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Validation of non-radiographic APECS software in comparison with standard radiographic measurement of full-length lower limb hip-knee-ankle angle in elderly obese women

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Abstract

Introduction. Evidence suggests that obesity and ageing in women are linked to angular knee abnormalities. The hip-knee-ankle (HKA) angle on a full-limb radiograph is the gold standard measure of lower limb alignment. The AI Posture Evaluation and Correction System (APECS) software is a non-radiographic mobile application designed for whole-body posture assessment. Since exposure to X-ray is associated with harmful effects, there is a need to find a safe and valid alternative for measuring HKA angle. The objective of this research was to determine the validity of the non-radiographic APECS software in comparison with standard radiographic measurement of HKA angle.

Methods. The present cross-sectional diagnostic accuracy study was conducted in a tertiary care hospital of Belagavi, Karnataka, India. Overall, 45 elderly obese females aged 60–80 years with a body mass index of ≥ 25 were included. HKA angle was marked bilaterally. Full-limb radiographs were taken and angles were marked with 2.0 version software, DXM model. For the APECS software, full-limb photographs were taken with landmarks indicated with radiant markers and angles were autogenerated by the software.

Results. The Pearson correlation coefficient between the APECS application and the gold standard (X-ray) was 0.9874 (98.74% of matching). The agreement between standard radiograph and the average of all examiners' APECS Pro measurements (including right and left sides) equalled 94.64% (kappa = 0.8323; p = 0.001), which suggests very good agreement.

Conclusions. The APECS application demonstrated a high percentage of matching (98.74%) and agreement (94.64%), indicating its excellent validity in measuring HKA angle.

Key words: X-ray, software application, ageing, women, obese, artificial intelligence

Introduction

Obesity has been identified as a global issue that affects millions of people worldwide, increasing the risk of death and limiting life expectancy [1]. The prevalence of obesity is variable in different parts of the world [2]. According to the World Health Organization (WHO), elderly individuals are more likely to be overweight and obese as a result of their sedentary lifestyles and lack of physical activity [3, 4], with the percentage of obese elderly females (42.1%) higher as compared with males (20.9%) [5–7]. Obesity and central adiposity are more common in women after menopause, possibly owing to oestrogen depletion during the menopause transition, which causes a shift in body composition [8].

Excess body mass is connected with musculoskeletal imbalance, osteoarthritis, low back pain, and soft tissue injuries. Obesity is related to altered mechanical pressures on joints, with increased likelihood of skeletal alignment abnormalities, which can lead to functional impairments. The knee joint plays a vital role in transmitting weight bearing forces during static and dynamic activities [9]. There is evidence to suggest that overweight and obesity are linked to skeletal anomalies, particularly angular knee abnormalities. The most significant skeletal abnormalities of the knee are genu varum and genu valgum; obese older women are more likely to develop these deformations. Affected individuals are at an increased risk of developing such comorbidities as patellofemoral joint injury and tibiofemoral joint osteoarthritis, as well as compensatory abnormalities in the ankle and foot joints [10].

The hip-knee-ankle (HKA) angle as measured on a full-length radiograph of the lower limb is the gold standard method of diagnosing changes in lower limb alignment. In research, HKA provides a quantitative measure to diagnose the severity of lower limb malalignment. Since the exposure to X-ray is associated with harmful effects, there is a need to reduce the use of X-ray and find a safer and valid alternative method of measuring the HKA angle [11, 12].

There is growing evidence on the use of artificial intelligence as a mode of patient assessment and treatment. Various mobile software applications are available for posture analysis and evaluation. The AI Posture Evaluation and Correction System (APECS) software is a non-radiographic mobile application that provides precise features for whole body posture assessment along with marking and measuring angles so as to indicate any pathological deviation or asymmetry [13]. Thus, this application was considered to measure the HKA angle so as to determine the diagnostic properties of the APECS application in order to find a safer alternative to radiographic assessment. In this context, the purpose of this research was to verify the validity in terms of matching and agreement between the non-radiographic APECS software and the standard radiographic measurement of the HKA angle.

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Subjects and methods

Study design

The present cross-sectional diagnostic accuracy study was conducted in a tertiary care hospital of Belagavi, Karnataka, India. The study was designed to compare the HKA measurements in elderly obese women taken with the APECS application with an accepted gold standard, i.e., full-length bilateral lower limb radiograph (X-ray) [12].

Participant selection

Considering the commonality of variations in the HKA angles to the population investigated in the present study, elderly obese female participants were chosen as the study population [14]. The sample size was calculated as more than 25 subjects in order to detect a correlation of more than 0.60 considering the power of 0.80 and alpha value of 0.05 [15]. The sample in the present study therefore comprised 45 elderly obese female volunteers from Belagavi city. These subjects were selected from the patient population visiting a tertiary care private hospital during a bone mineral density camp and from old age homes. The study included volunteer females aged 60–80 years with a body mass index of ≥ 25 in accordance with the WHO Asian classification [16]. Participants were excluded if they had history of severe musculoskeletal problems (osteoarthritis, rheumatoid arthritis, degenerative joint diseases), presence of any physical disability, diagnosed cancer, tumour, metastasis, history of any lower limb fracture, presence of implants or history of hip-knee replacement, history of any major lower limb surgeries performed in the previous 6 months, or if they received any medications that could have an effect on body fat mass (e.g. steroids, hormonal therapy). The principal investigator approached the participants with a document explaining the study objective and methods. If the subject consented, she was assessed for measuring the HKA angle both by radiological and non-radiological (APECS application) methods.

Training of the research examiners

The HKA angle measurement with the APECS application was taken by 3 physiotherapists. They were trained in the use of the APECS application and skeletal palpation technique of bony landmarks by the principal investigator. The 3 bony landmarks included head of femur, centre of patella, and tibial plafond. After the training, the research examiners' ability to palpate the bony landmarks and the use of the APECS application was examined for reliability. For marking HKA on an X-ray film, the principal investigator was trained by a radiologist. In this way, it was ensured that the angle measurements were blinded between the values obtained on X-ray and the values obtained in the APECS application.

HKA measurement procedure

X-ray (gold standard)

This procedure was conducted in a radiology room with a convention X-ray equipment (Siemens). The participant stood barefoot against the scanogram in full weight bearing, with the great toes joining in front and heels apart. Three X-ray film cassettes were added in the sockets for exposures to pelvis, thigh, and leg. Exposures were taken in the frontal plane with 90 kV X-ray beams with 200 mA, 128 mAs; the

Figure 1. Assessment of HKA angle with the gold standard X-ray mode

X-ray beams flashed from the hip to the ankle region. The X-ray technician who was trained for this protocol took the exposures, supervised by a radiologist. After the exposure, the X-ray films were transferred to a software-supported desktop to mark the HKA angles. With the help of the software, the 3 films were merged by the X-ray technician in the order of pelvis, thigh, and leg. Then, the principal investigator marked the HKA angle with a line joining the centre of head of femur to the centre of the knee and another line from the tibial plafond to the centre of the knee, intersecting the tibial spine, using 2.0 version software, DXM model manufactured by Agfa company [11, 12] (Figure 1).

AI Posture Evaluation and Correction System software [13]

The APECS Pro mode application was used to measure the HKA angle. For this, the participant was in a standing position barefoot in an anatomical position and the lower limbs were exposed from the pelvis to ankle. The HKA angle was measured by first palpating the 3 bony prominences. The head of femur was approximated by palpating the anterior superior iliac spine and the upper edge of the pubic symphysis, then drawing a 1.5-cm line distally from the mid-point to identify the head of femur [17]. The 2nd point was the centre of patella and the 3rd point was on the tibial plafond (anterior mid-point on the ankle between the 2 malleoli). A radium tape was applied for easy identification of the bony prominences. A picture of both lower limbs was taken with a normal camera with flash light on so that the radiant makers could glow on the image and the points could be easily marked on the application. The image thus taken was transferred to the APECS application, where the lines forming the angle were marked from the radiant markers. The angle was marked by 3 research investigators blinded to the radiographic values to assess the reliability and validity of the APECS application

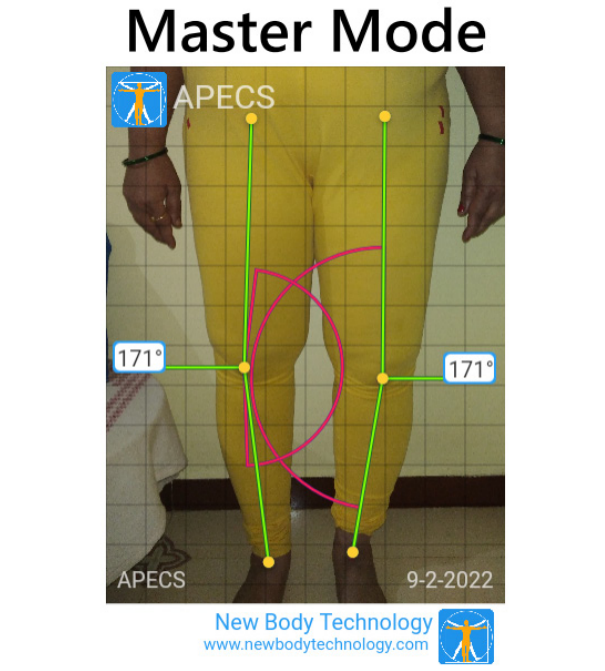

Figure 2. Assessment of HKA angle with the APECS application

in evaluating the HKA angle; the values were subsequently compared with the radiological angles (Figure 2).

Procedure for validation

All of the participants had their HKA angles assessed by using an X-ray and the APECS application. The principal investigator remained in the X-ray analysis room, marking the X-ray for the HKA angle. Three other examiners used the APECS application to assess the HKA angle. Each of the examiners was given a separate sheet to enter the recorded angle and after each measurement, the radium tape applied on the bony landmarks was removed to ensure blinding of the values for each examiner.

Statistical analysis

The statistical calculations were performed with the SPSS software, version 20.0 (IBM Corp., Armonk, NY, USA). To indicate the reliability in the angle measurement with the APECS application, the Pearson correlation coefficient was applied. The comparison and agreement for the HKA angle assessment by the standard radiograph and the APECS application were determined with the kappa statistic and dependent *t*-test.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Research Ethics Committee of KAHER Institute of Physiotherapy (approval No.: KIPT/30-12-2021/sl.no 699).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

Table 1 presents the demographic details of the study participants.

Table 1. Characteristics of the participants

Variables	Min	Max	Mean	Median	*SD*	*CV*
Age	60.00	73.00	63.48	63.00	3.19	5.02
Height (cm)	127.00	166.80	153.79	154.00	8.11	5.27
Weight (kg)	43.90	95.00	68.47	68.10	9.26	13.53
BMI (kg/m^2)	24.40	40.50	29.20	28.50	3.72	12.75

BMI – body mass index, *CV* – coefficient of variation

The correlation values between the right and left side almost matched; Table 2 depicts the average results for both sides. There was an excellent reliability between the 3 assessors. The Pearson correlation coefficient between the APECS application and the gold standard (X-ray) equalled 0.9874 (98.74% of matching), which indicates excellent correlation between the 2 measurement methods.

Table 2. Correlation between average hip-knee-ankle angle assessments of right and left sides by standard radiograph and APECS Pro application by 3 examiners

Assessment	*r*	% of matching	*t*	*p*
Average APECS Pro by all examiners	0.9874	98.74	41.3713	0.0001*
APECS Pro by examiner 1	0.9736	97.36	28.2715	0.0001*
APECS Pro by examiner 2	0.9681	96.81	25.6277	0.0001*
APECS Pro by examiner 3	0.9816	98.16	34.0950	0.0001*

APECS – AI Posture Evaluation and Correction System software
* $p < 0.05$

The agreement in the HKA angle assessment (average of right and left side) by standard radiograph vs. APECS Pro by using kappa statistic equalled 94.64% ($Z = 8.9700$), which suggests a good agreement. The average agreement of standard radiograph vs. APECS Pro was 94.84% (kappa = 0.8179) for examiner 1, 94.26% (kappa = 0.7908) for examiner 2, and 96.01% (kappa = 0.8570) for examiner 3; this suggest a good percentage of agreement (Table 3).

Table 4 presents the comparison of the HKA angle values for the right side, left side, and average of right and left between standard radiograph and the APECS Pro application by using an independent *t*-test. The results suggest an insignificant difference with $p > 0.05$, indicating good match in the angle values of the 2 measurement methods.

Discussion

The aim of this research was to determine the diagnostic features of using the APECS software application to measure the HKA angle. In view of the relatively limited literature on the diagnostic features of this software, the purpose of this study was to test the validity of the APECS application in the HKA angle assessment in comparison with the gold standard X-ray method so as to determine a safer alternative to X-ray.

Our findings show that the APECS application has strong validity ($r = 0.9874$), implying good agreement. The fact that

Table 3. Agreement in hip-knee-ankle angle assessment (right side, left side, and average) by standard radiograph and APECS Pro application by 3 examiners by kappa statistic

Sides	Between	Agreement	Kappa	*SE*	*Z*	*p*
Right	Standard radiograph vs. average APECS Pro by all examiners	93.63%	0.7824	0.0889	8.8000	0.0001*
	Standard radiograph vs. APECS Pro by examiner 1	94.63%	0.7599	0.0860	8.8400	0.0001*
	Standard radiograph vs. APECS Pro by examiner 2	94.49%	0.7778	0.0899	8.6500	0.0001*
	Standard radiograph vs. APECS Pro by examiner 3	95.91%	0.8197	0.0884	9.2700	0.0001*
Left	Standard radiograph vs. average APECS Pro by all examiners	94.16%	0.8111	0.0938	8.6500	0.0001*
	Standard radiograph vs. APECS Pro by examiner 1	94.29%	0.7854	0.0934	8.4100	0.0001*
	Standard radiograph vs. APECS Pro by examiner 2	93.34%	0.7502	0.0914	8.2100	0.0001*
	Standard radiograph vs. APECS Pro by examiner 3	95.94%	0.8408	0.0906	9.2800	0.0001*
Average	Standard radiograph vs. average APECS Pro by all examiners	94.64%	0.8323	0.0928	8.9700	0.0001*
	Standard radiograph vs. APECS Pro by examiner 1	94.84%	0.8179	0.0897	9.1200	0.0001*
	Standard radiograph vs. APECS Pro by examiner 2	94.26%	0.7908	0.0903	8.7600	0.0001*
	Standard radiograph vs. APECS Pro by examiner 3	96.01%	0.8570	0.0914	9.3700	0.0001*

APECS – AI Posture Evaluation and Correction System software, *SE* – standard error
* $p < 0.05$

Table 4. Comparison of hip-knee-ankle angle assessment (right side, left side) by standard radiograph and APECS Pro application

Sides	Methods	Mean	*SD*	Mean difference	*SD* difference	*t*	*p*
Right	Standard radiograph	4.63	4.36	–0.01	0.85	–0.1154	0.9087
	Average APECS Pro by all examiners	4.64	4.03				
Left	Standard radiograph	5.43	4.19	0.36	0.84	2.8718	0.0623
	Average APECS Pro by all examiners	5.08	3.73				
Mean	Standard radiograph	5.03	3.92	0.17	0.71	1.6364	0.1087
	Average APECS Pro by all examiners	4.86	3.54				

APECS – AI Posture Evaluation and Correction System software

the current study revealed good validity of the APECS application in measuring the HKA angle could be supported by the following: (1) the 3 examiners were well trained on palpation of bony landmarks; (2) the application autogenerates the HKA angle once the bony points are marked; (3) the training sessions for the examiners on use of the APECS application could have been a factor that decreased the measurement error. There are various mobile-based applications designed to evaluate joint range of motion and proprioception but not all of them give a provision for specific HKA angle measurement. This is in line with the previous literature on the use of smartphone applications like the TiltMeter application (a professional grade angle measurement tool) or iHandy Level on iPhone etc. for assessing range of motion, angle of inclination, and proprioception in clinical practice [18, 19].

On marking the points, the APECS application automatically generates the HKA angle and this had a positive influence in proving a good validity, unlike in the other software, like the human pose estimation application [20] that represents the orientation of a person in a graphical format but does not specifically assess the required angle.

In comparison with other non-radiographic techniques (umbilical, calliper, inclinometer method), the APECS application proved to have a good validity and agreement, which is in accordance with other techniques that showed an error in measuring the HKA angle. The umbilical method proved to be a valid alternative method in measuring the HKA angle in the obese population but the drawback of the study was that the umbilical femoral axis was positioned further medially when compared with the gold standard radiographic femoral axis; this resulted in an overestimation of the frontal plane alignment, giving a mean value of 8.1° more varus than in the gold standard radiographic method [21]. Similarly, the inclinometer method had an advantage over the calliper method; however, because the mechanical axis presents a poorer correlation than the anatomical axis, there is a higher risk of misclassification when using these clinical measurements of alignment instead of the anatomical axis [22]. On the basis of the previous literature and the results obtained [18–22], the APECS application exhibited a strong validity and agreement and can be used as an alternative mode for the HKA angle assessment. Nevertheless, it requires knowledge and training to identify the bony landmarks. As it is an Android application, it can be used in community settings to evaluate the HKA angle.

Because no previous studies on the validity of the APECS application have been conducted, it is rather difficult to compare our findings with earlier research. However, a few different software application-based studies to assess range of motion or angular deformities in cervical or lumbar spine have been performed in the recent past to determine the software applicability/reliability/validity. There are various mobile-based applications designed to determine joint range of motion and

proprioception [23]. Software application-based diagnosis or assessment has the advantage of being feasible, cost-effective, and handy, and hence should be widely promoted in research.

Limitations

If males had been included in the study, the results might have shown a difference related to gender distribution. The age range was centred on an elderly population; however, if a larger age range had been applied, the data could have offered a cause for the variance in the HKA angle, increasing the percentage of variation in angle measures.

Conclusions

The APECS application demonstrated a strong validity and agreement in comparison with the radiological HKA assessment, which suggests that this software-based application can be used as a safer alternative mode to measure the HKA angle. Further, the application provides an added advantage of its use for clinical and research outcomes for different patient populations, considering its feasibility and ease of utilization.

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Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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