

Interpretability and appropriate cut-off score of occiput-bed distance to indicate risk of hyperkyphosis in older adults

Roongnapa Intaruk^{1,2} Sirirut Multakorn¹ Wasunan Sornsamran¹ Metinee Yamtawech¹ Sugalya Amatachaya^{1,2}
Pipatana Amatachaya² Thiwabhorn Thaweewannakij^{1,2*}

¹School of Physical Therapy, Faculty of Associated Medical Science, Khon Kaen University, Khon Kaen Province, Thailand.

²Improvement of Physical Performance and Quality of Life (IPQ) Research Group, Khon Kaen University, Khon Kaen Province, Thailand.

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ABSTRACT

Background: Age-related hyperkyphosis has been described as a new geriatric syndrome. Therefore, early screening is critical. The occiput-bed distance (OBD) was developed as a new tool; however, there needed to be clear evidence supporting its clinical utility compared to the data from standard measurement.

Objective: To investigate the test-retest reliability and minimal detectable change (MDC) with standard measurement error (SEM). Moreover, the practical cut-off scores to determine the risk of hyperkyphosis are crucial compared to a standard Cobb's method.

Materials and methods: This study was designed as a cross-sectional study conducted in ninety-six hyperkyphosis older adults aged at least 60 years. All participants were assessed for their hyperkyphosis using the OBD. Within seven days, they were at a hospital to complete a radiographic examination to determine the appropriate cut-off score of hyperkyphosis. Additionally, the first 30 participants were assessed for their hyperkyphosis again using the OBD to determine the interpretability.

Results: The outcomes of the OBD had excellent test-retest reliability ($ICC_{3,3} = 0.887$, $p < 0.001$). The SEM and MDC_{95} values were 0.75 and 2.08 cm, respectively. In addition, the cut-off score of OBD was reported to be at least 7.40 cm (sensitivity 71.80%, specificity 73.70%, and $AUC = 0.734$) to indicate the risk of hyperkyphosis.

Conclusion: The OBD is consistent, reliable, and has good diagnostic properties for hyperkyphosis. The findings confirm the use of OBD as a practical alternative method for early detection of hyperkyphosis in older individuals, particularly those who cannot stand for long and cannot access radiology.

Introduction

Hyperkyphosis has been described as a new geriatric syndrome.¹ Its characteristic is an anterior curvature in the thoracic spine, and tends to increase with age (up to 40% in older adults).² Previous reports have found that hyperkyphosis can induce adverse health consequences and superimpose substantial effects on levels of independence and mortality rate in older adults.^{3,4} Although hyperkyphosis does not always lead to severe injuries, this condition can induce undesirable cosmetic consequence that causes low self-esteem.⁵ To reduce the risk of adverse consequences of hyperkyphosis, an early assessment with a standard practical screening tool should be conducted, followed by monitoring and providing an appropriate intervention.^{4,6}

Previous studies appraised that there were several hyperkyphosis measurements commonly used in community

* Corresponding contributor.

Author's Address: School of Physical Therapy,
Faculty of Associated Medical Science, Khon
Kaen University, Khon Kaen Province, Thailand.

E-mail address: thiwth@kku.ac.th

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settings, including the flexicurve ruler, inclinometer, goniometer, distance from the wall, and block method.^{7,8} However, most of them needed a specialist to identify bony landmarks of the spine, except the block method, which is an easy measurement in lying position using wooden blocks by experts and novices, including village health volunteers or healthcare professionals.^{9,10} Previously, the older adults considered the severity of hyperkyphosis using the number of blocks, including mild (1 block), moderate (2 blocks), and severe (at least 3 blocks) hyperkyphosis.¹¹ While Chokphukiao *et al.* reported that the number of blocks of at least two might indicate hyperkyphosis in older adults, they did not report its sensitivity and specificity.¹² Although the block method reported acceptable reliability and validity compared to Cobb's method ($ICC_3 = 0.82-1.00$, $p < 0.001$ and $r_s = 0.63-0.64$, $p < 0.05$, respectively),^{9, 10} it is at a constant block height. Such discrete data might result in errors in judgment and low sensitivity in detecting changes in the hyperkyphosis angle.

Therefore, the OBD (application of patent number 2203001689) was developed based on the block method protocol. The OBD can measure the distance from occiput to bed using continuous data. In our preliminary study, the OBD showed excellent intra- and inter-rater reliability ($ICC_{3,3} = 0.993-0.998$, $p < 0.001$) after proper training. Moreover, when applied in the older populations, it had an acceptable correlation to the occiput-wall distance (OWD) ($r = 0.779$, $p = 0.008$).¹³ Although this method might thus be practically applied for hyperkyphosis screening in older individuals, the interpretability of the tool must be considered to confirm its stability.¹⁴ Moreover, the practical cut-off scores to determine the risk of hyperkyphosis are crucial to promoting the effectiveness of community health care services. Therefore, the purpose of the present study was to investigate the test-retest reliability and minimal detectable change (MDC) with standard error of measurement (SEM). Additionally, the practical cut-off scores to determine the hyperkyphosis risk were explored and compared to a standard Cobb's method.

Materials and methods

Study design and participants

The study was cross-sectionally conducted in the older adults living in rural and semi-rural communities in Northeast Thailand. Eligible participants were aged at least 60 years with hyperkyphosis determined by at least three blocks and able to understand simple commands to complete the study protocol.¹² However, participants were excluded if they had scoliosis and abnormal supine symptoms, such as orthopnea. Other signs and symptoms that might influence the study were also excluded, such as dizziness, acute illness or injury, unstable heart disease (e.g., angina), and uncontrolled hypertension.

The sample size was separately calculated to assess the study's interpretability and cut-off scores of OBD. According to the number of participants in the study's interpretability, the level of significance (α) and estimate precision (e) were determined as 0.05 and 0.1, respectively. Therefore, at least 30 participants were needed for the

interpretability study.¹⁵ Furthermore, the number of participants for the cut-off scores was calculated from a pilot study (59 participants; $r = 0.61$, $p < 0.001$) and provided a sensitivity of 88%. Thus, the sample size required at least 96 participants to study cut-off scores. The protocols of this study were approved by the Khon Kaen University Ethics Committee for Human Research (HE644003). All participants completed a written informed consent form before participating in the study.

Research protocols

All eligible participants were assessed hyperkyphosis in two phases; each phase was separated within seven days. In the first phase, they were interviewed regarding their demographic characteristics, type, time, intensity, and frequency of physical activity and exercise. Additionally, a verbal numerical rating scale was used for pain. Then, the participants were assessed for their hyperkyphosis using the OBD. In the second phase, the participants were evaluated for their hyperkyphosis using OBD again; in addition, lateral spinal radiographic examination (Cobb's method) was performed at a hospital to determine the interpretability (test-retest reliability) and appropriate cut-off scores of OBD for the hyperkyphosis. Before both assessments, the participants were re-interviewed regarding their physical activity, exercise, and pain scale to confirm that there were no changes in these parameters affecting their hyperkyphosis condition since the baseline measurements were taken.

Hyperkyphosis measurement

OBD

The participants were asked to lie supine with their hands and arms beside the body on a firm bed with eyes gazing forward at the ceiling; the head was placed on the OBD plate in normal alignment in the horizontal view. If participants were lying flat without neck extension, they were deemed regular participants without hyperkyphosis. On the other hand, participants lying flat with neck extension were included as exhibiting hyperkyphosis.¹³ Then, the height of the OBD plate was adjusted until the forehead and ear lines were parallel to the table.

The measurement was repeated in three trials, with a period of sufficient rest in a sitting position between the trials (at least 1 minute). The average distance of three trials was converted from a millimeter to a centimeter scale.

Cobb's method

A Cobb's method is commonly used as a gold standard for hyperkyphosis measurement. The participants were asked to stand in a neutral position for lateral thoracic spine radiography. During the radiography process, the participants were required to flex the shoulder at 90 degrees.¹⁶ The Cobb angle was analyzed by drawing a straight line along the upper border of the fourth thoracic spine (T4) and another at the lower border of the twelfth thoracic spine (T12). Then, the Cobb angle was automatically computed based on the intersection between the 2 lines using the Surgimap Spine program, version 1.2 software.¹⁷

Participants with Cobb angles more than 40 degrees were arranged into the hyperkyphosis group.

Statistical analysis

The SPSS for Windows was used to analyze the collected data (SPSS Statistics version 18.0, IBM Corporation). Descriptive statistics were utilized to explain the demographic characteristics of participants and the study findings. A two-way random model ($ICC_{3,3}$) 's intraclass correlation coefficients were used to derive test-retest reliability. The standard error of measurement (SEM) was calculated using the following formula: $SEM = (SD) \times \sqrt{1 - r}$, where SD is the pooled SD of two trials and r is the test-retest reliability. The minimal detectable change at the 95% confidence interval (MDC_{95}) was calculated using the following formula: $MDC_{95} = 1.96 \times \sqrt{2} \times SEM$. In addition, the Receiver-Operated Characteristics (ROC) curve was used to identify appropriate cut-off scores with particular sensitivity, specificity, and area under the curve (AUC) of OBD to indicate the risk of hyperkyphosis. In general, an AUC was interpreted as no discrimination (less than

0.5), poor discrimination (0.5-0.6), acceptability (0.7-0.8), excellence (more than 0.8-0.9), and outstanding (more than 0.9).¹⁸ The significance level was set at less than 0.05.

Results

Characteristics of participants

Four hundred and eight participants were interested in participating in the study. However, 307 participants were excluded based on missing the inclusion criteria (Figure 1). After considering the exclusion criteria, 101 eligible participants met the inclusion criteria; however, five could not go to the hospital for radiography. Therefore, 96 participants (41 females and 55 males) were involved in the study to determine the cut-off score of OBD. Their average age was 72.05 ± 5.95 years (range 60-86 years), and average Cobb angles of 37.76 ± 9.95 degrees. In addition, the first 30 participants (18 females and 12 males) were appointed on day 7 to indicate the test-retest reliability for the interpretability study; their average age was 71.57 ± 6.45 years old, and body mass index was 25.44 ± 3.74 kg/m² (as shown in Table 1).

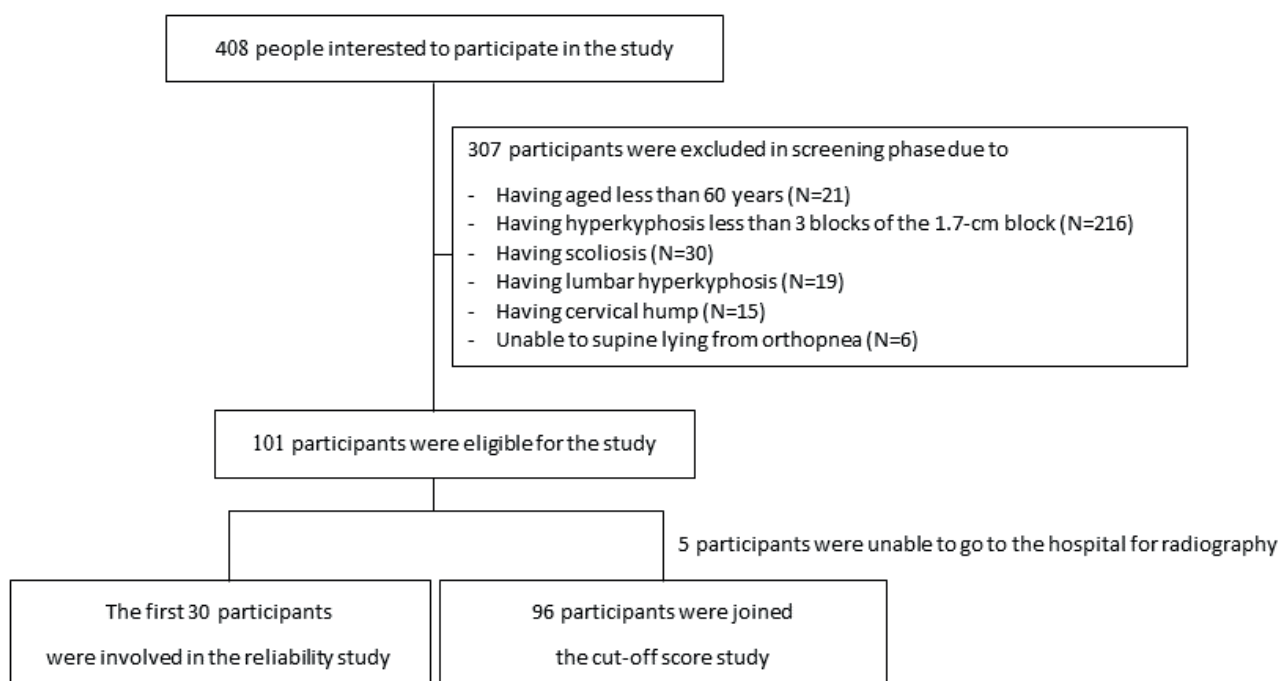


Figure 1. Participant flowchart.

Table 1 Demographic characteristics and hyperkyphosis data of participants.

Variable	Interpretability (N=30)	Group of participants ^a (N=96)		p value
		Normal (N=57)	Hyperkyphosis (N=39)	
Sex (female) ^b	18 (60.00)	29 (50.88)	12 (30.77)	0.050
Age (year) ^c	71.57±6.45 (69.16-73.98)	72.07±6.25 (70.41-73.73)	72.03±5.57 (70.22-73.83)	0.972
Weight (kg) ^c	59.86±10.61 (55.82-63.90)	61.69 ±10.01 (59.04-64.35)	60.75±8.88 (57.87-63.63)	0.637
Height (cm) ^c	153.27±7.68 (150.35-156.20)	156.01±7.98 (153.90-158.13)	157.26±7.79 (154.73-159.78)	0.451
BMI (kg/m ²) ^c	25.44±3.74 (24.02-26.86)	25.33±3.47 (24.41-26.26)	24.63±3.52 (23.48-25.77)	0.333
Number of 1.7-cm block (block) ^b				0.013*
3	17 (56.67)	29 (50.88)	7 (17.95)	
4	11 (36.67)	22 (38.60)	21 (53.85)	
5	2 (6.66)	5 (8.77)	9 (23.08)	
6	0 (0)	1 (1.75)	1 (2.56)	
7	0 (0)	0 (0)	1 (2.56)	
OBD (cm) ^c	6.41±2.20 (5.59-7.23)	6.50±1.72 (6.04-6.96)	8.36±2.33 (7.60-9.11)	<0.001*
Cobb angle (degree) ^c	-	31.26±6.44 (29.55-32.97)	47.26±5.52 (45.47-49.05)	<0.001*

Note: ^a The groups are categorized using radiologic data, ^b Data are demonstrated using the number of participants (percentage), ^c The data are presented using the mean±SD (95% confidence interval), * Statistically significant. BMI: body mass index, OBD: occiput-bed distance.

Test-retest reliability

There was no statistically significant difference in the OBD measurement between baseline and within seven days. The finding indicated that the OBD had excellent test-

retest reliability (as shown in Table 2). In addition, the SEM and MDC₉₅ values were 0.75 and 2.08 cm, respectively.

Table 2 Test-retest reliability of the OBD (N=30).

Measurement	Mean±SD (95%CI)		p value	Test-retest reliability (95%CI)
	Day-1 (cm)	Day-7 (cm)		
OBD (cm)	6.41±2.20 (5.59-7.23)	6.53±2.26 (5.68-7.37)	0.198	0.887* (0.762-0.946)

Note: *Statistically significant at 0.001. OBD: occiput-bed distance, SD: standard deviation, 95%CI: 95% confidence interval.

Cut-off scores to indicate risk of hyperkyphosis

The finding reported that 39 participants (40.63%) revealed more than 40 degrees of Cobb angle. These participants had statistically significant longer distances using OBD and larger degrees using Cobb's method than those without hyperkyphosis ($p<0.001$, as shown in Table 1). In addition, the cut-off score of OBD was reported to be at least 7.40 cm (sensitivity 71.80%, specificity 73.70%, and AUC=0.734) to indicate the risk of hyperkyphosis.

Discussion

This study aimed to quantify test-retest reliability and MDC₉₅; additionally, the cut-off scores were indicated by

the individuals with or without risk of hyperkyphosis. The study reported excellent test-retest reliability ($ICC_{3,3}=0.887$, $p<0.001$) with small SEM (0.75 cm) and MDC₉₅ showed 2.08 cm. The OBD was reported to have an appropriate cut-off score to identify the risk of hyperkyphosis with a cut-off score of at least 7.40 cm (sensitivity 71.80%, specificity 73.70%, and AUC=0.734).

The present study revealed excellent test-retest reliability ($ICC_{3,3}=0.887$, $p<0.001$) with a small amount of SEM (0.75 cm), which could confirm the practicality and stability method of OBD when applied over some time. Evidence supports that the SEM indicates a possible margin of measurement errors in an original unit, and the MDC

is a minimal change that falls outside the measurement errors in the test results. Thus, these values suggested the absolute reliability of the tools.¹⁹ Since the OBD was developed from the protocol of the 1.7-cm block to measure hyperkyphosis in a lying position, its principles were similar to measuring distance from the wall in a standing position, known as the OWD.^{20,21} Wiyanad *et al.* found smaller SEM and MDC values in people aged at least 10 years compared to the present study (0.44 cm and 1.21 cm, respectively).²¹ It might occur due to the characteristics of the spine in older adults being more rigid compared to younger people, which contributes to more severe hyperkyphosis in these individuals.^{2,9} However, Suwannarat and colleagues showed a similar level of test-retest reliability ($ICC_{3,3}=0.85$, $p<0.001$) with smaller SEM (0.20 cm) and MDC (0.55 cm) than the present study, when they measured the distance from a wall using the seventh cervical vertebra wall distance (C7WD) in older adults.²² The small value, even in similar participants' characteristics, could be due to the equation utilized for calculating the MDC, which depends on ICC, SD, and SEM values. The previous study showed lower SEM and SD than the present study, which might be related to lower MDC. Although prior studies have reported smaller SEM and MDC in both younger and older age groups,^{21,22} evidence suggests that the number of participants for the study's reliability should be at least 30 with a level of significance (α) and estimate precision (e) of 0.05 and 0.1, respectively.¹⁵ Previous research included 15 participants, while the present study had 30 participants. Nevertheless, more prominent participants may have a longer SD, thus it is necessary to determine these values.

Furthermore, a different position and landmark measuring in a standing position might influence back muscle activation for controlling posture against gravity and affect spinal loading.²³ As a result, the distance of OBD in the present study (6.41 ± 2.20 cm) was lower than that of C7WD in the prior report (7.66 ± 1.93 cm).²² In addition, the MDC_{95} of the OBD in the present study was reported as 2.08 cm, around 1-2 blocks of 1.7-cm block, similar to Huang *et al.* They reported that the cut-off score of the block method was at least one block, which could determine mild hyperkyphosis.¹¹ Although it is only mild hyperkyphosis, it can affect physical ability, and future falls by 1.5 times compared to those without hyperkyphosis.^{11,24} This information confirmed that a small amount of SEM and MDC_{95} were appropriate for monitoring and providing a suitable intervention in the early phase. The acceptable level of test-retest reliability of the present study might occur due to the simple protocol to adjust the spinal curve, and it does not require expertise to identify spinal bony landmarks in those with hyperkyphosis.

The findings revealed the appropriate cut-off score of OBD at least 7.40 cm (sensitivity 71.80%, specificity 73.70%, and $AUC=0.734$), which indicated the risk of hyperkyphosis in older people. Of all participants who completed the study, 39 participants (40.63%) had thoracic hyperkyphosis angle of more than 40 degrees. However, Wiyanad *et al.* reported the OWD cut-off score of at least 6.50 cm (sensitivity 71.4%, specificity 76.6%, and

$AUC=0.846$) to indicate hyperkyphosis.²¹ The different results between OBD and OWD might occur due to the previous study in younger people with more flexible spine (aged at least 10 years).^{9,21} On the other hand, Suwannarat *et al.* have reported the cut-off score of C7WD at least 7.50 cm (sensitivity 71.80%, specificity 82.40%, and $AUC=0.85$) to indicate hyperkyphosis.²² When considering a body structure in a sagittal plane, the bony prominence of C7 is closer to the body midline than the occiput.²⁵ As a result, when standing erect against a wall and utilizing the C7 as a landmark, the distance from the wall was more significant than the occiput landmark. Moreover, evidence supported that an acceptable level of AUC should be at least 0.7.¹⁸ This information confirmed the utility of a cut-off score of OBD at least 7.40 cm (average Cobb angle of 47.26 ± 5.52 degrees) to screen the risk of hyperkyphosis in older adults.

Nonetheless, this study has some limitations. The study included only older adults who reported high-incidence hyperkyphosis conditions. This may limit the generalizability of the findings for other age groups with a more flexible spinal column, such as children or younger adults. A further study should include participants with various characteristics and analyze for other variables that influence the diagnostic properties to improve the benefit of the OBD in clinical and research settings. Moreover, this study did not confirm the application in older adults with vertebral fractures, which is one of the impact consequences of hyperkyphosis. Thus, further study should confirm the ability of the OBD to indicate vertebral fracture in older populations.

Conclusion

The OBD method was verified as having excellent test-retest reliability with a small amount of SEM and an acceptable cut-off score to indicate the risk of hyperkyphosis in older adults. Thus, this method represented an alternative means of hyperkyphosis screening that could be practical to apply in older individuals, particularly those who cannot stand or stand for long; additionally, people who could not access radiology to screen their hyperkyphosis condition. The OBD would benefit health officers' consideration by applying an easy tool to identify their patients' problems.

Conflict of interest

The authors declare no conflict of interest.

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Reference

- [1] Katzman WB, Harrison SL, Fink HA, Marshall LM, Orwoll E, Barrett-Connor E, et al. Physical function in older men with hyperkyphosis. *J Gerontol A Biol Sci Med Sci*. 2015; 70(5): 635-40. doi: 10.1093/gerona/glu213.
- [2] Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. *Ann Intern Med*. 2007; 147(5): 330-8. doi: 10.7326/0003-4819-147-5-200709040-00008.
- [3] Ailon T, Shaffrey CI, Lenke LG, Harrop JS, Smith JS. Progressive spinal kyphosis in the aging population. *Neurosurgery*. 2015; 77(Suppl 4): S164-72. doi: 10.1227/NEU.0000000000000944.
- [4] Katzman WB, Wanek L, Shepherd JA, Sellmeyer DE. Age-related hyperkyphosis: its causes, consequences, and management. *J Orthop Sports Phys Ther*. 2010; 40(6): 352-60. doi: 10.2519/jospt.2010.3099.
- [5] Hinman MR. Comparison of thoracic kyphosis and postural stiffness in younger and older women. *J Spine*. 2004; 4(4): 413-7. doi: 10.1016/j.spinee.2004.01.002.
- [6] Azadinia F, Kamyab M, Behtash H, Ganjavian M, Javaheri R. The validity and reliability of noninvasive methods for measuring kyphosis. *J Spinal Disord Tech*. 2014; 27: 212-8. doi: 10.1097/BSD.0b013e31829a3574
- [7] Amatachaya P, Wongsas S, Sooknuan T, Thaweewannakij T, Laophosri M, Manimanakorn N, et al. Validity and reliability of a thoracic kyphotic assessment tool measuring distance of the seventh cervical vertebra from the wall. *Hong Kong Physiother J*. 2016; 35: 30-6. doi: 10.1016/j.hkpj.2016.05.001.
- [8] Wongsas S, Amatachaya S. Kyphosis assessments. *Arch AHS*. 2014; 26(2): 105-16.
- [9] Chokphukiao P, Wiyanad A, Suwannarat P, Amatachaya S, Mato L, Wattanapan P, et al. Validity and reliability of the block method for measuring thoracic hyperkyphosis. *Physiother Theory Pract*. 2022; 38(13): 3037-44. doi: 10.1080/09593985.2021.
- [10] Tran TH, Wing D, Davis A, Bergstrom J, Schousboe JT, Nichols JF, et al. Correlations among four measures of thoracic kyphosis in older adults. *Osteoporos Int*. 2016; 27(3): 1255-9. doi: 10.1007/s00198-015-3368-7.
- [11] Huang MH, Barrett-Connor E, Greendale GA, Kado DM. Hyperkyphotic posture and risk of future osteoporotic fractures: the Rancho Bernardo study. *J Bone Miner Res*. 2006; 21(3): 419-23. doi: 10.1359/JBMR.051201.
- [12] Chokphukiao P, Wiyanad A, Suwannarat P, Amatachaya S, Wattanapan P, Mato L, et al. Discriminative ability of 1.7-cm block for kyphosis measurement. *Proceedings of the national and international graduate research conference 2017*; 2017 March 10; Pote Sarasin Building, Khon Kaen University, Thailand, 2017. Available from: <https://gsbooks.gs.kku.ac.th/60/nigrc2017/pdf/MMP21.pdf>.
- [13] Intaruk R, Ruangsri J, Noiphum L, Amatachaya P, Amatachaya S, Thaweewannakij T. Concurrent validity of the Occiput-Bed Distance for measuring hyperkyphosis. *Thai J Phys Ther*. 2023; 45(2): 135-45.
- [14] Portney LG, Watkins MP. *Foundations of clinical research application to practice*. 3rd Ed. Upper Saddle River: Pearson Prentice Hall; 2009.
- [15] Morrow JR, Jackson AW. How "significant" is your reliability? *Res Q Exerc Sport*. 1993; 64(3): 352-5. doi: 10.1080/02701367.1993.10608821.
- [16] de Oliveira TS, Candotti CT, La Torre M, Pelinson PPT, Furlanetto TS, Kutchak FM, et al. Validity and reproducibility of the measurements obtained using the flexicurve instrument to evaluate the angles of thoracic and lumbar curvatures of the spine in the sagittal plane. *Rehabil Res Pract*. 2012; 2012: 186156. doi: 10.1155/2012/186156.
- [17] Suwannarat P, Wattanapan P, Wiyanad A, Chokphukiao P, Wilaichit S, Amatachaya S. Reliability of novice physiotherapists for measuring Cobb angle using a digital method. *Hong Kong Physiother J*. 2017; 37: 34-8. doi: 10.1016/j.hkpj.2017.01.003.
- [18] Mandrekar JN. Receiver operating characteristic curve in diagnostic test assessment. *J Thorac Oncol*. 2010; 5(9): 1315-6. doi: 10.1097/JTO.0b013e3181ec173d.
- [19] de Vet HC TC, Mokkink LB, Knol DL. *Measurement in Medicine*. 1st Ed. The United States of America by Cambridge University Press: New York; 2011.
- [20] Siminoski K, Warshawski RS, Jen H, Lee KC. The accuracy of clinical kyphosis examination for detection of thoracic vertebral fractures: comparison of direct and indirect kyphosis measures. *J Musculoskelet Neuronal Interact*. 2011; 11(3): 249-56.
- [21] Wiyanad A, Chokphukiao P, Suwannarat P, Thaweewannakij T, Wattanapan P, Gaogasigam C, et al. Is the occiput-wall distance valid and reliable to determine the presence of thoracic hyperkyphosis? *Musculoskelet Sci Pract*. 2018; 38: 63-8. doi: 10.1016/j.msksp.2018.09.010.
- [22] Suwannarat P, Amatachaya P, Sooknuan T, Tochaeng P, Kramkrathok K, Thaweewannakij T, et al. Hyperkyphotic measures using distance from the wall: validity, reliability, and distance from the wall to indicate the risk for thoracic hyperkyphosis and vertebral fracture. *Arch Osteoporos*. 2018; 13(1): 25. doi: 10.1007/s11657-018-0433-9.
- [23] Lewis JS, Valentine RE. Clinical measurement of the thoracic kyphosis. A study of the intra-rater reliability in subjects with and without shoulder pain. *BMC Musculoskelet Disord*. 2010; 11: 39. doi: 10.1186/1471-2474-11-39.
- [24] Thaweewannakij T, Wongsas S, Kamruecha, Khaengkhan J, Wongkuanklom J, Konkamtan, et al. Validity and discriminative ability on physical impairment relating to kyphosis using 1.7-cm block. *Asia Pac J Sci Technol*. 2012; 17: 660-70.
- [25] Schafer R. *Body Alignment, posture, and gait*. 2nd Ed. Baltimore: Williams & Wilkins; 1983.