Concurrent validity and reliability of the Microsoft kinect™ device in cervical spine range of motion assessment

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Abstract

This study assessed the cervical spine range of motion in asymptomatic individuals using the universal goniometer and the Microsoft Kinect™ device, respectively and also determined the validity and test-retest reliability of the Microsoft Kinect™ device with a view to establishing the accuracy and reproducibility of an alternative but a valid tool for the assessment of cervical spine range of motion.

This cross-sectional study involved 420 apparently healthy undergraduates from the Colleges of Health Sciences, Obafemi Awolowo University Ile–Ife and Ladoke Akintola University of Technology, Osogbo Campus, who were recruited consecutively after obtaining ethical clearance from the Health Research and Ethics Committee, Institute of Public Health, Obafemi Awolowo University, Ile-Ife, Nigeria. Cervical motions were evaluated using the universal goniometer and the Kinect™ device. The Microsoft Software Development Kit (SDK), version 1.8 and the Markus Bader Software solution were used to calculate the cervical motion based on Kinect skeleton tracking data. Anthropometric characteristics (age, height and weight) were recorded and body mass index was calculated. Every measurement was made twice and the average value used for statistical analysis. The intraclass correlation coefficient was used to investigate correlation and reliability between measurements obtained from the two techniques. An alpha level was set at $p<0.05$.

The cervical spine range of motion for flexion, extension, right and left lateral rotation and right and left lateral flexion for the goniometer were 36.71 ± 6.34^0, 43.11 ± 5.54^0, 49.15 ± 5.88^0, 47.69 ± 5.11^0, 23.22 ± 3.95^0 and 22.67 ± 3.83^0 while for the Microsoft Kinect™ were 48.80 ± 6.76^0, 15.34 ± 2.94^0, 15.73 ± 3.04^0, 15.09 ± 3.09^0, 23.49 ± 4.59^0 and 24.49 ± 4.72^0 , respectively. There was no significant correlation in all of the cervical spine range of motion measurements obtained using the Microsoft Kinect (extension $r = 0.09$, $p = 0.571$; right lateral rotation $r = 0.01$, $p = 0.614$; left lateral rotation $r = 0.008$, $p = 0.437$; right lateral flexion $r = 0.09$, $p = 0.571$; left lateral flexion $r = 0.01$ $p = 0.591$) with the exception of cervical flexion ($r = 0.198$, $p = 0.001$). The intra-rater reliability of both the Microsoft Kinect™ and goniometer in the assessment of cervical spine range of motion was excellent ($r > 0.75$). The intra-rater reliability values for flexion, extension, right and left lateral rotation and right and left lateral flexion for the Microsoft Kinect™ were 0.98, 0.93, 0.95, 0.96, 0.97, and 0.98 while for the goniometer were 0.98, 0.98, 0.98, 0.98, 0.96, and 0.96, respectively.

The Microsoft Kinect™ was found to be a reliable tool yet showing weak concurrent validity when compared with the universal goniometer in the cervical spine range of motion assessment, except for cervical flexion, among apparently healthy undergraduates.

Key words: range of motion; cervical spine; goniometry; Microsoft Kinect.

Introduction

The healthy cervical spine undertakes more than half a billion motions in a year [1]. Normal cervical movements are necessary for several Basic and Instrumental Activities of Daily Living (BIADL) and for maintaining quality of life. Neck dysfunctions contribute to many health challenges in the community and are a major cause of disability [2]. Generally, the average prevalence of cervical pain is 23.1% with an increasing incidence among people doing office and computer works [3]. Statistics reveals that many individuals (67%) may experience neck pain in their lifetime [4]. The prevalence of neck pain in children oscillates between 19% and 43% in the general population [5]. Neck pain is largely responsible for many hospital visitations [3]. The effects of cervical dysfunction are numerous, including pain and reduced range of motion [6], which may limit social interactions and lead to sick leaves [7].

As the cervical range of motion can well indicate how healthy the individuals are, its parameters have to be assessed quickly and accurately. In the physiotherapy practice, the assessment of cervical spine is essential [8] to diagnose cervical dysfunctions [9], analyze the progression of diseases [10], assess the outcomes of different interventions[11], and follow up patient's progress in rehabilitation[12].

Although there is diversity of electronically aided instruments, such as electrogoniometers, spinal motion analyzers, inclinometers, CROM devices, and videos cited in the literature for the assessment of neck mobility, there is no agreement among clinicians on the best method or tool to be used or suited and on protocols to be followed [13]. In the literature, radiograph is the tool accepted as the gold standard for cervical spine range of motion assessment but it is limited in use clinically due to excessive radiation exposure of patients and cost [14]. A variety of alternative non-invasive methods are available, i.e. visual estimations, goniometer, inclinometer, potentiometer, compasses, videos and electromagnetic devices but some of them have limited intra-rater and inter-rater reliability, require high technical expertise to operate, and are very expensive [15].

The universal goniometer is a tool used most commonly for assessing cervical spine range of motion in the clinical settings. Several studies have enumerated the design and the procedures to employ while using the universal goniometer [16]. The device has been demonstrated to have excellent within-session (ICC2, 1 = 0.83 to 0.98) and between session (ICC 2, 2 = 0.79 to 0.97) intra-rater reliability and excellent inter-rater reliability (ICC2, 2 = 0.79 to 0.92) with high validity [17] in assessing neck motion.

The device, however, is limited by the difficulty in recording complex motions in a joint with multiple torsion angles, like the cervical spine. It is difficult to keep the fixed arm of the device static while moving the joint in order to read the values on the goniometer at the end of assessment. Removing the device from the joint to read the goniometer values may result in errors of measurement [18], thereby lowering its reliability [19].

Recently motion sensing technology has been used in different fields of endeavor, including health. One example of motion sensing technology is the Microsoft Kinect™ device. The Microsoft Kinect™ is a portable, non-handheld device, which offers much lower cost than traditional cervical goniometry instrumentation, e.g. electrogoniometers, spinal motion analyzer, videos and CROM devices. The Microsoft Kinect™ employs infra-red light and a video camera to create a 3D map of objects placed on its path [20]. Close to real time it automatically creates human skeleton landmarks using forest algorithm [21]. The real advantages of Kinect™ are also recognizable in several fields, such as security, sports, ergonomics etc. The Kinect™ device has been used

for the human motion assessment and measurements [22-24]. The Microsoft Kinect™ ability and validity is now increasing. Several studies have attempted to determine its validity prior to making further research on the dynamic ability. Varieties of studies on the validity of Kinect™ for measuring 3D position at work, in dancing and for human motion evaluation [25-27] are available. As reported by Bonnechèreet et al. [28], the validation of Kinect™ device in terms of angular assessment and reliability in functional evaluation has been undertaken. In order to establish the accuracy and sensitivity of the Microsoft kinect™ device in the assessment of cervical spine range of motion, it is essential to validate it with some other known methods. This study evaluated the concurrent validity and reliability of the Microsoft Kinect™ device in the assessment of cervical spine range of motion in asymptomatic individuals.

Material and methods

Four hundred and twenty apparently healthy undergraduates of Colleges of Health Sciences, Ladoke Akintola University of Technology, Osogbo and Obafemi Awolowo University, Ile-Ife, who were recruited consecutively, participated in this study. Each participant was given full explanation and verbal instructions concerning the purpose and procedure of the study and all participants signed an informed consent form prior to participating. The participants were assessed by the same instruments. Ethical approval was obtained from the Health Research and Ethics Committee (HREC NO: IPHOAU/ 12/ 1038), Institute of Public Health, College of Health Sciences, Obafemi Awolowo University, Ile-Ife, Nigeria.

Inclusion criteria

Eligibility for this study was being asymptomatic of cervical pain and no history of cervical pain up to three months prior to the study.

Exclusion criteria

- history of pain or muscle spasm 3 month prior to this study.
- history of musculoskeletal or neurological dysfunctions of the cervical, thoracic and shoulder regions.
- history of cervical trauma, bone pathologies, arthritis, cervical rib, forward head posture or other inflammatory disorders.

Procedure

The participants were asked to sit on a chair with their back straight. Their ankles, knees and hips were positioned at right angles and their arms placed on their knees. Each subject was assessed in a set sequence of six active cervical ranges of motion, i.e. flexion, extension, right lateral flexion, left lateral flexion, right lateral rotation and left lateral rotation. For all cervical spine movements, two consecutive values were obtained for all participants using goniometry and Kinect techniques.

Measurement of cervical spine range of motion using the universal goniometer

Cervical spine goniometry was performed using the universal goniometer (66fit™), a 12-inch full circle plastic device featuring three separate scales calibrated according to the International Standards of the Measurement System. The measurements were made following the protocol of Cynthia and White [29]. For flexion and extension, the center of goniometer was on the external auditory meatus and the stationary arm perpendicular to the ground while the moving arm was at the base of nares at the end of the test (Figs. 1a and 1b). For lateral flexion (right and left), the center of the goniometer was over

spinous process of C7 and the stationary arm over the spinous processes of thoracic vertebrae while the moving arm was at the dorsal midline of the head (occipital protuberance) at the end of the test (Figs. 1c and 1d). For rotation (right and left), the center of the goniometer was over the center of cranial aspect of the head and the stationary arm parallel to an imaginary line between the two acromial processes while the moving arm was at the tip of the nose (Figs. 1e and 1f). Each movement was performed and recorded twice.

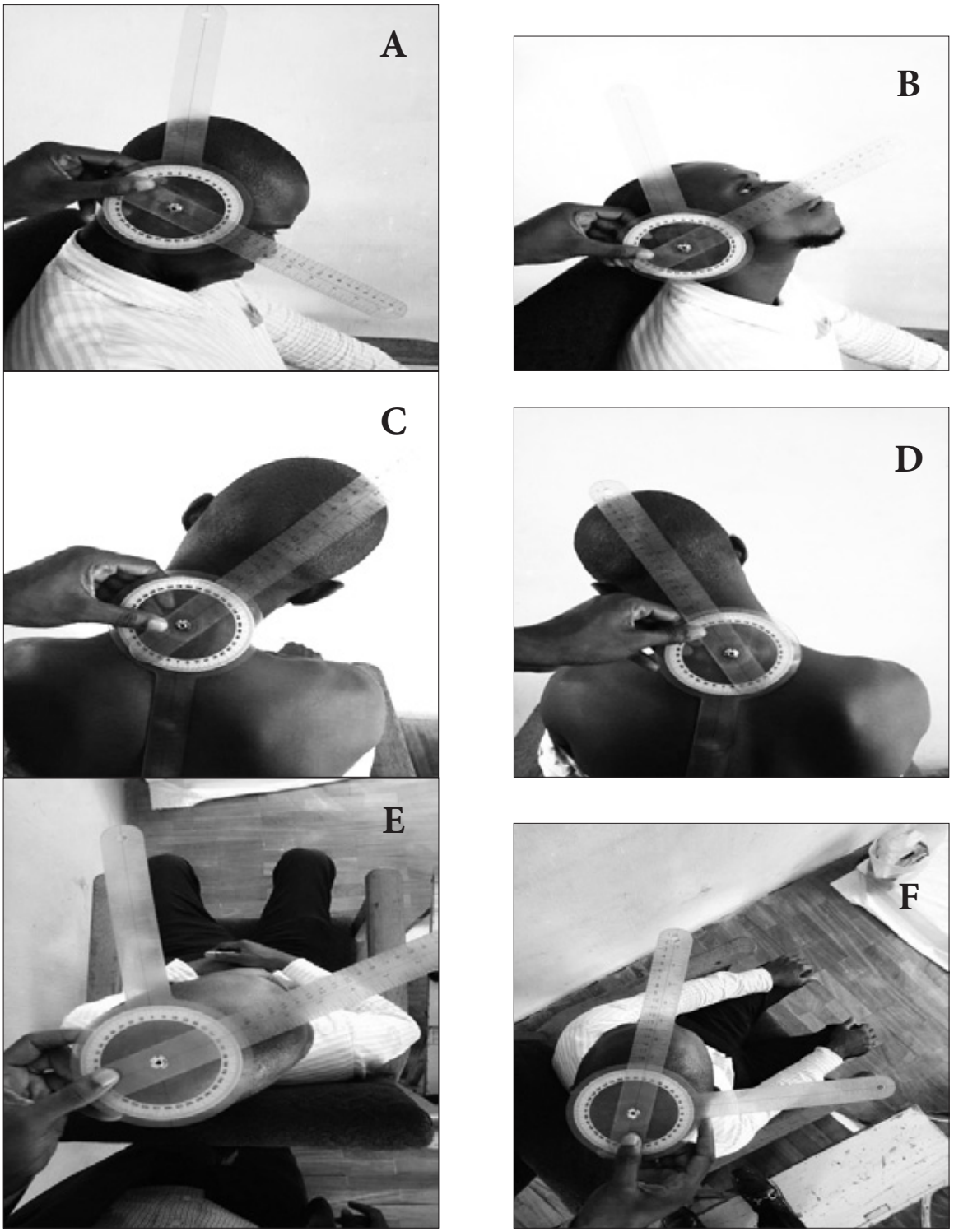


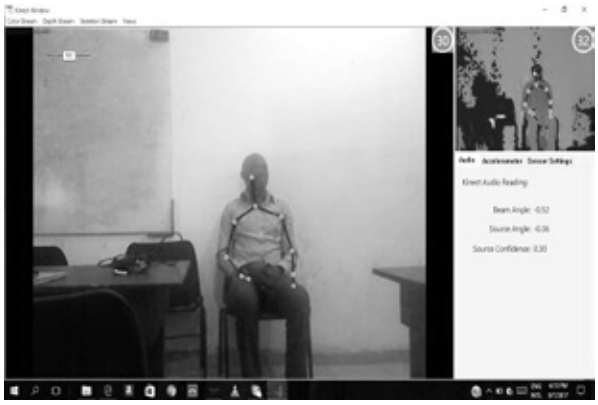
Fig. 1. Assessment of cervical spine range of motion using the universal goniometer

Measurement of cervical spine range of motion using the Microsoft kinect™ device

The Microsoft Kinect™ with an image sensor assessing AROM was used to obtain a marker-based three-dimensional motion analysis (3DMA) during two repetitions of cervical flexion, extension, right lateral flexion, left lateral flexion, right lateral rotation and left lateral rotation. The Microsoft kinect™ device was placed on a platform (1m) while being connected to a laptop. A room was provided with a wide space area (2m) so that the Kinect sensor interacted with the participant. The anatomical landmarks helped in creating the anatomical coordinate system of each body segment. The official Microsoft Software Development Kit version 1.8 (SDK) was used to obtain the anatomical landmark and coordinates of each subject.

A trial of all cervical spine movements was conducted before the actual assessment allowing for synchronization between the Kinect™ sensor and the motion tracking system (Fig. 2a). The ©Markus Bader (MB) Software Solutions (MB Ruler), an on-screen protractor application was used to assess the displacement in each set of the cervical spine flexion (Fig. 2b), extension (Fig. 2c), lateral flexion (Figs. 2d and 2e) and rotation (Figs. 2f and 2g) by carefully allayed the MB ruler on a screen tool to the stickman model captured in the form of JPG (often used in cameras) on the computer screen (Window 8 PC) displaced by the Microsoft Kinect™ device. All cervical spine angular displacements during the procedure were measured from the neck landmark of the Kinect™ as a reference point.

A



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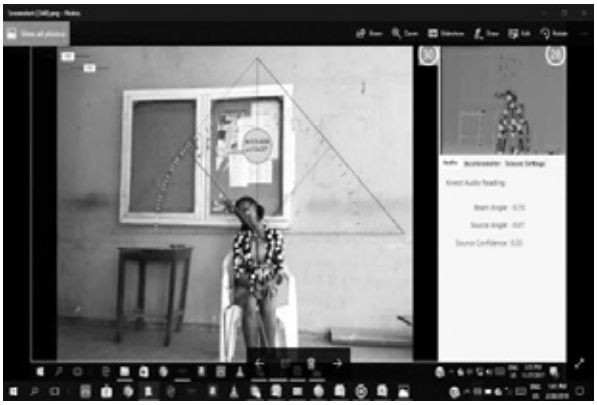

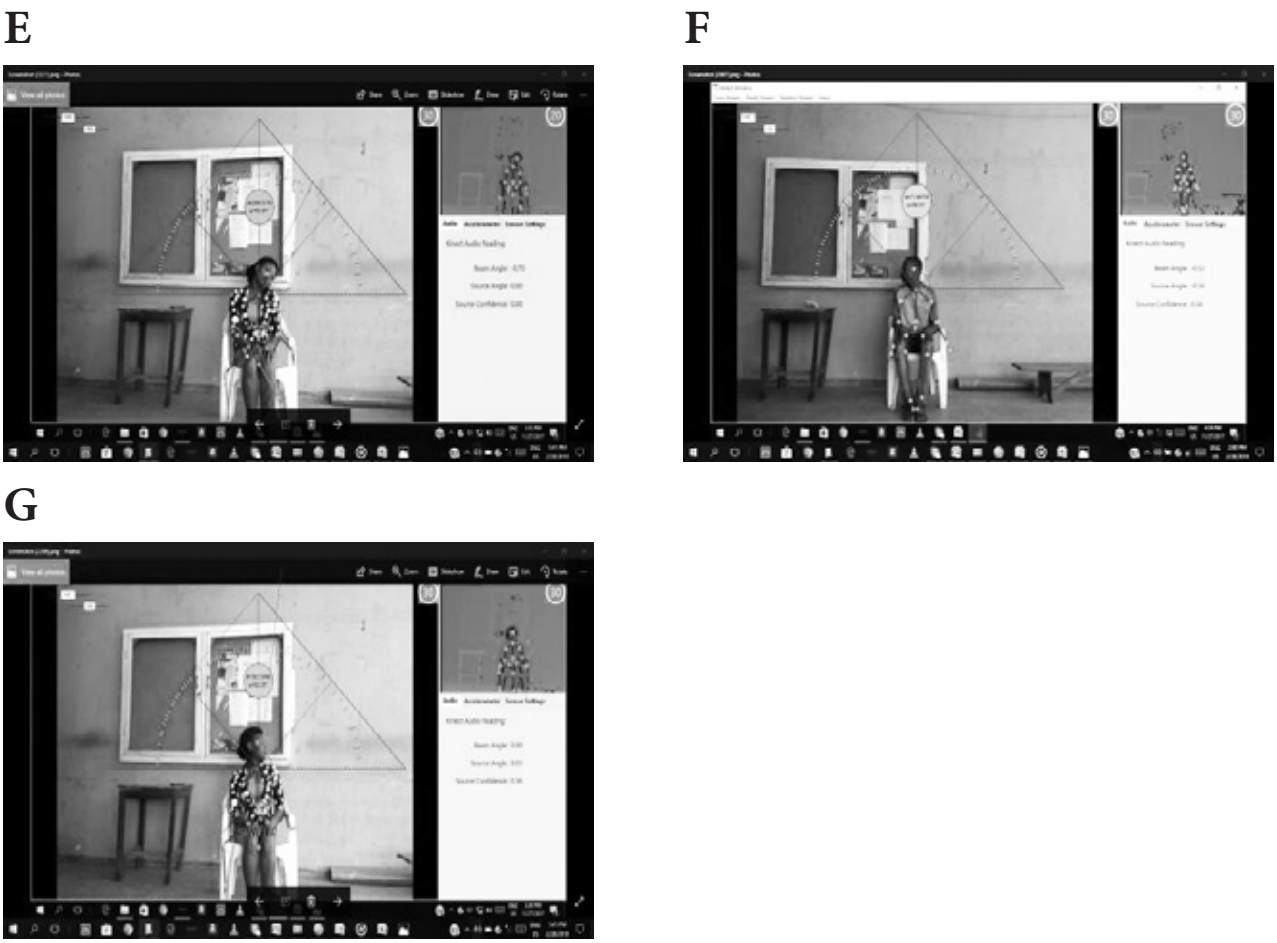

Fig. 2. Assessment of cervical spine range of motion using the Microsoft Kinect™ with a M-B ruler superimposed

Data analysis

The data were analysed using descriptive statistics of mean and standard deviation. The intraclass correlation coefficient (ICC) was used to explore the relationship between the data from the Universal goniometer and the Microsoft Kinect™ device. The reliability and internal consistency of the Microsoft Kinect™ motion measurements were calculated using the intraclass correlation coefficient (ICC) and Cronbach's alpha. An alpha level was set at $p < 0.05$. The Statistical Package for Social Sciences (SPSS Inc., Chicago, USA) version 21 was used for data analysis.

Results

The mean age, weight, height and body mass index of the participants was 20.04±2.40 years, 1.64±0.07m, 60.8±6.20Kg, and 22.8±2.61 Kg/m^{2,} respectively (Table 1). The number of male participants was higher (254) than that of female ones (166).

Table 1. Physical characteristics of the participants (n= 420)

Variables	Mean	±SD
Age (yrs)	20.04	2.40
Height (m)	1.64	0.07
Weight (kg)	60.8	6.20
BMI (kg/m^2)	22.8	2.61

Mean values of cervical range of motion measurements

Table 2 shows the average mean values and standard deviations of the cervical motion measurements obtained by the Microsoft Kinect™ and the goniometer. The mean scores

ranged from 15.09 to 48.80 degrees for the Kinect and from 22.67 to 49.15 degrees for the goniometer. The highest mean score in Kinect measurements was found for flexion (48.80) while in goniometer measurements for right lateral rotation (49.15). The lowest mean score was observed for left lateral rotation (15.09) and for left lateral flexion (22.67) , respectively.

Table 2. Mean values and standard deviations of cervical range of motion measurements obtained by use of Microsoft Kinect and Goniometer

Variables	Device	All participant n=420 Mean ±SD
Flexion (^{0})	Kinect Goniometer	48.80 ± 6.76 36.71 ± 6.34
Extension (^{0})	Kinect Goniometer	15.34 ± 2.94 43.11 ± 5.54
Rt Lat. Rotation (^{0})	Kinect Goniometer	15.73 ± 3.04 49.15 ± 5.88
Lt Lat. Rotation (^{0})	Kinect Goniometer	15.09 ± 3.09 47.69 ± 5.11
Rt Lat. Flexion (^{0})	Kinect Goniometer	23.49 ± 4.59 22.22 ± 3.95
Lt Lat. Flexion (^{0})	Kinect Goniometer	24.49 ± 4.72 22.67 ± 3.83

SD= Standard deviation

Table 3 shows concurrent validity of cervical ROM measurement values of the Microsoft kinect and the universal goniometer using intraclass correlation. The intraclass correlation (r) of measurements was within the range of 0.008 and 0. 198. The highest correlation was found for cervical flexion (r=0.198, p=0.001) and the lowest one for left lateral rotation (r=0.008, p=0.437).

The Intraclass Correlation Coefficient (ICC) ranges from 0.937 to 0.989 for the Kinect and from 0.969 to 0.989 for the goniometer. Cervical flexion had the highest value (0.989) while cervical extension had the lowest value (0.937) for the Kinect. In goniometry, cervical flexion had the highest value (0.989) while right and left flexion had the lowest value (0.969).

The internal consistency of the Microsoft Kinect and universal goniometer using the Cronbach's alpha and intraclass correlation coefficient (ICC) in cervical motion measurements is shown in Table 4. All the movements had the Cronbach's alpha ranging from 0.967-0.994 for the Kinect and 0.984-0.994 for the goniometer. Cervical flexion had the highest value (0.994) while cervical extension had the lowest value (0.967) for the Kinect; cervical

Table 3. Concurrent Validity of Microsoft Kinect in the measurement of cervical spine range of motion

Variable	Correlation(r)	95% confidence interval		p-value
		Lower class	upper class	
Flexion	0.198	0.103	0.291	0.001*
Extension	0.090	0.107	0.089	-0.571
Rt Rotation	-0.014	-0.112	0.084	0.614
Lt Rotation	0.008	-0.090	0.106	0.437
Rt Lat. Flexion	-0.090	-0.107	0.089	0.571
Lt Lat. Flexion	-0.011	-0.109	0.087	0.591

Keys:
r= intraclass correlation coefficient
Rt Rotation= Right rotation
Lt Rotation= Left rotation
Rt Lat. Flexion= Right lateral flexion
Lt Lat. Flexion= Left lateral flexion
*= significant correlation at $\alpha = 0.05$

Table 4. Test-retest reliability of cervical spine range of motion using Microsoft kinect and Universal goniometer N=420

Variable	Device	Test-retest	Internal consistency
		(ICC; 95% CI)	α
		Reliability(r)	Internal Consistency (α)
Flexion(^{0})	Kinect Goniometer	0.989 0.989	0.994 0.994
Extension(^{0})	Kinect Goniometer	0.937 0.986	0.967 0.993
Rt Rotation(^{0})	Kinect Goniometer	0.950 0.986	0.975 0.993
Lt Rotation(^{0})	Kinect Goniometer	0.961 0.981	0.980 0.990
RtLat Flexion(^{0})	Kinect Goniometer	0.978 0.969	0.989 0.984
Lt Lat. Flexion(^{0})	Kinect Goniometer	0.984 0.969	0.992 0.984

flexion had the highest value (0.994) while right and left flexion had the lowest value (0.984) for goniometry.

Discussion

This study was conducted to determine the concurrent validity and reliability of the Microsoft Kinect™ device in cervical spine range of motion assessment. There was a weak correlation between the Kinect and universal goniometer systems of measurements for all cervical movements, except for cervical flexion where the correlation was statistically significant (p= 0.001). The correlation values of flexion, extension and right lateral flexion angles were better than those of right and left lateral rotation and left lateral flexion.

This finding is in agreement with the study by Young et al. [30], who investigated the validity of the Microsoft Kinect™ in the assessment of continuous cervical motion. They compared the values of cervical spine measurements of the Kinect system and the optical motion capture system (MoCap). They have reported a less favorable agreement between the MoCap and the Kinect (95% LoA>10^0) in the assessment of continuous cervical ROM in all directions. According to their findings, the Kinect showed larger measurement errors compared with MoCap in monitoring cervical continuous motion [30].

Moreover, Hawi et al. [31], evaluating the validity for elbow range of motion, have reported a poor to moderate correlation between Kinect-based measurements compared to universal goniometer measurements (ICC=0.28-0.68). They have inferred that even subjective measurements, for which low reliability has been reported [32], have a better correlation with goniometer-based measurements, as compared to Kinect-based measurements.

On the other hand, the results of the above study are inconsistent with the findings reported by Allahyari et al. [33], who evaluated the accuracy of the Microsoft Kinect™ in the cervical spine measurements when compared with electrogoniometry. They have reported a moderate to excellent correlation between the measurements made with the Kinect system and the electrogoniometer. Noteworthy, the

researchers modified the S.D.K (1.8) software in such a way that the Kinect automatically recorded cervical motion measurements as being done by volunteers [33]. Conversely, in this our study, the M-B ruler was used to calculate the angle on the computer screen after capturing the cervical movements as done by the participants. The process of this manual measurement may have introduced the differences noticed in cervical motion measurements.

Despite this, a critical look at the mean values of cervical motions obtained from the Kinect measurements in the study by Allahyari et al. [33] has revealed a somewhat close agreement with the mean values obtained in our study. For instance, the mean value and standard deviation obtained for extension and rotation in their study compared with the values of our study were 15.30 ± 0.78 vs. 15.34 ± 2.94, and 15.54 ± 2.02 vs. 15.73 ± 3.04 (right) and 15.09 ± 3.09 (left), respectively. The mean values for lateral flexion were also comparable, except for cervical flexion for which their values were wide apart. This invariably implies that the Kinect obtained fairly similar construct for cervical motions in both studies but their correlation coefficients differ partly because of somewhat different procedures and different reference or gold standard used in both studies. Additionally,, the sample size of their study was very small (10), as compared to our study (420). Moreover, they have reported a weaker correlation between the Kinect and electrogoniometry systems in rotation than in any other cervical movement as obtained in our study.

The Kinect accuracy can be affected by the distance between subjects and the recognition precision [30]. According to the Kinect sensor user manual, the best field of view for the Kinect is obtained when the sensor is located at a distance of 0.8–2.5 m (for seated mode) from participants, although the maximum and minimum range for the Kinect for tracking is between 0.8-6.5m [34]. In our study, the participants were placed 2.0 m in front of the camera. It has been reported that the Kinect measurements result in occlusion and tracking errors if the distance of an object is close either to the minimum or maximum distance value. According to another study, the localization error increases in proportion to the marker distance from the motion sensor, which is consistent with a linear relationship between the distances generated by the sensor and the actual distances in the analyzed range [35]. Hawi et al. [31] have concluded that some improvements have to be made in positioning and the measurement protocol before using the Kinect to assess the range of motion in the clinical setting due to its measurement error.

Moreover,, the face detection algorithm failed to accurately detect the face in some angles, especially in cervical extension and rotation. The Kinect has been reported to produce measurement errors when subjects do not wholly face the sensor or when that part of the body is not visible to the camera fully [33]. To overcome this flaw, the authors have suggested that a system with several Kinect sensors at different heights and positions should be designed to measure the neck angles that combine information captured concurrently with several Kinect sensors to increase measurement accuracy.

Furthermore, it should be pointed out that the Kinect has higher measurement errors in rotation angle measurements [33] in comparison with other cervical motions. Young et al. [30] have found as high as 14.25^0 measurement errors in axial rotation by the

Kinect and this may be responsible for its lower correlation compared to other cervical motions as observed in our and other studies..

Our previous study demonstrated that cervical lateral flexion; flexion/extension and rotation were not independent motions but with small amplitude of lateral flexion with flexion/extension accompanied rotation [36]. This phenomenon was defined to mean that the axis of axial rotation can tilt during axial movement in relation to the body. Moreover, the axis of each cervical motion is not static. Instead, it is rather complex and dynamic [37]. A multi-joint model rather than a single-joint model is needed to describe the cervical spine [30].

The Kinect-based and goniometer-based techniques showed excellent test-retest reliability in all six cervical spine ranges of motion investigated in this study. This finding agrees with the findings of Allahyari et al. [33] who have reported good-to-excellen test-retest reliability (ICC ≥0.75) for The Kinect in neck angle measurements. Moreover, Hawi et al. [31], trying to evaluate the validity, reliability and time requirements of the kinect™ in shoulder range of motion assessment, compared the Kinect™ measurements of shoulder joint movements with measurements obtained using the goniometer and subjective estimation. Theu have reported that the Kinect™ displayed excellent (ICC >0.90) test-retest reliability in all four motions tested in the shoulder joint.

As regards the assessment of cervical range of motion measurements by the goniometer, there was excellent intra-rater reliability for all the motions investigated. Likewise,, Youdas, Carey and Garrett have found moderate-to-excellent intra-rater reliability levels of all cervical range of movements evaluated using the goniometer [38].

The Kinect system not only demonstrated excellent intra-rater reliability, in fact, the Kinect™ had better reliability than the goniometer in some of the cervical motions evaluated in our study. The similar finding has been reported by Hawi et al. when examining intra-rater reliability of the Kinect compared to the goniometer for shoulder joint range of motion [31]. The lower reliability levels obtained through goniometry compared to the Kinect in some of these motions may be due to differences in handling of the two devices. In goniometry, the difficulty in locating anatomical reference points and the depth of soft tissue along the cervical spine [39] should be taken into account when placing the axis as well as fixed and movable arms of the device.

In addition to possible errors concerning handling of the equipment, there is also the error introduced by the examiner. To perform the Kinect measurement, the examiner has to instruct the volunteer to perform the movements and has to read the angle captured by the Kinect at the end of a particular movement. On the other hand, with goniometry the examiner has to carry out the same procedures, but also needs to visually locate the anatomical structure that will be used as the reference for determining the position of the movable arm. Thus, training and experience of examiners may contribute towards raising the reliability levels of goniometry for cervical ROM evaluation and minimizing the effect of these errors when performing the procedure. For jaw ROM evaluation, higher reliability values were observed after the examiners were retrained [40].

A limitation of our study is the small age range distribution. Age has been found to have negative correlation with active cervical ROM [41, 42]. It will be more suitable to

apply the Microsoft Kinect in cervical spine ROM measurements in older populations. Moreover,, this study did not consider differing somatotypes or inherent differences in neck morphology and dimension. It has been reported that assessment of cervical range of motion is incomplete without giving consideration to neck dimension [43]. Finally, our study did not attempt to assess the validity of the Microsoft Kinect™ system in people with cervical disorders. Consequently, further research, particularly in populations whose conditions (e.g. non-specific neck pain) may influence the ability of the Microsoft Kinect to accurately assess cervical range of motion, is required. Nevertheless, the population of our study was chosen so as not to burden patients with a device that still has limited established validity.

Conclusion

The Microsoft Kinect™ is a reliable tool but has weak concurrent validity when compared with the universal goniometer in cervical spine range of motion assessment, except for cervical flexion, among apparently healthy undergraduates.

Recommendation

It is recommended that the Kinect™ should be considered in the assessment of cervical flexion range of motion. Moreover,, future studies should focus on the comparison of the Microsoft Kinect™ with other technologically inclined motion assessment tools to further test its validity.

Competing interests

We declare no conflict of interest.

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