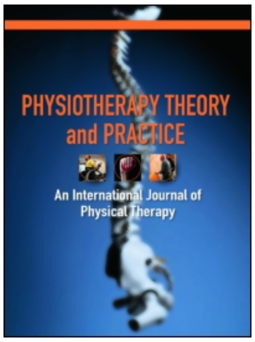

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Inclinometric measurement of kyphotic curvature: Description and clinimetric properties

Laurie Devaney, PT, MSc[a], Richard Bohannon, PT, EdD[b], Jon Rizzo, MSPT, PhD[a], Maryclaire Capetta, PT, DPT[a], Jeremy Vigneault, MSPT[a], and Katherine Van Deveire, DPT[a]

[a]Department of Kinesiology, University of Connecticut, Storrs, CT, USA; [b]Department of Physical Therapy, Campbell University, Buies Creek, NC, USA

ABSTRACT

Background: Hyperkyphosis is associated with physical impairments, activity limitations, and reduced quality of life. Therefore, a simple, reliable, responsive, and valid clinical measure of dorsal kyphosis would be valuable to clinicians. ***Objective***: To describe a novel procedure for measuring kyphotic curvature—the inclinometric kyphosis measure (IKM)—and provide an estimation of reliability, responsiveness, and validity. ***Methods***: During 2 sessions spaced days apart, we used a bubble inclinometer to measure dorsal kyphosis in 68 patients receiving outpatient physical therapy. We also documented occiput-to-wall status and tragus-to-wall distance. ***Results***: Intra-rater reliability of the IKM was supported by intra-class correlation coefficients ($ICC_{3,1}$) of 0.94 and 0.91 for relaxed and cued conditions, respectively. Responsiveness, as indicated by minimal detectable change, was 8.0 and 10.0 degrees under relaxed and cued conditions, respectively. Validity was supported by significant correlations between the IKM and tragus-to-wall and by differences in the IKM between: 1) relaxed and cued conditions; 2) patients who could and could not touch occiput to the wall; and 3) patients who were older versus younger than 50 years of age. ***Conclusions***: The IKM is a simple, reliable, responsive, and valid method for assessing posture in patients with musculoskeletal conditions.

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Measurement; posture; reliability; responsiveness; validity

Introduction

Kyphosis is a naturally occurring posterior convexity of the spine in the sagittal plane that increases as adults age (Fon, Pitt, and Thies, 1980). The consequences of excessive kyphosis are more than aesthetic and include: impairments in neck and shoulder range of motion (Otoshi et al, 2014); compromised pulmonary function (Quek, Pua, Bryant, and Clark, 2013); limitations in mobility; and reductions in quality of life (Kamitani et al, 2013; Katzman et al, 2011).

Given the consequences of excessive kyphosis, the measurement of kyphosis is clearly important. The Cobb angle obtained from plain radiographs is the gold standard for measuring kyphosis. When the Cobb angle of thoracic kyphosis exceeds 40 degrees, an individual is considered to be hyperkyphotic (Fon, Pitt, and Thies, 1980). However, radiographs involve exposure to radiation and are costly. Portable alternatives to radiography have been described. They include measurements derived from: flexicurve tracings (Barrett, McCreesh, and Lewis, 2013; Greendale et al, 2011; Hinman 2004); Debrunner kyphometer (Greendale et al, 2011; Katzman et al, 2007; Korovessis, Petsinis, Papazisis, and Baikousis, 2001); Spinal Mouse (Kellis, Adamou, Tzilios, and Emmanouilidou, 2008); and linear measures (e.g., occiput-to-wall, tragus-to-wall, wall to seventh cervical vertebra) (Vosse et al, 2006). A survey of 220 physiotherapists' practice found that the three most commonly used tools to measure hyperkyphosis were visual inspection, X-ray, and tragus-to-wall distance (Perriman et al, 2012).

Another non-radiologic measurement option reported in several studies, and the focus of our study involves the application of inclinometers to the back. The procedure typically entails the simultaneous application of two inclinometers, one over T1/T2 and the other over T12/L1. Investigators using the procedure have reported excellent reliability for measurements obtained from: swimmers (Barrett, McCreesh, and Lewis, 2013); healthy young adults (Van Blommestein, Lewis, Morrissey, and MacRae, 2012); and adults with and without shoulder pain (Czaprowski et al, 2012; Lewis, Green, and Wright, 2005; Lewis and Valentine, 2010). We are not aware, however, of any literature addressing the responsiveness of inclinometer derived

CONTACT Laurie Devaney, PT, MSc laurie.devaney@uconn.edu Doctor of Physical Therapy Program, Department of Kinesiology, 358 Mansfield Rd U-1101, University of Connecticut, Storrs, CT 06269, USA.

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measures of thoracic kyphosis. The validity of inclinometer measures of kyphosis has been examined in only two studies: In one, high correlations were reported between dual inclinometer measurements and radiographic Cobb angles (Azadinia et al, 2014); in the other, moderate correlations were found between inclinometry and flexicurve measures (Barrett, McCreesh, and Lewis, 2013).

Although inclinometer measurements may be a practicable alternative for documenting kyphotic curvature, the inclinometric procedures described in the literature require accurate identification of spinal levels, are not supported by evidence for responsiveness, and are minimally supported by evidence for validity. Moreover, they do not acknowledge that kyphotic curvature may involve more than the thoracic spine. Our purpose, therefore, was to evaluate a new procedure for measuring kyphotic curvature, the Inclinometric Kyphosis Measure (IKM), in an outpatient orthopedic population, and to report its reliability, responsiveness, and validity.

Methods

Participants

Participants were recruited between September 2013 and June 2014 at an outpatient physical therapy facility at the University of Connecticut. Patients were eligible for inclusion if they were referred for an orthopedic condition and were 18 years or older. Patients were excluded if they were unable to stand independently or follow directions. Consecutive patients meeting these criteria were provided on their initial examination with an information sheet regarding the study. The physical therapist examiner then provided each patient the opportunity to ask questions prior to obtaining written informed consent. The Institutional Review Board at the University of Connecticut approved the study protocol. Written informed consent was obtained from all participants, and participants' rights were protected in compliance with the approved protocol (Approval number H13-176).

Sample size calculation

Sample size estimate was based on pilot data from 11 participants. For differences between inclinometer measures under relaxed and cued conditions, a minimum of 18 subjects per group would be required for 80% power (p < 0.05) to adequately estimate reliability and validity.

Raters

Postural testing was performed by three licensed physical therapists with clinical experience in an outpatient orthopedic setting ranging from 2 to 24 years. Examiners participated in a one-hour training session for instruction in and practice of the measurement techniques as part of clinical skills training at the physical therapy facility.

Procedures

Examiners independently performed and recorded three postural measures during the initial physical therapy examination and during a second visit within seven days. The order of collection of the measures was: occiput-to-wall (OTW); tragus-to-wall (TTW); and IKM. During the patient's second visit, the same examiner performed the same three measures without reference to Session One measurements. Efforts were made to collect data at approximately the same time of day to

Figure 1. Assessment of occiput-to-wall. Participants stood with their buttocks and back against the wall with shoes off, heels against a four-inch block placed against the wall, and knees straight. The examiner instructed participants to remain looking straight ahead and, with a maximum effort, stand straight and tall to attempt to touch the back of their head to the wall. The examiner scored the participants' ability to touch occiput-to-wall as "yes" or "no."

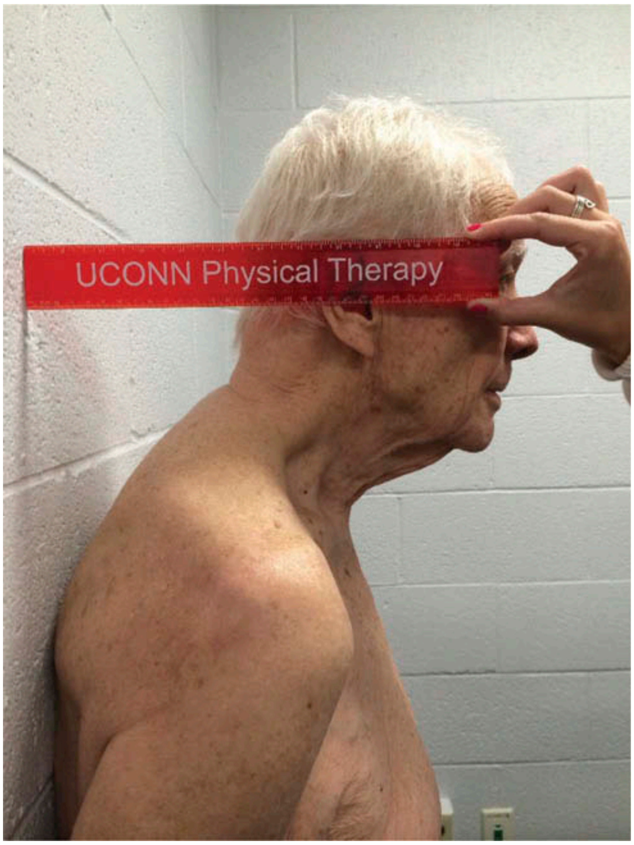

Figure 2. Measurement of TTW. Participants stood with their buttocks and back against the wall with shoes off, heels against a four-inch block placed against the wall, and knees straight. The examiner instructed participants to remain looking straight ahead and, with a maximum effort, to stand straight and tall and try to touch the back of their head to the wall. The examiner measured the distance from the participants' right TTW and left Tragus-to-wall with a straight ruler and measured to the nearest 0.1 centimeter. The final score was calculated as an average of the right and left TTW measurements.

minimize diurnal fluctuations (See Figures 1 and 2 for description of OTW and TTW procedures).

A Baseline bubble inclinometer (Fabrication Enterprises, White Plains, NY) was used for the IKM. Measurements were taken under two conditions: the first with participants in a self-selected or relaxed posture and the second with participants in a straight and tall posture. Prior to measurement, the examiner zeroed the inclinometer to a vertical angle. Male participants were measured with shirt removed and female participants wore an examination gown open in the back to expose the spine with shirt and bra removed. Participants were then asked to stand with their anterior thighs lightly contacting a treatment table. Ultrasound gel was applied to the midline of the lower thoracic and lumbar spine and to the upper thoracic and lower cervical spine to facilitate glide of the inclinometer on the skin to facilitate smooth, continuous skin contact with the inclinometer. Participants were then instructed to stand still with a relaxed posture and look straight ahead. To obtain the first measurement, the examiner aligned the inclinometer along the lower lumbar spinous processes. With light and even contact on the skin, the examiner then slid the inclinometer superiorly along the spine until the maximum posteriorly inclined angle was reached (Figure 3). The therapist then recorded the angle in degrees. The inclinometer was then aligned along the upper mid-thoracic spinous processes. While maintaining light contact with the skin, the

Figure 3. Measurement of IKM thoracolumbar angle. The examiner aligned the inclinometer along the lower lumbar spinous processes. With light and even contact on the skin, the examiner then slid the inclinometer superiorly along the spine until the maximum ***posteriorly*** inclined angle was reached. The therapist then recorded the angle in degrees.

Figure 4. Measurement of IKM cervicothoracic angle. The inclinometer was aligned along the upper mid-thoracic spinous processes. While maintaining light contact with the skin, the examiner slid the inclinometer superiorly along the spine until the maximum ***anteriorly*** inclined angle was reached. This angle was then recorded in degrees. The two recorded angles (thoracolumbar and cervicothoracic) were then added together and their sum subtracted from 180 degrees to derive the IKM.

examiner then slid the inclinometer superiorly along the spine until the maximum anteriorly inclined angle was reached (Figure 4). This angle was then recorded in degrees. The two recorded angles were then added together and their sum subtracted from 180 degrees to derive the IKM. It is noteworthy that palpation of landmarks was not used to determine the measurement; the recorded number was the maximum posterior angle (thoracolumbar) and anterior angle (cervicothoracic) observed. With the IKM, a lower score indicates greater kyphotic curvature. An IKM score of 180 degrees would indicate no kyphotic curvature. The examiner then repeated these two measurements under the second condition, while participants were cued to "stand as straight and tall as possible while looking ahead."

Statistical analysis

The authors conducted data analysis using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, Illinois), version 21.0 for Macintosh. Basic descriptive statistics were calculated. Thereafter, data obtained from participants completing both test sessions were used to determine the reliability and responsiveness of the IKM. Test–retest reliability of IKM measurements was described using intra-class correlation coefficient ($ICC_{3,1}$). Responsiveness was described using the minimal detectable change (MDC_{95}) derived from the standard error of measurement (SEM) and the ICC: $SEM = SD\sqrt{1\text{-}ICC}$ [7] and $MDC_{95} = 1.96 * SEM * \sqrt{2}$.[43-45]. The MDC_{95} values were rounded to the nearest degree to reflect the smallest unit of measurement on the inclinometer.

Validity was examined using data obtained from all patients enrolled in the study using data collected during the first session. Convergent validity involved calculating Pearson's correlations between IKMs obtained under the relaxed and cued conditions and TTW measures and IKMs under each condition. Convergent validity is an indicator of the extent to which two measures demonstrate similar results. Our interpretation of the *r* value was based on guidelines offered by Portney and Watkins (2009) where a value of 0.26–0.50 is considered fair, a value of 0.51 to 0.75 is considered moderate to good, and a value greater than 0.75 is considered good to excellent. Known conditions/groups validity was examined via comparisons of the IKM between: (1) the relaxed and cued conditions; (2) patients whose occiputs did or did not touch the wall; and (3) patients who were less than 50 years or older than 50 years. The decision to dichotomize at age 50 was based on prior research suggesting that the mean kyphosis increases after age 50 in women and age 55 in men (Milne and Lauder, 1974). The first comparison involved a paired t-test. The second and third comparisons were made using independent sample t-tests.

Results

Sixty-eight patients were enrolled in the study and completed one testing session (36 women and 32 men, age 18–93 years, mean [SD] age = 47.7 [20.8]). Participants' diagnoses were typical of an outpatient orthopedic population, and patients with both spinal and non-spinal conditions were enrolled to allow for sufficient variability in postural measures. Seventeen patients did not return for a second visit within the allotted two to seven days due to illness, inclement weather, and scheduling issues. The remaining 51 patients completed a second session, 26 women and 25 men (mean [SD] age= 46.9 [20.2]).

Findings relative to reliability are presented in Table 1 and Figures 5 and 6. The data demonstrate excellent intra-rater reliability for relaxed IKM (ICC) = 0.94(95% CI 0.89–0.96) and cued IKM ($ICC_{3,1}$) = 0.91(95% CI 0.84–0.95). Findings relative to responsiveness are also presented in Table 1. Rounded to the nearest degree, the MDC_{95} was 8.0 degrees for the IKM relaxed and 10.0 degrees for the IKM cued. This means that a change in IKM relaxed of eight degrees is necessary to ensure that the change isn't simply the result of measurement error.

Convergent validity was supported by the strong correlation between IKM relaxed and IKM cued ($r = 0.85$, $p < 0.001$). It was upheld further by a fair correlation between IKM relaxed and TTW ($r = -0.48$, $p < 0.01$) and a moderate correlation between IKM cued and TTW ($r = -0.53$, $p < 0.01$))

Supporting known groups validity, Table 2 displays TTW, relaxed IKM, and cued IKM measurements for participants not able to achieve occiput-to-wall ($n = 15$) versus those who could ($n = 53$). The IKM was significantly greater under the cued than under the relaxed condition (difference = 8.1 degrees, $t = -11.18$, $p < 0.001$) suggesting a decrease in kyphosis. Those who could touch their occiput to the wall had significantly higher relaxed IKM ($t = 2.89$, $p = 0.01$), and cued IKM ($t = 4.06$, $p = 0.001$) than those who could not. That is, they were less kyphotic. Table 3 displays the same 3 measurements with a dichotomy of those less than 50 years ($n = 33$) and those more than 50 years ($n = 35$). Compared to participants less than 50 years of age, those who were greater than 50 years of age had significantly lower IKM relaxed ($t= -3.94$, $p < 0.001$) and IKM cued ($t = -5.12$, $p < 0.001$). That is, they were more kyphotic.

Table 1. Summary of statistics describing the reliability and responsiveness of inclinometric measurements of dorsal kyphosis.

Condition	Session 1 Angle (°) Mean (SD)	Session 2 Angle (°) Mean (SD)	Intra-class correlation coefficient (3,1) (95% CI)	Standard error of measurement (°)	Minimal detectable $change_{95}$ (°)
Relaxed	124.1 (10.8)	125.1 (11.5)	.94 (.89–.96)	3.0	8.0
Cued	132.4 (11.4)	132.0 (12.0)	.91 (.84–.95)	3.0	10.0

SD = Standard deviation.

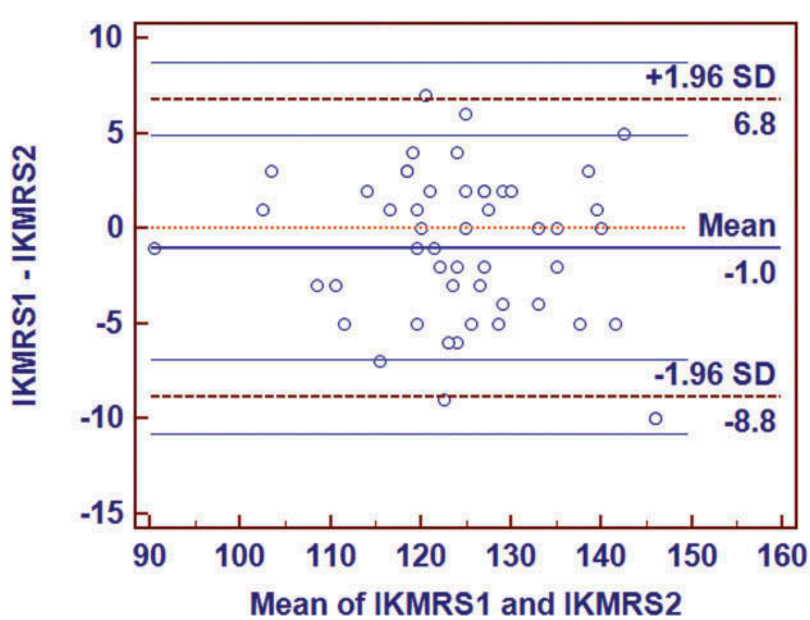

Figure 5. Bland-Altman plot comparing inclinometric measures of kyphosis obtained under relaxed conditions during two test sessions (IKMRS1 and IKMRS2). The limits of agreement range from −8.8 to 6.8 degrees.

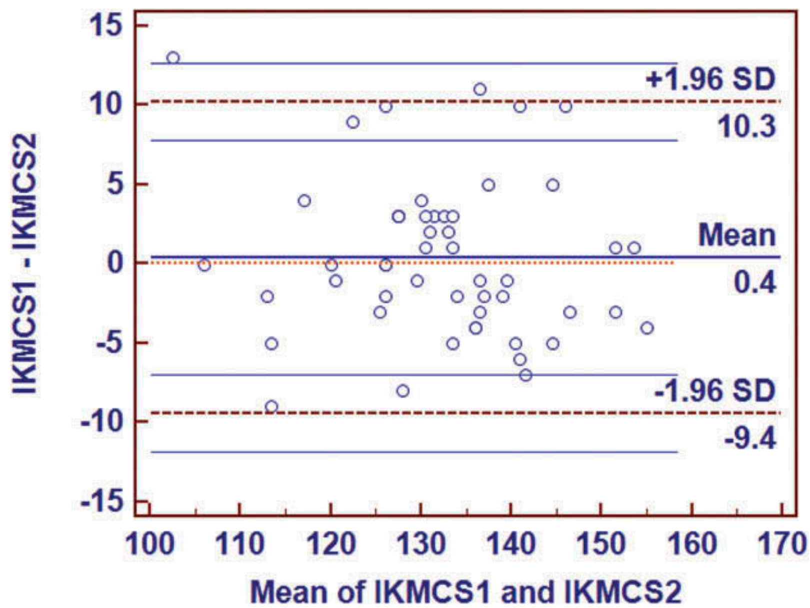

Figure 6. Bland-Altman plot comparing inclinometric measures of kyphosis obtained under cued conditions during two test sessions (IKMCS1 and IKMCS2). The limits of agreement range from −9.4 to 10.3 degrees.

Table 2. Summary of postural measures obtained during the first measurement session for participants not able (No) and able (Yes) to touch occiput-to-wall.

Occiput-to-wall	Tragus-to-wall (cm) Mean (SD)	Relaxed IKM (°) Mean (SD)	Cued IKM(°) Mean (SD)
Not able to touch (n = 15)	12.1 (3.1))	117.0 (12.3)	122.7 ((11.3)
Able to touch (n = 53)	10.1 (0.9	126.9 (9.1)	135.7 (9.4)
Combined (n = 68)	11.6 (2.8)	124.7 (10.6)	132.8 (11.2)

SD = standard deviation.

Table 3. Summary of Postural measures obtained during the first measurement session for young (<50 years) and old (>50 years) participants.

Age	Tragus-to-Wall (cm) Mean (SD)	Relaxed IKM (°) Mean (SD)	Cued IKM (°) Mean (SD)
<50 (n = 33)	10.4 (1.5)	129.4 (8.1)	138.9 (9.0)
>50 (n = 35)	12.8 (3.3)	120.3 (10.9)	127.1 (10.0)
Combined (n = 68)	11.6 (2.4)	124.8 (9.5)	133.0 (9.5)

SD= standard deviation.

Discussion

This first purpose of this study was to evaluate a new procedure for measuring dorsal kyphosis. The procedure we describe, the IKM, uses a single inclinometer to quickly characterize the entirety of dorsal kyphosis without reference to vertebral levels. We believe that this is important as the dorsal convexity of the spine is not necessarily determined by the thoracic vertebrae alone and measures dependent on the surface identification of specific spinal vertebral levels can be erroneous (Haneline and Young, 2009). The IKM is not directly comparable to the Cobb angle or the angle of thoracic kyphosis determined by dual inclinometers as both of these measures are limited to the thoracic spine and increase in magnitude as kyphosis increases. With the IKM, the greater the magnitude, the less the kyphosis. If there were no kyphosis, the IKM would be 180 degrees. Both the IKM and angle of thoracic kyphosis involve the summation of superior and inferior inclinometer angles. However, with the IKM, the sum of the angles is subtracted from 180 degrees, and with the angle of thoracic kyphosis, the sum of the angles is the measure (Barrett, McCreesh, and Lewis, 2013; Lewis and Valentine, 2010). As the angle of thoracic kyphosis is circumscribed by T1/T2 and T12/L1 and the IKM is not, one might expect the sum associated with the IKM to be larger. A comparison between the sum associated with the IKM relaxed for patients less than 50 years old in our study (55.3 degrees) and the angle of thoracic kyphosis for young adults in a study by Van Blommestein, Lewis, Morrissey and MacRae (2012) (32 degrees) suggest this to be the case.

The second purpose of this study was to describe the intra-rater (test-retest) reliability, responsiveness, and validity of the IKM. We found the IKM to demonstrate excellent intra-rater reliability for both the relaxed condition ($ICC_{(3,1)}$ = 0.94 (95% CI 0.89–0.96)) and cued condition ($ICC_{(3,1)}$ = 0.91 (95% CI 0.84–0.95)). These estimates are comparable to those reported by others who used double inclinometers to measure thoracic kyphosis (Barrett, McCreesh, and Lewis, 2014; Lewis and Valentine, 2010; Van Blommestein, Lewis, Morrisssey, and MacRae, 2012) and comparable or superior to those reported by when using the flexicurve (Azadinia et al, 2014; Greendale et al, 2011). Based on the $MDC_{95\%}$ we calculated for the relaxed and cued conditions, the IKM can be considered to be responsive. As a percentage, the values represent 6.4% and 7.6% of the mean relaxed and cued IKMs of the first session. There are no $MDC_{95\%}$ values for inclinometer measures of kyphosis to which our IKM can be compared. Others, however, have reported SEMs of 2.1–2.4 degrees (Lewis and Valentine, 2010; Van Blommestein, Lewis, Morrissey and MacRae, 2012). Our SEM for both the relaxed and cued positions was approximately 3.0 degrees.

Our study demonstrated both the convergent and known groups validity of the IKM. The very high correlation between the IKM relaxed and IKM cued shows that the two measures are quantifying the same construct-dorsal kyphosis. The correlations between the IKMs and TTW measurements, though significant, show that the measurements may be capturing the same construct but different constructs as well. Tragus-to-wall has been consistently used as a measure of flexed spinal posture and mobility (Ozaras et al, 2014; Pile et al, 1991; Shipe et al, 2013; Vosse et al, 2006) with reported inter-tester reliabilities from 0.94 to 0.99 (Pile et al, 1991; Vosse et al, 2006). Jenkinson et al. (1994) described criterion validity relative to radiological measures as 0.92. Another study reported significant correlations between TTW and radiological spinal changes in patients with ankylosing spondylitis ($p < 0.01$) (Viitanen, Kokko, Heikkilä, and Kautiainen, 1998). However, it is not a direct measure of kyphosis and is influenced by other factors, specifically forward head posture. Thus, though related, the IKM and TTW should not be used interchangeably.

Unlike previous studies involving dual inclinometers, our study also demonstrated known conditions and known groups validity. As might be expected, the IKM was greater under the cued condition than under the relaxed condition. Notably, the difference (8.1 degrees) exceeds the $MDC_{95\%}$ of 8.0 degrees for the relaxed condition. This finding suggests that dorsal kyphosis is not fixed and can be reduced by efforts to stand up straight in response to cues. This certainly has implications for patient/client-related instruction as an intervention for individuals whose kyphosis is a target of correction. Also as expected based on prior studies, IKM was greater in groups who could touch their occiput to the wall and who were younger indicating less kyphotic curvature (Assassi et al, 2009; Fon, Pitt, and Thies, 1980; Gravina et al, 2012). This may be reflective of increased spinal mobility in the groups who could touch the wall consistent with prior research on OTW as related to spinal mobility in individuals with: ankylosing spondylitis (Davis and Gladman, 2007); reduced shoulder elevation (Otoshi et al, 2014); and radiographic thoracic wedging (Vosse et al, 2006). This could have implications for spinal mobilization as an intervention in reducing kyphotic curvature. The IKM, therefore, might prove useful in documenting changes in kyphosis in response to treatment when OTW status remains unchanged over time or with older individuals.

Limitations

An inherent limitation of this study is the nature of a skin-surface method of kyphosis measurement. Clinical measures like the IKM conform to the surface anatomy and only capture the position of the vertebrae as estimated by contact with the spinous processes. Thus, distribution of adipose tissue may influence the reliability and validity of the measurement, and we did not obtain anthropometric measurements from our patients. Although we compared the IKM with other postural measures, the IKM was not compared to the gold standard, sagittal radiograph.

In looking at reproducibility of the test, we only estimated intra-rater reliability, so reliability between raters cannot be assumed. Future research should account for anthropometric characteristics, include multiple raters, and compare the IKM to standing sagittal radiographs to establish inter-rater reliability and criterion validity.

Conclusion

The IKM had excellent intra-rater reliability over a two to seven day period with a MDC of 8.0–10.0 degrees in patients with varied musculoskeletal diagnoses. The measure has potential as a valid method for measuring kyphosis in patients with musculoskeletal conditions but must be further studied in comparison with gold standard radiographs. The IKM has comparable clinimetric properties and several advantages over other methods of clinical measurement of kyphosis including simplicity, low risk, and feasibility of use in the outpatient setting.

Declaration of interest

The authors affirm that they have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.

ORCID

Jon Rizzo http://orcid.org/0000-0002-1837-1702

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