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ORIGINAL ARTICLE

Radiographic measurement of the sagittal plane deformity in patients with osteoporotic spinal fractures evaluation of intrinsic error

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Abstract Cobb method has been shown to be the most reliable technique with a reasonable measurement error to determine the kyphosis in fresh fractures of young patients. However, measurement errors may be higher for elderly patients as it may be difficult to determine the landmarks due to osteopenia and the degenerative changes. The aim of this study is to investigate the intrinsic error for different techniques used in evaluation of local sagittal plane deformity caused by OVCF. Lateral X-rays of OVCF patients were randomly selected. Patient group was composed of 28 females and 7 males and the mean age was 62.7 (55–75) years. The kyphosis angle and the vertebral body height were analyzed to reveal the severity of sagittal plane deformity. Kyphotic deformity was measured by using four different techniques; and the vertebral body heights (VBH) were measured at three different points. The mean intra-observer agreement interval for kyphosis angle measurement techniques ranged from ±7.1 to ±9.3° while it ranged from ±4.5 to ±6.5 mm for VBH measurement techniques. The mean interobserver agreement interval for kyphosis angle ranged from ±8.2 to ±11.1°, while it was between ±4.5 to ±6.5 mm for vertebral body height measurement techniques. This study revealed that although the intra and interobserver agreement were similar for all techniques, they are still higher than expected. These high intervals for measurement errors should be taken into account when interpreting the results of correction in local sagittal plane deformities of OVCF patients after surgical procedures such as vertebral augmentation techniques.

Keywords Osteoporotic vertebral compression fracture · Vertebroplasty · kyphoplasty · Measurement error

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Introduction

Osteoporotic vertebral compression fractures (OVCF) are major source of morbidity in the elderly population. Vertebroplasty and kyphoplasty are two new treatment modalities that are introduced over the past decade to treat osteoporotic compression fractures. The main purpose of these treatment modalities is alleviation of pain. Compression fractures may also result in kyphosis, which may lead to restrictive changes in pulmonary function and secondary cardiopulmonary morbidity [27]. Therefore, correction of the deformity has become an intention in addition to pain relief while treating this patient group.

Eventually, in addition to pain relief, the efficiency of deformity correction has become an important measure of outcome while reporting the results of vertebral augmentation techniques. However, there is no consensus in the literature regarding which method should be used and what is the reliability of different methods in the setting of osteoporotic compression fractures [13, 16].

Several types of measurement techniques have been used to demonstrate the correction of deformity in previous studies by either measuring the correction of the vertebral body height [8, 12, 15, 18, 19] or analyzing the correction in kyphosis angle [1, 14, 23, 32] or both [6, 7, 10, 11, 24, 26, 30, 31]. Recently, McKiernan et al. has demonstrated the variability in apparent magnitude of vertebral height restoration when this outcome was reported by four different calculation methods commonly used in vertebroplasty literature [22].

In young patients with deformity, Cobb method has been shown to be the most reliable method with less measurement error for evaluation of kyphosis [17]. Recently, Teng et al [30], evaluated intra- and interobserver reproducibility of wedge angle, local kyphosis angle and height restorations as a part of their report about deformity correction capacity of vertebroplasty and demonstrated that Cobb method is more reliable than local kyphosis angle and vertebral body height measurement. However, there is not yet any published study on the agreement intervals of the methods currently used to evaluate local sagittal plane deformity in elderly patients. Osteoporotic patients are generally older patients and the landmarks in the X-rays may be difficult to determine due to low bone density and the degenerative changes which may lead higher measurement errors.

The purpose of this study was to determine the measurement error of commonly used techniques in the setting of osteoporotic compression fractures, first when the same observer and then when different observers measured the same radiographs to determine the severity of kyphotic deformity.

Materials and methods

Thirty-five lateral radiographs of thoracolumbar osteoporotic compression fractures were randomly selected. All patients had bone mineral densities indicating osteoporosis. The radiograms were taken according to a standardized protocol and the beam was centered on the fractured vertebra. Two parameters were measured to reveal the severity of local sagittal plane deformity; the angle of kyphosis and the vertebral body height.

Kyphotic deformity was measured using four different techniques:

(1) Measuring the angle between the superior and the inferior endplates of the fractured vertebral body (FVB) (Fig. 1a)
(2) Measuring the angle between the inferior endplate of the vertebral body just above the fracture and the inferior endplate of the FVB (Fig. 1b)
(3) Measuring the angle between the inferior endplate of the vertebra above and the superior endplate of the vertebra below the FVB (Fig. 1c)
(4) Measuring the angle between the superior endplate of the vertebral body above and the inferior endplate of the vertebral body below (Fig. 1d)

Three different heights (anterior, mid and posterior) of vertebral body were measured to determine the vertebral body height (VBH). To measure the mid-body height (MBH), the first step was to determine the most antero-superior (a), postero-superior (c) points of the superior, and the most antero-inferior (b), postero-inferior (d) points of the inferior endplates of the fractured vertebral body. Then,

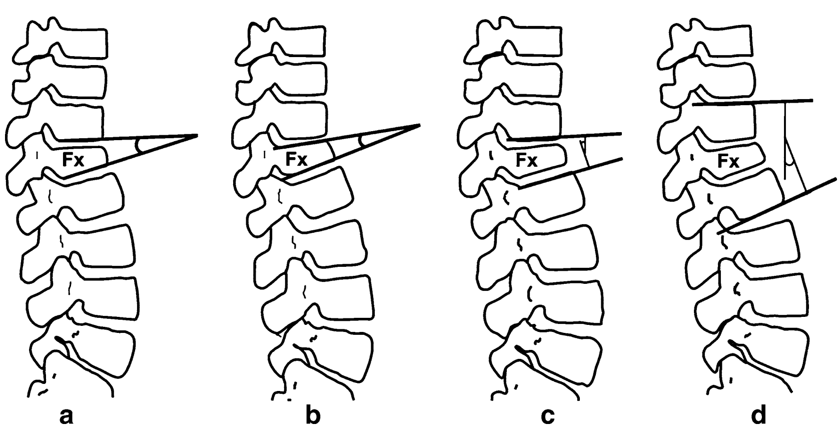

Fig. 1 The measurement techniques that were used to evaluate the magnitude of the kyphotic deformity, measuring the angle between the superior and the inferior endplates of the fractured vertebral body (FVB) **a**, measuring the angle between the inferior endplate of the vertebral body just above the fracture and the inferior endplate of the FVB **b**, measuring the angle between the inferior endplate of the vertebra above and the superior endplate of the vertebra below the FVB **c**, measuring the angle between the superior endplate of the vertebral body above and the inferior endplate of the vertebral body below **d**

the line connecting the point b and d were drawn and its midpoint (mp) was signed. The intersection points of the line vertical to mp with the superior and inferior endplates were named as point e and f. The anterior, mid- and posterior vertebral body heights were measured between points a and b, c and d, e and f, respectively (Fig. 2).

Written instructions for measurement methods were given to all observers and a consensus meeting was done before starting measurements. Measurements were done on two occasions with 3 weeks interval by three fellowship trained spine surgeons. The observers were blinded as to the dates of the radiographs and the identities of the patients. Between the measuring sessions, the radiographs were cleaned completely of all marks with soft alcohol pads to avoid scratching the radiograph emulsion. All measurements were done by using the same goniometer (DePuy, Acromed) and marking implement (Schwann-Stabilo). Each observer rated subjective quality of each radiographs as excellent, good, fair and poor.

The data were analyzed using a statistical software program, SPSS 11.0 for PC. The distribution of differences were checked by drawing a normal plot, then the intra- and inter-observer limits of agreement of the techniques was calculated by using Bland–Altman method [2]. The agreement interval method has been specifically designed to compare different methods measuring a single value. Contrary to other statistical methods that are used to test reliability of measurement methods, agreement interval provides objective values that would allow the clinicians to evaluate whether these values are clinically important or not [4, 20]. This method provides the limits within which a repeat measurement is going to lie in 95% of the time with 95% confidence. It is calculated with the following formula:

$$\mathrm{AI} = \mathrm{AD} \pm \mathrm{SD} \times \sqrt{(n + 1/n)}$$

where AI is agreement interval, AD is average difference between the readings, SD is standard deviation of the differences between the readings, *n* is the sample size. For example, as shown in Table 2 in the absence of any true change, when using method 4, Observer B can be 95% confident that 95% of the time he is going to measure either 8.0° lower or 8.0° higher than his previous measurement due to observer error alone. In other words, in order to be 95% confident that a measured change represents true correction, this change must be more than 8°. The effect of film quality over measurement differences is evaluated with Kruskal–Wallis test.

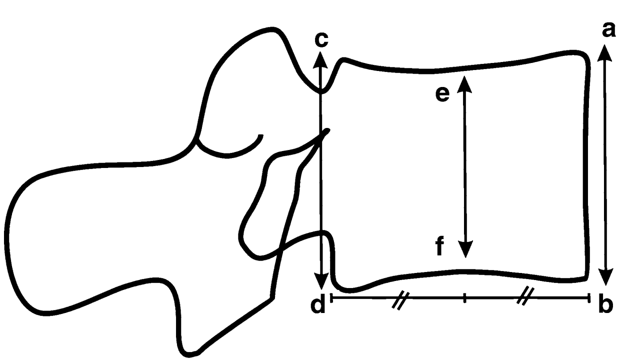

Fig. 2 The reference points that were used to measure the vertebral body heights

Results

Patient group was composed of 28 females and 7 males and the mean age was 63 (55–75) years. All patients had bone mineral densities indicating osteoporosis with an average *T* score of –3.57 (–2.51, –5.44). Fracture types were classified according to Eastell et al. [9] as wedge (*n* = 17), biconcave (*n* = 10) and compression (*n* = 8). The fractures were located between T6 and L4 and distributed as 18 thoracic and 17 lumbar fractures. Each of the three independent observers performed eight measurements on 35 lateral radiographs on two separate occasions.

Intra-observer agreement

The agreement interval method has been specifically designed to compare different methods measuring a single value. This method provides the limits within which a repeat measurement is going to lie in 95% of the time with 95% confidence. For example, in the absence of any true change, Observer B can be 95% confident that 95% of the time he is going to measure either 8.0° lower or 8.0° higher than his previous measurement due to observer error alone. In other words, in order to be 95% confident that a measured change represents true correction, this change must be more than 8°.

The intra-observer variability of each observer in terms of average difference between the readings (ADBR) (algebraic mean) and agreement intervals for each method was calculated. The ADBR values presented in the tables represent the absolute values (Table 1). While calculating the agreement intervals, the algebraic means were calculated which were not significantly different from zero, hence ignored in the calculation (Table 2). This test also showed that the first readings were not consistently smaller or larger than the second. The agreement intervals and the average difference between the readings for each method were calculated as the average of the measurements of the three observers. The average difference between the readings for each method was calculated as 2.7° for method 1,

Table 1 Intra-observer average difference between the readings values for the kyphosis angle and vertebral body height measurements (mean ± SD)

	Method 1 (°)	Method 2 (°)	Method 3 (°)	Method 4 (°)	ABH (mm)	PBH (mm)	MBH (mm)
Observer A	2.3 ± 1.7	2.3 ± 1.8	2.8 ± 3.1	3.0 ± 3.1	1.1 ± 1.1	1.3 ± 1.6	1.9 ± 2.0
Observer B	2.7 ± 2.4	3.1 ± 2.7	3.8 ± 3.4	2.9 ± 2.7	1.5 ± 1.6	1.7 ± 2.0	2.9 ± 2.5
Observer C	3.0 ± 2.5	2.4 ± 2.6	2.9 ± 3.3	2.6 ± 2.9	1.7 ± 2.3	1.7 ± 1.3	2.5 ± 2.1
Average	2.7	2.6	3.2	2.8	1.4	1.6	2.4

Table 2 Intra-observer agreement intervals for the kyphosis angle and vertebral body height measurements

	Method 1 (°)	Method 2 (°)	Method 3 (°)	Method 4 (°)	ABH (mm)	PBH (mm)	MBH (mm)
Observer A	±5.7	±5.9	±8.5	±8.7	±3.3	±4.2	±5.3
Observer B	±8.0	±7.2	±8.9	±8.0	±5.8	±4.0	±6.5
Observer C	±7.5	±8.2	±10.4	±7.1	±4.4	±5.3	±7.8
Average	±7.1	±7.1	±9.3	±7.9	±4.5	±4.5	±6.5

2.6° for method 2, 3.2° for method 3 and 2.8° for method 4 (Table 1). The agreement intervals for each method was calculated as ±7.1 for method 1, ±7.1 for method 2, ±9.3 for method 3, and ±7.9 for method 4 (Table 2).

Average difference between the readings and agreement intervals of each observer for VBH measurements was also calculated similar to the kyphosis angle values (Tables 1 and 2). The average difference between the readings for each method was calculated as 1.4 mm for ABH, 1.6 mm for PBH, and 2.4 mm for MBH. The agreement interval for each method was calculated as follows: ±4.5 for ABH, ±4.5 for PBH, and ±6.5 for MBH (Tables 1 and 2).

The inter-observer agreement

The average difference between the readings and agreement intervals for inter-observer variability were calculated similar to the intra-observer values. The inter-observer values for observer A and observer B, observer A and observer C, AND observer B and observer C was calculated separately (Tables 3 and 4). Then, the averages of these values were accepted as the ADBR and agreement intervals for each method. The average difference between the readings for each method was calculated as 3.2° for method 1, 3.0° for method 2, 4.2° for method 3 and 3.4° for method 4. The agreement intervals for each method was calculated as follows, ±8.2 for method 1, ±8.2 for method 2, ±11.1 for method 3, and ±8.4 for method 4 (Tables 3 and 4).

Average difference between the readings and agreement intervals of each observer for VBH measurements were also calculated similar to the kyphosis angle values (Tables 3 and 4). The average difference between the readings for each method was calculated as 1.8 mm for ABH, 2.3 mm for PBH, and 3.5 mm for MBH. The agreement interval for each method was calculated as follows; ±4.5 for ABH, ±4.5 for PBH, and ±6.5 for MBH (Tables 3 and 4).

Film quality effect

The quality of the radiographs was rated as excellent for 15, good for 15, fair for 4 and poor for 1 radiographs. In order to evaluate the effect of film quality over measurements, one observer was selected randomly and median values of the differences between his measurements were compared within the film quality scores (Kruskal–Wallis test) There was no association between film quality and the differences between the kyphosis angle measurements. Considering the vertebral body heights, there was no association between film quality and the differences between the anterior and posterior vertebral body height measurements. However the differences between measurements for midvertebral body height were significantly higher as the film quality worsened ($P < 0.02$).

Discussion

Determination of local sagittal plane malalignment secondary to compression fractures in osteoporotic patients became an important issue following the progress in vertebra augmentation techniques. It has been demonstrated that these treatment modalities, particularly kyphoplasty, provided correction in kyphotic deformity. However, there is still debate regarding the efficacy of these techniques in

Table 3 Inter-observer average difference between the readings for the kyphosis angle and vertebral body height measurements (mean ± SD)

	Method 1 (°)	Method 2 (°)	Method 3 (°)	Method 4 (°)	ABH (mm)	PBH (mm)	MBH (mm)
Observer A-B	2.9 ± 2.5	2.5 ± 3.1	4.3 ± 4.5	3.4 ± 2.9	1.9 ± 1.6	2.8 ± 1.9	3.5 ± 3.1
Observer A-C	3.7 ± 2.8	3,3 ± 2.3	4,3 ± 3.8	2.9 ± 2.2	1.3 ± 1.1	2.3 ± 1.6	3.3 ± 2.4
Observer B-C	3.1 ± 3.0	3.1 ± 2.8	4.0 ± 2.5	3.9 ± 2.9	2.0 ± 2.2	1.9 ± 2.0	3.8 ± 3.9
Average	3.2	3.0	4.2	3.4	1.8	2.3	3.5

Table 4 Inter-observer agreement intervals for the kyphosis angle and vertebral body height measurements

	Method 1 (°)	Method 2 (°)	Method 3 (°)	Method 4 (°)	ABH (mm)	PBH (mm)	MBH (mm)
Observer A-B	±7.2	±8.1	±12.7	±8.9	±3.3	±4.2	±5.3
Observer A-C	±8.6	±8.0	±11.4	±7.2	±5.8	±4.0	±6.5
Observer B-C	±8.8	±8.5	±9.2	±9.2	±4.4	±5.3	±7.8
Average	±8.2	±8.2	±11.1	±8.4	±4.5	±4.5	±6.5

terms of correction in kyphosis. The main reason for this confusion is the lack of consensus among spinal surgeons regarding the method to be used to report the radiographic outcomes of the studies [3, 25]. This uncertainity also causes significant difficulty when comparing the results of different studies [13, 16]. Besides, there is not yet any study evaluating the intrinsic measurement error interval for the commonly used techniques for the elderly population. In fact, the measurement error may be higher in this patient population due to osteopenia and degenerative changes.

The only study in the literature about sagittal plane analysis following vertebrae fractures is about fresh burst fractures. Kuklo et al [17] studied five different methods that measures local kyphosis angle, and the Cobb method was found to be the most reliable. He showed that by using Cobb method, 90% of the paired observer measurements were within 5° of each other. Our results demonstrated no superiority of either technique to each other in terms of agreement intervals. When the Cobb method was used, we found a lower agreement as, 79% of the observers were within 5° of each other. This lower success of precision with the Cobb method in elderly patients could be due to the difficulty to determine the landmarks in aged and osteoporotic spine.

Carman et al analyzed the interobserver variations for measurements of Cobb angle on radiographs of patients who had kyphosis. They found the average difference between readings as 3.3° and 11° change was necessary to be 95% confident that a measured change indicates true progression between radiographs [5]. Stotts et al. analyzed Cobb method in evaluation of Scheuermann's kyphosis and found a mean intraobserver variance of 4.3° and 95% tolerance interval of ± 9.6°, whereas the mean interobserver variance and tolerance interval was 3.4 and ±8.7°, respectively [29]. These results should lead us to question the general acceptance of 5° as measurement error in kyphosis measurements. Indeed, these results are in parallel to ours demonstrating that the error interval in measuring kyphosis is higher than 5°.

The vertebral body height restoration is another commonly used method for analyzing the local sagittal plane deformity in osteoporotic patients. Our results demonstrated that, to be 95% certain that an observed change was not due to measurement error alone and thus, indicate a true restoration, the change must be more than 6.6 mm for mid-vertebral body height and 4.5 mm for anterior and posterior body heights. We observed that as the film quality worsened, the difference between the measurements of mid-vertebral body height increased significantly. This was probably due to the large number of biconcave and compression fractures where the endplates were usually irregular, making determination of landmarks more difficult. McKiernan et al. analyzed the influence of calculation methods on the amount of height restoration [21]. The authors demonstrated that the apparent magnitude of height restoration might change nearly to fourfold depending on initial fracture severity and reporting method. Their suggestion was to come to a consensus on one single method in calculating and reporting the height restoration. However, our results with a considerably high measurement error with a range of 4.5 to 6.5 mm bring into mind that, reporting the radiographic outcome in terms of height restoration may not be valid even if a standard calculation method is to be used.

The correction rates of the body height and/or kyphosis angle reported in the studies on the efficacy of vertebral augmentation techniques are either within or slightly above the limits of measurement error intervals demonstrated by the present study [1, 6–8, 10–12, 14, 15, 18, 19, 23–27, 30–33]. Hence, we think that one should always consider the measurement error while evaluating the efficacy of vertebral augmentation techniques in restoration of body height. Besides, the lack of consensus in the literature with regard to reporting deformity correction following vertebral augmentation techniques still remains to be an issue. Digital imaging and computerized measurement techniques may increase the reliability of these measurements. Shea et al. demonstrated lower intra- and interobserver values with digitized measurement techniques when compared to the manual methods by using Cobb method in scoliosis patients [28].

Conclusion

The intra and inter-observer reliability were similar for the commonly used techniques for evaluation of kyphosis, demonstrating no single best method in the elderly population. Since Cobb method (method 4) has been used for decades and familiar to every spine surgeon, we believe it may be the standard method to be used for reporting deformity correction. In terms of height restoration, we believe that very high measurement errors may preclude the use of these parameters as an outcome measure. Regardless of the method used, high intervals for measurement errors should be taken into account when interpreting the results of correction in local sagittal plane deformities of OVCF patients after surgical procedures such as vertebral augmentation techniques.

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