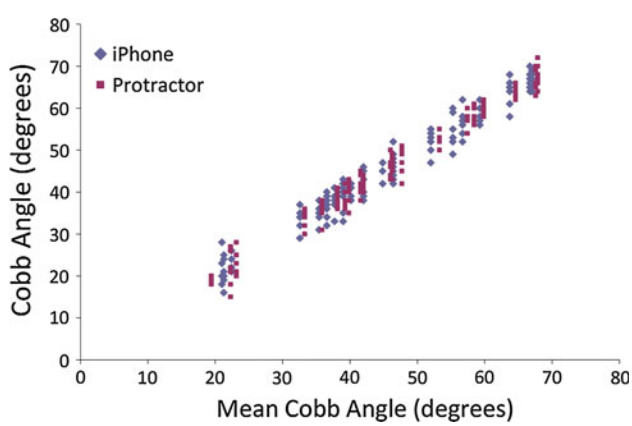

Fig. 2 Scatter plot of all Cobb angle measurements for both iPhone and protractor, plotted versus mean Cobb angle for the radiograph being measured

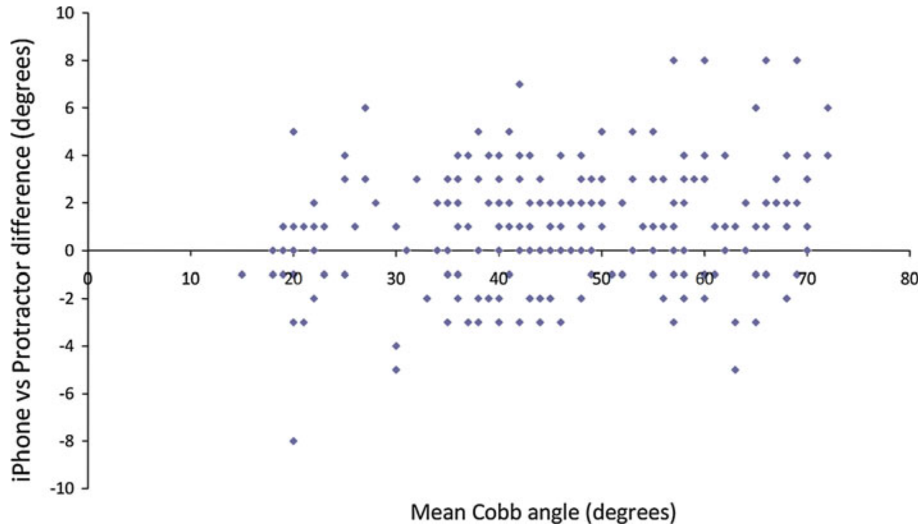

Fig. 3 Scatter plot showing the signed difference between pairs of measurements performed by the same observer on the same radiograph using the iPhone first, followed by the protractor. Plotted versus mean Cobb angle for the measurement pair

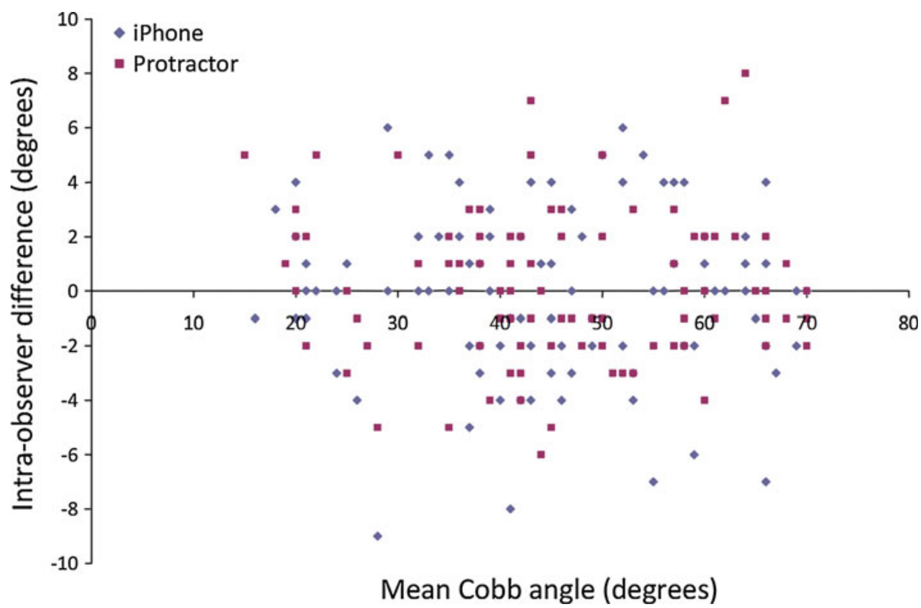

Fig. 4 Scatter plot of intra-observer difference between successive measurements (at least 1 week apart) by the same observer on the same patient using the same measuring tool, plotted versus mean Cobb angle for the measurement pair. Data points for iPhone and protractor are shown using *different symbols*

absolute intra-observer difference was 2.1° ± 1.7° (range 0°–8°, 95% CI = 3.3°) for the protractor, and 2.3° ± 2.0° (range 0°–9°, 95% CI = 3.9°) for the iPhone, suggesting that the intra-observer variability of the iPhone is equivalent to the protractor. Figure 5 compares the 95% confidence interval for intra-observer differences using the iPhone in this study with values reported in previous studies [8–17] for manual measurement of major curves in idiopathic scoliosis patients. Only data from studies using plane radiographs with no endplate pre-selection were included in this graph. Note that the corrected data [18] for Facanha-Filho et al. [14] is used in this graph.

Inter-observer variability

Based on a single reading by each observer, the SD of a Cobb angle measurement was 2.8° for the iPhone and 2.4° for the protractor. The inter-observer error (standard deviation of the difference between measurements by two different observers) is therefore $\sqrt{2} \times \mathrm{SD} = 4.0°$ for the iPhone and 3.4° for the protractor[4]. The 95% confidence intervals for inter-observer error were ±8.3° and ±7.1° for the iPhone and protractor, respectively, calculated using 2.09 × SD (t-distribution with 19 dof). Figure 6 compares the 95% inter-observer confidence limits for iPhone and protractor given above with values reported in previous studies [8–19] for manual measurement of idiopathic scoliosis using plain radiographs with no endplate pre-selection.

Endplate selection variability

Table 1 gives details of the difference in upper and lower endplate selection between successive pairs of iPhone and

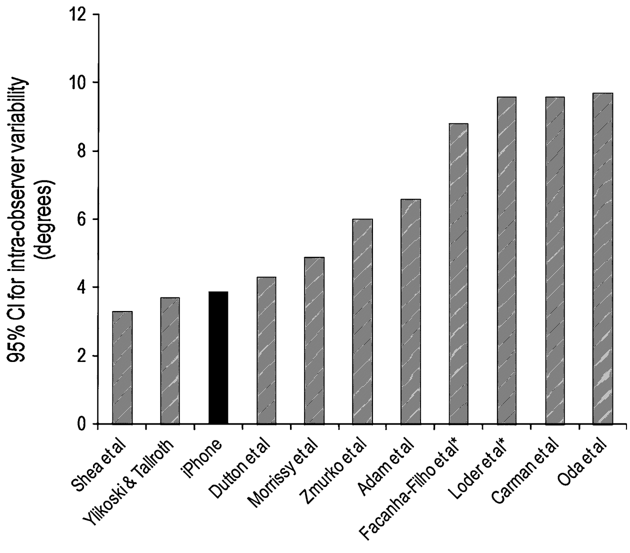

Fig. 5 Comparison of 95% confidence intervals for intra-observer variability between the iPhone (current study) and a range of previous studies [8–18]. Only data from studies using plane radiographs with no endplate pre-selection were included in this graph. Note that the corrected data [18] for Facanha-Filho et al. [14] is used in this graph. Includes two studies on congenital scoliosis are marked with *asterisk*

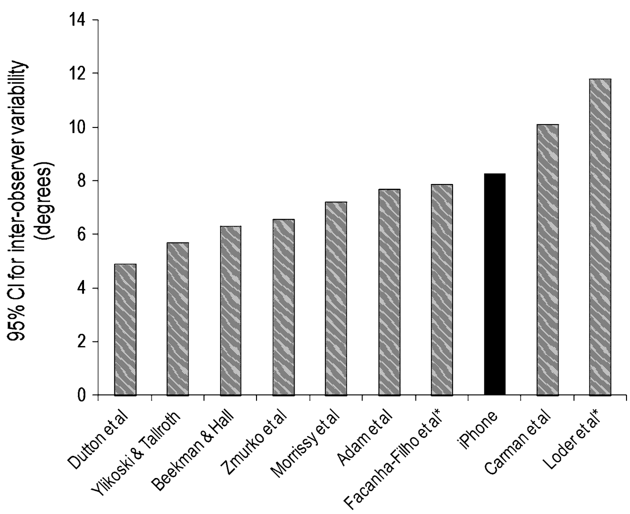

Fig. 6 Comparison of 95% confidence intervals for inter-observer variability between the iPhone (current study) and a range of previous studies [8–19]. Only data from studies using plane radiographs with no endplate pre-selection were included in this graph. Note that the corrected data [18] for Facanha-Filho et al. [14] is used in this graph. Includes two studies on congenital scoliosis are marked with *asterisk*

protractor Cobb measurements. As shown in Table 1, there was good to excellent agreement between iPhone and protractor end level selection, with slightly more consistent level selection for lower endplates (80% agreement in upper endplate selection vs. 90% agreement for lower endplates, 19% of endplates within ±1 level for upper endplates, vs. 9% for lower endplates). However, the difference between lower and upper endplate selection variability was not statistically significant at the 5% level ($P = 0.10$, paired t-test).

Table 1 Endplate selection variability comparing iPhone and protractor

	Proportion of total (%)
Upper endplate selection	
iPhone upper endplate 2 levels higher than protractor	1
iPhone upper endplate 1 level higher than protractor	10
No difference in levels	79
iPhone upper endplate 1 level lower than protractor	9
iPhone upper endplate 2 levels lower than protractor	1
Lower endplate selection	
iPhone lower endplate 2 levels higher than protractor	0
iPhone lower endplate 1 level higher than protractor	4
No difference in levels	90
iPhone lower endplate 1 level lower than protractor	5
iPhone lower endplate 2 levels lower than protractor	2

Discussion

The recent emergence of mobile phones incorporating MEMS accelerometers has provided a new technology for accurate electronic measurement of angles. The ubiquitous nature of these devices and the ready availability of software applications mean that they may have a significant impact on efficiency and convenience in spinal clinics for assessment of spinal deformities. In this study, we assessed the measurement performance of the iPhone compared with standard protractor technique for assessing Cobb angles on plane radiographs of scoliosis patients.

In some situations, manual measurement of Cobb angles using radiographs is being replaced by software-based measurements of digital radiographs available through hospital PACS systems. However, many clinicians still consult with patients from multiple locations and may run clinics in rural and regional areas where digital radiographic technology is unavailable. Due to geographical isolation, physicians may have radiographs mailed or emailed from distant locations and are unable to access the digital Cobb angle tools that are built into their hospital PACS system to measure these radiographs. Patients also may present with radiographs on computer discs whose included software does not incorporate a Cobb angle tool. In these cases, smartphones offer a convenient tool to measure the scoliosis curve magnitude either directly on the computer screen, or from a hardcopy version of the radiograph. The mean time taken to measure the group of radiographs with the iPhone was just over 3 minutes faster

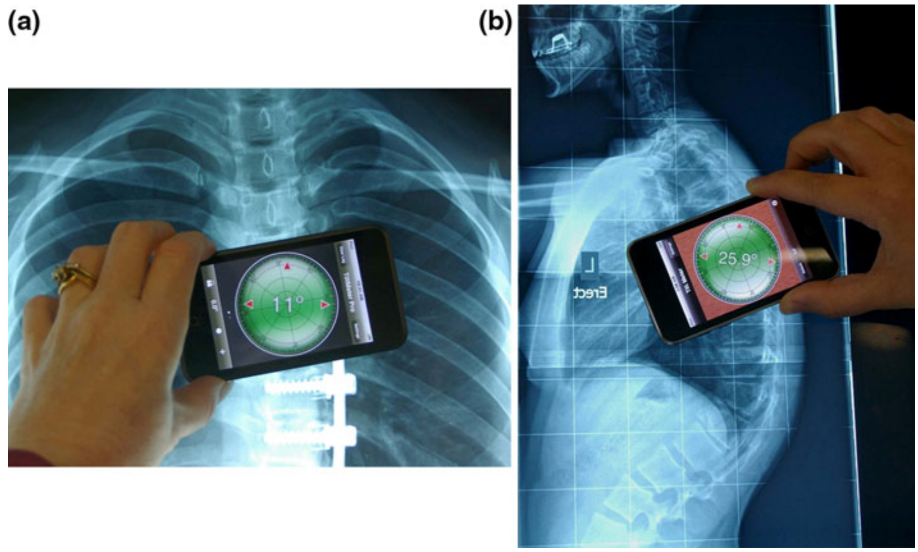

Fig. 7 Application of the iPhone for measurement of **a** post-operative Cobb angles and **b** sagittal plane kyphosis

than using the protractor for the same group, although this slight time advantage would probably not be clinically significant for the measurement of single radiographs in a hospital setting.

As mentioned in the "Materials and methods", observers were not given any specific instruction on how to alter their Cobb angle measurement technique to account for the non-transparency of the smartphone. The measurement variability results indicate that the opacity of the smartphone did not increase Cobb angle measurement variability, and we therefore conclude that the observers adapted their technique successfully.

Endplates were deliberately not preselected in this study to better align with everyday clinical practice where an observer is required to make a judgement as to which vertebrae to include in the Cobb angle. The Cobb angle by definition asks each observer to choose the most inclined upper and lower vertebral endplates at each presentation of the patient. At subsequent appointments, the endplates chosen may change as the scoliotic curve progresses. Therefore, endplate selection contributes to both the inter-observer and intra-observer variability in this study as well as in the clinical setting (see Table 1).

In this study, the differences between iPhone and protractor measurements were small, with a mean absolute difference of just over 2°, bias of 1° and a 95% confidence interval of just over 3°. All of these are much less than the 5° difference which is widely accepted as signifying a clinically significant difference in Cobb angle. Therefore, we conclude that the iPhone is a clinically equivalent measuring tool to the traditional protractor. Furthermore, the inter- and intra-observer measurement variability using the iPhone were similar to that of the protractor in the current study, and within the range of previously published manual measurement studies using a standard protractor on plain radiographs with no endplate pre-selection (Figs. 5, 6) [8–19]. As with nearly all previous studies, the 95% confidence intervals for inter-observer variability were higher than those for intra-observer variability, for both the iPhone and the protractor. Carman et al. [16] note that the intra-observer variability is a more clinically relevant parameter than the inter-observer variability because intra-observer differences can lead to misdiagnosis of curve progression, thus influencing clinical treatment decisions. However, we note that inter-observer variability may be equally important in large public spinal clinics where the same clinician does not always assess the same patient.

As well as automatically adding upper and lower endplate angles to obtain the Cobb angle, newer versions of the Tiltmeter Pro software enable the user to store previous measurements allowing comparison of current readings with previous readings for a particular patient. Although the radiograph measurement capability of the smartphone was only assessed for coronal radiographs of pre-operative AIS patients in this study, the basis of the Cobb measurement technique is the same when performing post-operative Cobb measurements, or sagittal plane kyphosis/lordosis measurements (Fig. 7); therefore, after appropriate comparison with manual measurement techniques, the smartphone could likely be used in a range of clinical measurement situations.

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