RELIABILITY OF COMPUTERIZED SOFTWARE IN MEASURING ELBOW JOINT RANGE OF MOTION

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ABSTRACT

Objective: A lot of tools can be used in measuring Range of motion; the most accurate tool is the objective and computerized one. Kinovea is video-based computerized software obtains joint range of motion values using a virtual goniometer. The intra- and inter-rater reliabilities of this software were investigated for assessment range of motion of the elbow in non-disabled subjects. Methods: one hundred healthy subjects (55 females, 45 males) participated in the study, with age were (27.6 ± 4.2) years, and was evaluated using Kinovea 0.8.15 software. The inter-rater reliability was assessed by 3 trained assessors in a blinded random way, whereas the intra-rater reliability was investigated by a single rater. Results: Inter-rater reliability ranged from 0.87 to 0.98, whereas intra-rater reliability ranged from 0.92 to 0.99. The inter-rater reliability standard error was between (0.88° and 1.3°) and the intra-rater reliability standard error ranged between (0.6° and 0.86°). The minimal detectable change for inter-rater reliability was (2.5° and 3.6°) and for intra-rater reliability was (1.7° and 2.4°). Conclusions: When applied in healthy subjects, the present study demonstrated high reliability and low minimal detectable change for evaluating elbow range of motion obtained with Kinovea software.

Keywords: Kinovea, elbow joint, Range of motion, inter-rater reliability, intra-rater reliability.

I-INTRODUCTION

It is well recognized that the upper limb works as a mechanical linkage unit and that immobilization or pain of one joint has a potential impact on movement patterns of the entire upper limb, causes mobility and functional impairments, making it impossible for the individual to go about their everyday lives normally (Gripp et al., 2013).

As the range of motion (ROM) is a primary reference tool in assessing the integrity of the upper limb joints (Kurillo et al., 2012; Mullaney et al., 2010). In the diagnostic and functional assessment of patients with musculoskeletal disorders, a clinician's primary concern is evaluating the range and patterns of movement. (Sengupta et al., 2012), as well as in normal subjects as a method of following up of their normal activity daily living, physical training or therapy interventions and finally to have a normative data for joints' range of motion.

There are numerous tools available for assessing joints ROM in the human body, where it is categorized from the universal goniometer the easiest and cheapest one (Vauclair et al., 2018), end with the motion analysis software the most technologist one.

Chapleau et al. (2011) investigated the universal goniometer's validity against radiographic measures. By evaluating extension, flexion ROM, and elbow carrying angle with three repetitions of each movement. When the ROM was measured using the goniometer, the results revealed a high ICC of the universal goniometer with reporting maximum errors of 10 degrees.

Some authors found drawbacks related to the universal goniometer such as the need to hold and stabilizing the goniometer's arms manually while taking a measurement (Mehta et al., 2017; Roach et al., 2013).

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Kinematic data describes the movement of limbs and is used in biology, sports, orthopedics and rehabilitation medicine. The data is generally acquired using motion tracking systems, imaging systems or computer simulation.

Systems for capturing motion one of the more precise and detailed instruments can allow for a more full, impartial, and objective evaluation of the patient's mobility. ROM, velocity, acceleration, and other derived kinematic and dynamic parameters can be measured using optical-tracking devices. However, they have limitations that preclude them from being used in clinical practice, such as marker occlusion, the requirement for an instrumented environment, and time-consuming preparations, which all add up to a large economic and computational expense (Tsushima et al., 2003; Mehta et al., 2017).

Costa et al. (2020) utilized therapists to evaluate inertial sensors for detecting active ROM in the elbow (flexion and pronation-supination) and wrist (flexion and pronation-supination), as well as intra-rater and inter-rater reliability when compared to goniometers. It was shown that measurements taken using inertial sensors and those taken with a goniometer have a high degree of agreement.

Researches directed toward using the motion analysis software program, there are many of them. The Microsoft Kinect system is used for tracking of human limbs, Baena et al., (2012) test the validity of the Kinect system compare with the optical motion capture in measuring the joints movements of the upper and lower body, find that the precision of the Kinect system is less than the optical motion capture system.

The ideal measuring system is one that is simple to use and does not require the usage of sensors linked to the body (Valdivia et al., 2013). Accurate and reliable measuring devices are thus critical for both clinicians and researchers seeking to objectively monitor disease progression, outcomes, and mobility impairments. (Hanney et al., 2011).

Kinovea is a video analysis program that contains an angle selection tool for measuring angular position with 1° increment precision (Richardson et al., 2014). Kinovea can measure both passive and active range of motion without the use of physical sensors (Valdivia et al., 2013); the overview function displays a video's summary image. It takes regular snapshots from the video and compiles them into a composite image that allows you to view the motion at a glance. The Reverse function allows you to reverse the motion. It simply revert the order of the images in the working zone, A Key Image is a time position of special interest. It could be a reference image you would like to enrich with comments, a technical pose you want to highlight with lines or arrows, a key point in the motion flow, also able to save images, videos, and loading and sharing analysis data (Balsalobre- Fernández et al., 2014). Software reliability for upper limb joints evaluated by (Embaby et al., 2016; Ali et al., 2015), found that its reliable for measuring wrist and shoulder range of motion.

The need for a simple, easy to use, and cost-effective tool and highly economical for assessment ROM of the upper extremity joints that may be used in a variety of clinical situations is the driving force behind this research. The current study aimed to explore the intra and inter-rater reliabilities of the Kinovea program for measuring elbow joint range of motion in normal subjects.

II-MATERIALS & METHODS

Cross sectional study was conducted in the physical therapy department at Al-Haram hospital, during the period from July 2019 to August 2019. The Research Ethical Committee authorized this study, Faculty of physical therapy, Cairo university (No:P.T.REC/012/00222).

One hundred participants of both sexes (55 males and 45 females) randomly participated in the study from the surrounding community of the Al-Haram Hospital (employees, students). Their age ranged from 20-35 years, where 89 had right dominant upper limb tested and 11 had left dominant upper limb tested. With no history of musculoskeletal or neurological disorders, elbow pathology, surgery, or hypermobility of the dominant upper extremity, the elbow flexor and extensor muscles have grade 3 muscle test. Their BMI (body mass index) ranged from 18 to 25 kg/m². Their Mid-Upper Arm Circumference (MUAC) ranged from 23-25 cm for males and 20-23 cm for females (Chapleau et al., 2013).
Three raters with at least five years of experience in orthopedic physical examination and goniometry were trained for 3 weeks on the kinovea 0.8.15 (Assessor A had 20 years’ experience, Assessor B had 12 years of experience, and Assessor C had 8 years of experience.).

**Procedures**

A demographic data were collected on the participant's age, height, weight, BMI and MUAC of the dominant limb. To measure MUAC, the arm was in a relaxed position next to the body; a regular 1-mm-increment medical measuring tape was used to measure the mid-brachial circumference at the midpoint between the acromion and the olecranon process, at its estimated widest circumference (Mehrotra et al., 2014).

They were asked to wear light clothes to avoid motions restrictions. The movements that were assessed were repeated three times to ensure that the participants were familiar with them. One rater drew cross marks on pre-selected anatomic land marks (olecranon process, lateral epicondyle, radial styloid process) on the testing limb with a pen-marker.

The Participants were placed on a treatment table in supine position. A 5 cm thick towel was placed under his distal humerus, and his forearm was positioned off the edge of the plinth. This position allowed complete elbow extension range of motion.

Asking him performed at maximal (end-range) joint movement at his/her own pace without going too fast, then capture the image.

To record the sagittal planes profile of the elbow joint, images of each subject were obtained by a digital camera (Nikon Coolpix S3200. Nikon corp., JAPAN, Effective pixels 16MB). For maintaining the same distance between the camera and the subjects by tapping the tripod onto the floor at a distance of 1.5 m away from the subjects on a tripod, at a height of 80 cm.

The image of each participant was paste on a computer system using the kinovea program to analyze the ROM. For the inter-rater reliability, the three Raters were view each image only once and repeated the assessment one week later and They were blind to each other's results. The study's intra-rater reliability phase was conducted by a single rater (Rater C) to measure elbow joints ROM three times on the same participants within the same day.

*Elbow Flexion*, the virtual goniometer of the kinovea software was aligned with the arm in full extension according to the procedure outlined by (Sawant, 2004). To form the elbow flexion angle, a line was drawn parallel to the lateral midline of the humerus, pointing at the acromion process (the stationary arm of the goniometer), and another was aligned with the lateral midline of the radius and the styloid process (the goniometer's moveable arm). The angle of the intersection of the two lines was measured by Kinovea, 0.8.15(Copyright © 2006–2011, Joan Charmant & Contrib, [http://www.kinovea.org/](http://www.kinovea.org/)).

*Elbow Extension*, the virtual goniometer was aligned with the arm in full flexion, and then the same procedure for measurement of elbow flexion was followed.
Statistical analysis

We utilized the Kolmogorov-Smirnov test with a 95% confidence interval to analyze the normality of data distribution, which confirmed the normality of these data. After data descriptive analysis, the relative reliability was expressed as the inter-rater correlation coefficients (ICC3,1) and intra-rater correlation coefficients (ICC2,2) with the statistical program SPSS for Windows version 20. For ICCs, 95% confidence intervals (CI) were given. In the current study, the reference values for the ICC were those stated by (Jonson & Gross, 1997) as small reliability until 0.25; low, 0.26-0.49; moderate, 0.50-0.69; high, 0.70-0.89; and very high, above 0.90.

Absolute reliability was expressed as standard error of measurement (SEM), which was calculated using the equation:

\[ \text{SD} \times \sqrt{1-\text{ICC}} \]

where SD is the standard deviation of all measurements, and the ICC value was obtained from the intra-rater and inter-rater analyses. Furthermore, the minimal detectable change (MDC), representing the magnitude of change necessary to exceed the measurement error of two repeated measures at a specified CI, was calculated for the 95% CI as:

\[ \text{MDC}_{95} = \text{SEM} \times 1.96 \times \sqrt{2} \]

where 1.96 is the two-sided tabled z value for the 95% CI and \( \sqrt{2} \) is used to account for the variance of two measurements.

III-Results

One hundred healthy subjects (55 females and 45 males) enrolled in the study, with an average age of (27.6±4.2) years, a height of (168.9±7) cm, a weight of (69.9±8.2) kg, and an MAUC of (24.2±1.6) cm. The dominating side was right in 89%. Tables (1) and (2) demonstrate the mean SD of intra-rater and inter-rater measurements of Kinovea software.

Table (1): Intra-rater measurements of Kinovea software \( \overline{X} \pm SD \)

<table>
<thead>
<tr>
<th>Joint Movement</th>
<th>Intra-rater Measurement (Mean±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st</td>
</tr>
<tr>
<td>Elbow Flexion</td>
<td>41.92±3.09</td>
</tr>
<tr>
<td>Elbow Extension</td>
<td>170.32±3.61</td>
</tr>
</tbody>
</table>

SD: Standard Deviation  
X: Mean

Table (2): Inter-rater measurements of Kinovea software \( \overline{X} \pm SD \)

<table>
<thead>
<tr>
<th>Joint Movement</th>
<th>Inter-rater Measurement (Mean±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rater 1</td>
</tr>
<tr>
<td>Elbow Flexion</td>
<td>41.93±3.22</td>
</tr>
<tr>
<td>Elbow Extension</td>
<td>170.37±4.26</td>
</tr>
</tbody>
</table>

SD: Standard Deviation  
X: Mean

Inter-rater and intra-rater Reliabilities of Elbow ROM:

The inter-rater reliability of elbow joint measures varied from 0.91 (CI: 0.877-0.936) for flexion to 0.923 (ICC: 0.895-0.945) for extension, with the SEM between assessors ranging from 0.9° (flexion) to 1.1° (extension) (Table 3). MDC95 values ranged from 2.5° (flexion) to 3° (extension) (Table 3). Overall, flexion and extension measurements confirmed the supposedly lowest and maximum meaningful reliable properties.
The intra-rater reliability of Kinovea software measurements was confirmed, with ICC values for elbow measurements ranging from 0.965 (CI: 0.952-0.975) for flexion to 0.963 (CI: 0.949-0.974) for extension, as shown in Table 3. The SEM was small for all elbow ROM directions (table 3), ranging from 0.6° (flexion) to 2° (extension). The MDC95 values were between 1.7° (flexion) and 2° (extension) (table 3). Overall, measurements taken in flexion and extension revealed the potentially lowest and greatest significant reliability properties.

### Table (3): Inter-rater and Intra-rater reliabilities of Elbow ROM

<table>
<thead>
<tr>
<th>Joint movement</th>
<th>Inter-rater Reliability</th>
<th>Intra-rater Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC (95% CI)</td>
<td>SEM°</td>
</tr>
<tr>
<td>Elbow Flexion</td>
<td>0.91 (.877-936)</td>
<td>0.9</td>
</tr>
<tr>
<td>Elbow Extension</td>
<td>0.923 (.895-945)</td>
<td>1.1</td>
</tr>
</tbody>
</table>

ICC: Intra-class Correlation Coefficient; SEM: Standard Error of Mean; MDC: Minimal Detectable Change

The in-rater reliability of Kinovea software measurements was confirmed, with ICC values for elbow measurements ranging from 0.965 (CI: 0.952-0.975) for flexion to 0.963 (CI: 0.949-0.974) for extension, as shown in table (4). The SEM was small for all elbow ROM directions (table 3), ranging from 0.6° (flexion) to 2° (extension). The MDC95 values were between 1.7° (flexion) and 2° (extension) (table 3). Overall, measurements taken in flexion and extension revealed the potentially lowest and greatest significant reliability properties.

### IV-DISCUSION

The study shows that the video-based method of assessing ROM on plain video recordings of upper limb joint movements using Kinovea software is accurate. In comparison with the available literature on bi-dimensional analysis, the presently described technique is free, open-source, fast to use, and presents with interesting advantages in terms of its applicability, when taking into account that it requires no tripods, lighting systems, extra foci, or electric outlets and it could be freeze at the appropriate time of joint (ROM) (Balsalobre-Fernández et al., 2014; Baude et al., 2015).

According to previous Kinovea literature, this method does not require prior understanding in video capture and analysis to yield extremely accurate and trustworthy results (Balsalobre-Fernández et al., 2014; Valdivia et al., 2013). This is in contrast to the current study's protocol, in which raters attended training sessions to improve the accuracy of their analyses. This is consistent with the findings of (Baude et al., 2015; Elwardany et al., 2015), who suggested training protocol sessions for raters to improve Kinovea's reliability in motion analysis.

Elwardany et al. (2015) explore the intrarater and interrater reliability of the Kinovea computer program in evaluating cervical range of motion in the sagittal plane in healthy participants. Moral-Muoz et al. (2015) also claimed that the Kinovea program is a highly reliable and objective method for testing hamstrings flexibility. However, the reliability of Kinovea software for assessing elbows joint ROM has not before been investigated.

Furthermore, as a practical method to increase the study's reliability, a land mark was used to identify the joint fulcrum (center of motion) in the current investigation. This is consistent with the procedure used by Baude et al. (2015), who utilized face paint to create dots on each subject's face on preselected anatomical facial markers. Furthermore, Richardson et al. (2014) put athletic tape markers on participants' shoes to help digitize foot striking angle in novice runners, and (Damsted, Larsen, & Nielsen, 2015) employed a hip marker to quantify knee and hip angles during foot strike during running. Furthermore, (Moral-Muoz et al., 2015) marked the subjects' skin in order to evaluate hip and knee joint angles as hamstring flexibility measures. Also, (Elwardany et al., 2015) employed 1.5 cm circular markers that were pasted to cervical and neck bone landmarks.

In the current study three raters participated in order to test the inter-rater reliability of the kinovea software, come in agreement with (Schaun, Ribeiro, Vaz, & Del Vecchio, 2013) used three raters to test the reliability of kinovea in assessment the lower limb movement in a volley ball female player and (Baude et al., 2015) used three raters tested the inter rater reliability of kinovea software in facial muscle motion analysis. Elwardany et al., 2015 also three assessors (A, B and C) evaluated the cervical (ROM) measurement.

Cunha et al. (2020) showed that kinovea is a valid and reliable tool for assessing joint angles during functional activity with high correlations for repeated measures and comparison to gold standard angle measurement instruments.

The test-retest comparisons were used to establish the intra-rater reliability of the Kinovea program. The test-retest ICCs for all observers ranged from 0.93 to 0.99, putting them at the high end of the excellent range for agreement. The inter-tester reliability coefficients (ICCs) for elbow joint measurements varied from 0.91 for flexion to 0.923 for extension.

Reda et al., (2021) tested the reliability of kinovea program for assessing shoulder ROM in hemiplegic patient, while in the current study we tested the reliability of kinovea program on non-disabled participants.
In a study conducted by (Armstrong et al., 1998), 5 testers examined intra-tester, inter-tester, and inter-device reliability of universal standard goniometers, a computerized goniometer, and a mechanical rotation measurement device. Meaningful changes in intra-tester range of motion measurements performed with a universal goniometer occur with 95% confidence if they are greater than 6 degrees for flexion and 7 degrees for extension. This is in contrast to our findings, where the MDC95 values ranged between 1.7° (flexion) and 2° (extension).

Furthermore, a meaningful difference in inter-observer range of motion measures was expected if the difference exceeded 4 degrees for flexion and 6 degrees for extension with the computerized goniometer, compared to 10 degrees and 10 degrees, respectively, with the universal goniometer. These contradict from our findings, in which the MDC95 values ranged between 2.5° (flexion) and 3° (flexion) (extension).

Hoffmann, Russell, & Cooke, (2007) compared an upper limb’s universal goniometer measure to that obtained by specialized software that analyzed the patients’ still and video pictures. The researchers’ remote measuring method also shown high intra- and inter-rater reliability for elbow goniometry in stroke patients (ICC=0.97). Despite the differences in the analyzed sample, Kinovea has shown comparable reliability to these photographic-based techniques.

In addition, Chapleau et al. (2013) studied inter-tester reliability of the goniometer and radiographic measurements in measuring elbow joint ROM. Their findings agreed with ours, with ICCs ranging from 0.945 to 0.973 for goniometric measurements and from 0.980 to 0.991 for radiographic measurements. In comparison to radiography, Kinovea is a non-invasive, low-cost method for measuring ROM.

Our results confirmed those of (Ferriero et al., 2011), who evaluated the reliability of Smart phones (Dr Goniometer) compared with a small plastic universal goniometer (UG) for elbow ROM measurement, with high intra- and inter-rater correlation (ICC=0.998, 95% confidence interval 0.998-0.999, and ICC=0.998, 95% confidence interval 0.996-0.999, respectively). They stated, on the other hand, that the use of landmarks in daily practices is uncommon, and they chose not to place any label on the limb to be measured.

In addition, our findings are in accordance with Blonna et al., (2012) who found photography-based goniometry was accurate and reliable for measuring elbow ROM. Despite the agreement, there are some methodological variances identified. In their investigation, a nonprofessional photographer photographed patients with elbow contractures in full extension and flexion with a digital camera, and elbow extension and flexion were evaluated using a blinded goniometer on the digital image displayed on the computer screen.

In the aforementioned study, they stated that when obtaining reference measures from images rather than directly from the patient in the clinic, the least experienced observer was better able to approximate them, and clinical goniometry had lower inter-rater reliability than photography-based goniometry. Fish & Wingate, (1985) reported on the use of photography to determine elbow ROM in healthy volunteers with pre-labeled bone landmarks. They claimed that joint angle measuring by photography was more accurate than traditional goniometry.

V-CONCLUSION

The current investigation discovered high reliability as well as a low minimal detectable change. When normal people were measured for elbow joint range of motion using Kinovea software, the inter-rater reliability was higher than the intra-rater reliability.

Limitation:
Marking the landmarks along with the standardized photography procedure is time consuming and requires a place that may not be available in every clinic.

Recommendation:
Further studies should test the reliability of kinovea program on patients with elbow disorders.

Abbreviations:
- ROM: Range of motion
- AROM: Active range of motion
- 3D: three dimension
- 4D: four dimension
- BMI: Body Mass Index
- MUAC: Mid-Upper Arm Circumference
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Conflict of interest:
The author(s) have no conflict of interest to declare.

Ethical approval:
This study was approved by the Research Ethical Committee, Faculty of physical therapy, Cairo university (No:P.T.REC/012/00222). Date: 8/9/2021

Authors contribution:
R. M. A conceived and designed the study, conducted research, provided research materials, and wrote final draft of article, K.A.H wrote initial draft of article, and organized data, analyzed, collected and interpreted data. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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