Reliability of a smartphone-based goniometer for knee joint goniometry

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The aim of this study was to assess the reliability of a smartphone-based application developed for photographic-based goniometry, DrGoniometer (DrG), by comparing its measurement of the knee joint angle with that made by a universal goniometer (UG). Joint goniometry is a common mode of clinical assessment used in many disciplines, in particular in rehabilitation. One validated method is photographic-based goniometry, but the procedure is usually complex: the image has to be downloaded from the camera to a computer and then edited using dedicated software. This disadvantage may be overcome by the new generation of mobile phones (smartphones) that have computer-like functionality and an integrated digital camera. This validation study was carried out under two different controlled conditions: (i) with the participant to measure in a fixed position and (ii) with a battery of pictures to assess. In the first part, four raters performed repeated measurements with DrG and UG at different knee joint angles. Then, 10 other raters measured the knee at different flexion angles ranging 20–145° on a battery of 35 pictures taken in a clinical setting. The results showed that inter-rater and intra-rater correlations were always more than 0.958. Agreement with the UG showed a width of 18.2° [95% limits of agreement (LoA) = −7.5/+10.7°] and 14.1° (LoA = −6.6/+7.5°). In conclusion, DrG seems to be a reliable method for measuring knee joint angle. This mHealth application can be an alternative/additional method of goniometry, easier to use than other photographic-based goniometric assessments. Further studies are required to assess its reliability for the measurement of other joints.

Das Ziel der vorliegenden Studie war die Beurteilung der Reliabilität einer Smartphone-basierten Anwendung, die für die foto-basierte Goniometrie, DrGoniometer (DrG), entwickelt wurde, indem ihre Messung des Kniegelenkswinkels mit der eines Universal-Goniometers (UG) verglichen wird. Die Goniometrie ist eine gängige klinische Messtechnik, die in vielen Disziplinen angewandt wird, insbesondere in der Rehabilitation. Eine validierte Methode ist die foto-basierte Goniometrie, wobei das Verfahren i.d.R. komplexer Natur ist: Das Bild muss von der Kamera auf einen Computer heruntergeladen und dann mit einer speziellen Software bearbeitet werden. Bei der neuen Generation der Mobiltelefone (Smartphones) mit erhöhter Computerfunktionalität und einer integrierten Digitalkamera ist dies kaum noch ein Nachteil. Diese Validierungsstudie wurde unter zwei verschiedenen Kontrollbedingungen durchgeführt: (i) mit dem Teilnehmer zwecks Messung in einer festen Position und (ii) mit einer Fülle von Fotos, die es zu bewerten gilt. Im ersten Teil nahmen vier Bewerter wiederholte Messungen mit DrG und UG bei unterschiedlichen Kniegelenkswinkeln vor. Anschließend maßen zehn andere Bewerter das Knie bei unterschiedlichen Beugungswinkeln von 20 bis 145° mit einer Fülle von 35 im klinischen Umfeld gemachten Fotos. Die Ergebnisse zeigten, dass die Inter-Rater- und Intra-Rater-Übereinstimmungen stets bei über 0.958 lagen. Die Übereinstimmung mit dem UG wies eine Breite von 18.2° [95% Limit of agreement (LoA) = −7.5/+10.7°] und 14.1° (LoA = −6.6/+7.5°) auf. DrG scheint schlussfolgernd eine zuverlässige Methode der Messung des Kniegelenkswinkels zu sein. Diese mHealth-Applikation kann eine alternative/zusätzliche Methode der Goniometrie sein, die leichter in der Anwendung ist als andere foto-basierte goniometrische Beurteilungen. Zur Beurteilung der Reliabilität der Applikation für die Messung anderer Gelenke ist die Durchführung weiterer Studien erforderlich.

El objetivo de este estudio fue evaluar la fiabilidad de una aplicación de un teléfono inteligente que ha sido diseñada para su uso en un goniómetro con fotografía, DrGoniometer (DrG), mediante la comparación entre las medidas del ángulo de la articulación de la rodilla tomadas por DrG y las medidas tomadas por un goniómetro universal (GU). La goniometría articular es un método muy común de evaluación clínica que se utiliza en numerosas disciplinas y, en particular, en la rehabilitación. Uno de los métodos validados es la goniometría mediante fotografía, pero a menudo se trata de un proceso complicado: la imagen debe descargarse de la cámara a un ordenador y, a continuación, debe ser editada utilizando un programa informático específico. Esta desventaja puede ser eliminada gracias a la nueva generación de teléfonos móviles (teléfonos inteligentes) que poseen una funcionalidad similar a la de un ordenador y una cámara digital integrada. Este estudio de validación se llevó a cabo de acuerdo con dos condiciones controladas distintas: (i) con las mediciones de los participantes en una posición fija y (ii) con la evaluación de una serie de fotografías. En el primer caso, cuatro evaluadores realizaron un número de mediciones repetidas con DrG y GU a distintos ángulos de la articulación de la rodilla. A continuación, otros diez

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evaluadores llevaron a cabo mediciones de la rodilla a distintos ángulos de flexión, entre los 20° y los 145°, basándose en 35 fotografías tomadas en un entorno clínico. Los resultados mostraron que las correlaciones intra e interclasificadores siempre eran superiores al 0.958. La concordancia con GU presentó una amplitud de 18.2° [límites de concordancia (LC) del 95% = − 7.5/ + 10.7°] y 14.1° (LC = − 6.6/ + 7.5°). En conclusión, DrG parece ser un método fiable para medir el ángulo de la articulación de la rodilla. La aplicación mHealth puede representar un método alternativo/adicional de goniometría, más fácil de usar que otras evaluaciones goniométricas basadas en fotografía. Es preciso llevar a cabo futuras investigaciones con el fin de analizar la fiabilidad de esta aplicación en la medición de otras articulaciones.

Cette étude avait pour objet d'évaluer la fiabilité d'une application pour smartphone développée pour la goniométrie photographique, le DrGoniometer (DRG), en comparant sa mesure de l'angle de l'articulation du genou avec celle obtenue avec un goniomètre universel (GU). La goniométrie des articulations est un mode courant d'évaluation clinique utilisé dans de nombreuses disciplines, en particulier la rééducation. La radiogoniométrie photographique est une méthode validée, mais la procédure est généralement complexe: l'image doit être téléchargée depuis l'appareil photo vers un ordinateur, pour y être traitée par un logiciel spécial. Cet inconvénient peut être surmonté par la nouvelle génération de téléphones portables (les smartphones) qui disposent de fonctionnalités de type ordinateur et d'un appareil-photo numérique intégré. Cette étude de validation a été effectuée sous deux conditions contrôlées différentes: (i) avec le participant pour effectuer la mesure dans une position fixe et (ii) avec une série de photos à évaluer. Dans la première partie, quatre évaluateurs ont effectué des mesures répétées avec DrG et GU à des différents angles de l'articulation du genou. Puis, 10 autres évaluateurs ont mesuré le genou à des angles de flexion différents allant de 20–145° sur une série de 35 photos prises dans un contexte clinique. Les résultats ont montré que les corrélations inter et intra-évaluateurs étaient toujours supérieures à 0.958. L'accord avec le GU a montré une largeur de 18.2° [limite d'accord 95 % (LdA) = − 7.5/ + 10.7°] et 14.1° (LdA = − 6.6/ + 7.5°). En conclusion, le DrG semble constituer une méthode fiable pour mesurer l'angle de l'articulation du genou. Cette application mHealth peut être une méthode de radiogoniométrie alternative/ complémentaire, plus facile à utiliser que les autres évaluations goniométriques photographiques. Des études complémentaires seront nécessaires pour évaluer sa fiabilité pour la mesure des autres articulations. *International Journal of Rehabilitation Research* 36:146–151 © 2013 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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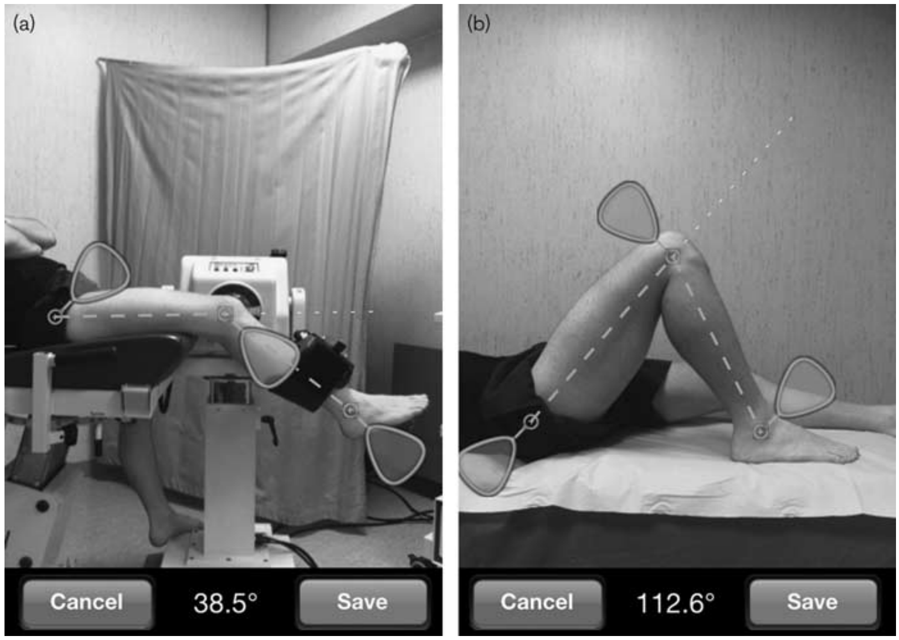
Introduction

Joint goniometry is a common mode of clinical assessment used in many disciplines, including rehabilitation (Fish and Wingate, 1985; Cleffken *et al.*, 2007), for clinical decision making, outcome analysis, and compensation interests (Ellis *et al.*, 1997; Russell *et al.*, 2003; Lenssen *et al.*, 2007). In the clinical setting, joint angles are normally measured by visual estimation or, for a more reliable measurement, by a goniometer (Watkins *et al.*, 1991; Bennett *et al.*, 2009; Colaris *et al.*, 2010). A variety of instruments exist to measure joint goniometry (Goodwin *et al.*, 1992). Some goniometers are mechanical, such as the standard universal goniometer (UG); others are digital, for example electrogoniometers or digital inclinometers. Among the different goniometers available, the most widely used in the clinical setting is the UG (Russell *et al.*, 2003; Huang *et al.*, 2012).

Photographic joint angle measurement is another method of goniometric assessment that uses an image to show the degree of joint motion limitation (Fish and Wingate, 1985; Georgeu *et al.*, 2002; Russell *et al.*, 2003; Dunlevy *et al.*, 2005; Bennett *et al.*, 2009; Smith *et al.*, 2009; Verhaegen *et al.*, 2010; Naylor *et al.*, 2011; Blonna *et al.*, 2012). This method has several advantages with respect to UG: it produces a permanent and printable report; investigators can take the measurements on the photograph at any time; as it does not require any contact with the skin, it can find application in intra-assessor settings; it may be used in telemedicine to assess patients at home; and it can help to improve patient compliance to treatment by showing patients sequential pictures demonstrating the change (Russell *et al.*, 2003; Bennett *et al.*, 2009; Verhaegen *et al.*, 2010; Naylor *et al.*, 2011; Blonna *et al.*, 2012). The measurement procedure consists of the following: (i) taking a picture of the joint correctly according to a standard procedure and (ii) placing a virtual goniometer on the picture using a dedicated software. The procedure has been shown to be valid but complex in that the measurement requires the transfer of data from one instrument (camera) to another (personal computer).

Fig. 1



Angular measurements using DrGoniometer with the participant in a fixed position (a) and in one of the pictures of the set (b).

Today, this disadvantage may be overcome by the new generation of mobile phones (smartphones) that are all-in-one instruments, having computer-like functionality and an integrated digital camera. The use of smartphones in healthcare is increasing thanks to a large number of downloadable applications (Terry, 2010). Recently, an iPhone-based (Apple Inc., Cupertino, California, USA) application that functions as a virtual goniometer has been developed, called DrGoniometer (DrG) (CDM s.r.l., Milano, Italy). Its aim is to provide a simpler, faster measurement of limb joint mobility with all the advantages of photographic joint angle goniometry (Ferriero *et al.*, 2011). In the DrG application, the virtual goniometer is placed dragging on the photographed body landmarks some cursors by the fingers, directly on the mobile phone's small screen.

The aim of this study was to assess the intra-rater and inter-rater reliability of DrG for joint angle measurement at the knee, comparing its performance with that of the commonly used UG under two different controlled conditions: (i) with the participant to measure in a fixed position (part 1) and (ii) with a set of pictures (part 2) available from Apple iTunes store.

Methods

DrGoniometer application

DrG is an iPhone-based application for joint goniometry. Measurement with the DrG application is obtained by positioning a virtual goniometer, visible on the smartphone screen, on a photograph obtained using the smartphone camera (Fig. 1).

The clinician takes a photo of the limb, saves it, measures the joint angle, and observes the value. Pictures must be taken with the camera positioned parallel to the body segment plane. An inclinometer guides the rater to find the perpendicular line to the ground, changing color when the mobile camera is in the correct position. To reduce perspective error, it is recommended to maintain the optical axis perpendicular to the (average) postural angle plane and to minimize the (average) distance between the optical axis and the body segment of interest (Paul and Douwes, 1993). When the photo has been taken and saved, three small red cursors connected by two dotted lines appear on the screen (i.e. the virtual goniometer). The central red cursor moves the fulcrum and the two lateral ones move the goniometer arms (Fig. 1). The cursors can be dragged across the screen to place the virtual goniometer on the body landmarks of the photographed joint, finely adjusting them until the goniometer is positioned correctly. Pictures judged subjectively wrong by the clinician because of a perspective error can be deleted. The measurements and pictures judged correct can be stored in the smartphone database for further analysis as required.

To assess ROM by photographic-based goniometry, it is necessary to take two pictures (e.g. in flexed and extended positions) and to assess passive ROM of large joints, two individuals are required: one to take the picture and one to execute the passive ROM.

Additional features of the application include the following: (i) notes can be added to each picture; (ii) the rater can be blinded to the angle value by deactivating the 'show the measure' option in the mobile settings section; and (iii) all data can be uploaded easily to a computer for printing, storage, or to restore data if the mobile stops working or is lost.

Procedure

In this study, a 3G iPhone model with 320×480 pixel screen resolution was used, set in flight mode to avoid interference with the electrical medical equipment. Each picture was judged adequate – that is, without evident perspective error – by the raters. The rater positioned the virtual goniometer on the screen placing the three cursors as follows: on the center of the knee (in line with the patella, midway between the anterior and the posterior surfaces), on the hip along the estimated line of the femur, and on the middle of the lateral malleolus (Marks and Karkouti, 1996; Naylor *et al.*, 2011).

Raters were blinded to all joint angles, to the other raters' assessments, and to their own previous results. Participants provided written consent before taking part in the study and their privacy was respected. The study was approved by the local ethics committee.

Participant in fixed position

Four raters – two experts (physiotherapists) and two novices (first-year physiotherapy students) – were recruited to determine whether skill and experience is an important component for DrG reliability. A healthy individual was seated on an isokinetic device with the right leg fixed (Fig. 1). By moving the arm of the isokinetic device, the right knee was placed at different angles and measured by a UG.

Each of the four raters took 25 pictures of the leg at 20° knee flexion and another 25 pictures at 80° (to calculate the DrG response stability). The same raters then took 10 pictures at each of the following angles: 35, 45, and 60°; these, together with the first 10 pictures taken at 20 and 80°, were used to assess the intra-rater and inter-rater correlation and agreement. After each picture, the camera was placed flat on a table to take the measurement by positioning the virtual goniometer. In this way, only the reliability of DrG was estimated, with all other confounding factors held as constant as possible.

Set of pictures

Thirty-five pictures of knees measured by the UG at different angles (ranging between 20 and 145° of flexion) in a sample of 10 healthy individuals were assessed with DrG by 10 raters. Measurements were repeated after 1 week to assess the intra-rater and inter-rater correlation and agreement with the UG.

Statistical analysis

Statistical analysis was carried out using the SPSS software (SPSS Inc., Chicago, Illinois, USA). Response stability was calculated in terms of mean ± SD (Portney and Watkins, 2000). The intraclass correlation coefficient (3.1) was calculated to assess intra-rater correlation (test–retest reliability coefficient) and inter-rater correlation of both DrG and UG (Portney and Watkins, 2000). Intraclass correlation coefficient values higher than 0.90 are considered adequate to ensure reasonable validity (Portney and Watkins, 2000).

Once the normal distribution of data was confirmed, the limits of agreement (LoA) (mean difference ± SD of the differences × 1.96) were used to determine the agreement between the two instruments (Bland and Altman, 1986; Portney and Watkins, 2000). The LoA define the range within which 95% of the differences between measurements by the two methods are predicted to lie.

Results

Participant in fixed position

Mean and SD values were 22.6 ± 3.3° at 20° and 76.9 ± 2.0° at 80°. Intra-rater and inter-rater correlation was, respectively, 0.958 [95% confidence interval (CI), 0.936–0.974] and 0.994 (95% CI, 0.989–0.997).

Agreement analysis showed a width of 95% LoA equal to 18.2° (LoA = −7.5/ + 10.7°). Figure 2 presents Bland–Altman plots of the differences in measurement, showing that most of the outliers consisted of novice raters' measurements.

Set of pictures

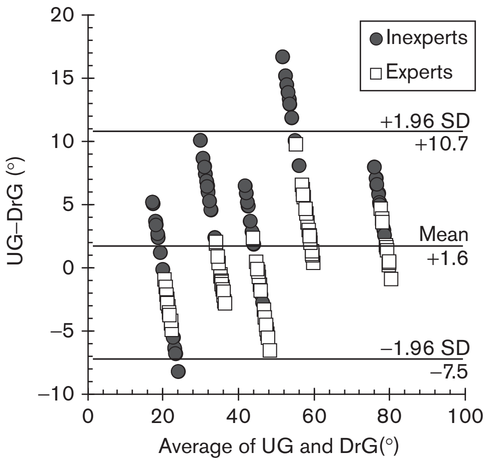
As novices were judged less reliable, only expert clinicians were considered for the second part of the study, because the aim was to assess the reliability of the entire procedure. Ten raters (five physiotherapists and five physicians, working in five different academic and clinical facilities) participated in this part of the study.

Intra-rater and inter-rater correlation was, respectively, 0.996 (95% CI, 0.995–0.997) and 0.994 (95% CI, 0.991–0.996). Figure 3 shows the agreement between the two instruments. In particular, the width of 95% LoA between DrG and UG was 14.1° (LoA = −6.6/ + 7.5°). Figure 4 shows plots of the difference in measurements.

Discussion

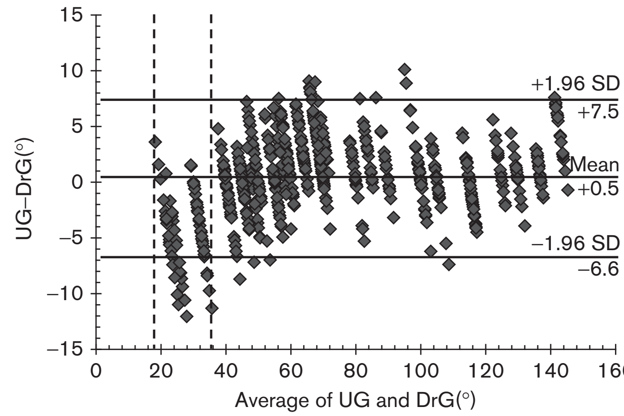
A reproducible and accurate measurement method is essential for the assessment of joint mobility before, during, and after any treatment aimed at improving joint mobility (Cleffken *et al.*, 2007).

Fig. 2



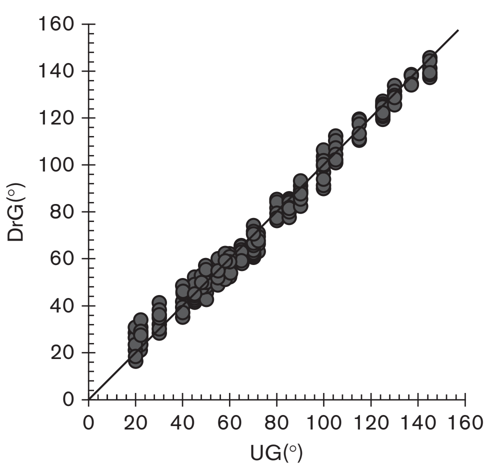
Bland–Altman plots with 95% limits of agreement (upper and lower lines) between DrGoniometer (DrG) and the universal goniometer (UG) with the participant in a fixed position. Only measurements taken by novice raters (dots) fall outside the limits of agreement.

Fig. 4



Bland–Altman plots with 95% limits of agreement (upper and lower lines) between DrGoniometer (DrG) and the universal goniometer (UG) in the set of picture measurements. A large number of measurements ranging between 20 and 35 flexion degrees (UG) fall outside the limits of agreement.

Fig. 3



Scatterplot of the DrGoniometer (DrG) and universal goniometer (UG) measurements in the set of pictures. The line of identity arising from the origin shows that the two methods agree.

Photographic-based methods using a digital camera and a computer with image analysis software have been validated in the knee joint (Russell *et al.*, 2003; Dunlevy *et al.*, 2005; Bennett *et al.*, 2009, Verhaegen *et al.*, 2010; Naylor *et al.*, 2011). These methods are subject to the limitations of standard digital-photographic goniometric measurement (Hambly *et al.*, 2012). Like other instruments, DrG is subjected to error, especially if the correct procedures are not strictly observed. When using the DrG, there are two main potential sources of error: (i) while taking the picture and (ii) while positioning the virtual goniometer on the mobile screen. The first part of the study assessed the response stability of the DrG measurements, showing that the error of the measure because of the photographic technique could be considered acceptable. We showed the photographic procedure to be reliable, with adequate intra-rater and inter-rater correlation. Nevertheless, expert raters had better correlation indices than novice raters, suggesting caution when DrG is operated by inexperienced persons. A similar correlation was also found in the second part of the study. Results showed a satisfactory level of agreement between DrG and UG. Only in the joint angle measurements ranging between 20 and 35° (measured by UG) was agreement really lacking, with DrG tending to overestimate UG measurements. These data are in agreement with previous reports stating that both UG and photographic joint angle goniometry are more reliable with greater degree of knee flexion (Rothstein *et al.*, 1983; Brosseau *et al.*, 2001; Verhaegen *et al.*, 2010; Naylor *et al.*, 2011). The lower reliability for extension angles has been attributed to the difficulty in identifying the proper placement of the goniometer fulcrum over the center of rotation of the minimally flexed knee (Naylor *et al.*, 2011). However, as the reliability of UG throughout all the ROM of knee flexion has never been assessed, it is impossible to conclude that this loss of agreement is exclusively because of a DrG error of the measure.

An a posteriori agreement analysis that excluded measurements ranging from 20 to 35° showed that the width of LoA between DrG and UG was reduced to 12.1° (LoA = 4.9/ + 7.2°). This result showed that when the lower degrees of knee flexion are excluded, the agreement between the two methods is good.

The results of this study cannot be generalized. A limitation of our study is that the participants were healthy individuals, and consequently, this made it easier to place the virtual goniometer on their pictures than would be the case, for instance, in individuals with obesity, orthosis, or limb deformations. Another limitation is that we did not assess the entire measurement procedure as in a clinical condition, because we wished to standardize the two different moments of the measurement to reduce bias (fixing the participant on a chair and using a common set of pictures).

Conclusion

In this study, it was found that DrG is a reliable method for knee joint angle measurement. UG is the instrument of choice to assess ROM in clinical settings because it is an inexpensive device with proven reliability and validity that can be easily used in clinical practice. DrG can provide an alternative or an additional method of measurement, useful for different needs in many different clinical settings (e.g. follow-up after treatment, assessment of intraoperative joint mobility, for medicolegal purposes). Moreover, the images of the measurement can be included in the patient's medical record as evidence of the quality of care provided. With respect to other photographic modes of joint angle measurement, DrG has the added advantage that it is based on a handheld device (smartphone) easily available for use. Further studies are required to assess the validity of this simple application in measuring ROM of other joints and in other clinical conditions, and to verify its feasibility as a method for use interchangeably with the UG.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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