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ORIGINAL STUDY

Are clinical photographs appropriate to determine the maximal range of motion of the knee?

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Goniometry is a commonly used method for the clinical assessment of range of motion (ROM) of the knee. A digital photograph of the knee in maximal flexion and extension could provide a more objective way to assess the ROM. The aim of our study was to investigate the reliability of the use of digital photographs as a method for measuring the ROM of the knee.

Four observers examined 49 patients. Digital photographs of the knee in maximal flexion and extension were compared with standard clinical goniometric measurements in the same position.

We observed higher intra-observer reliability for the digital method in flexion ($p < 0.0001$) and extension ($p = 0.005$) compared to goniometry. The extension results were numerically lower when using goniometry compared to the digital method ($p < 0.001$).

For both methods, the intra-observer reliability for extension was lower compared to flexion. The intra-observer standard error of measurement (SEM) of the digital method was smaller than the goniometric SEM ; the digital method thus appeared more reliable.

Measuring maximal flexion and extension on digital photographs is more reliable for both extension and flexion compared to standard goniometric measurements.

Keywords : knee ; range of motion ; goniometry ; digital photography.

INTRODUCTION

The consistency of clinical measurement of the range of motion of the knee joint has always been questioned (*13*). However, the reliability of goniometric measurement is proven (*4,7,10,11,12,13*), nevertheless the inter-observer reliability of goniometric measurement is consistently lower than the intra-observer reliability (*2,3*). Digital photography is being used increasingly in clinical practice (*15*). It could be viewed as an easy–to-use system for measurement of ROM, considering that digital photographs are re-accessible and repeatedly

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useable. As the two-arm goniometer is the most widely used device, we preferred to use this standard plastic goniometer as comparison (*4,9-12*) (fig 1). The aim of our study was the investigation of the inter- and intra-observer reliability of a digital photographic measurement of knee joint range of motion. If a high level of reliability should be found, measurement of ROM on digital photograph could provide a powerful tool in daily clinical use.

MATERIALS AND METHODS

The trial was divided into two parts. Part I consisted of a measuring session with digital images, taken by a nurse, and goniometric measurements taken by the four observers at the consultation of the orthopaedic department of our institution. In part II each observer measured the digital images taken by the nurse using angle measurement software. The setup of our study does not include radiographs, the literature's gold standard (*2*). However the set-up of this study was not the comparison of the observed measurements against the true measurements, but to determine whether measurement of the maximal range of motion of the knee is reproducible with a digital photograph. As such we preferred to use as comparison a frequently used and frequently studied method, i.e. goniometry (*8*). Forty nine patients volunteered and gave written consent to participate in the study. These patients with a varying medical history (ranging from no significant antecedents to major bone surgery) were all consulting the orthopaedic knee consultation. If the patient had a knee pathology, the measurement was always made on the leg the patient suggested as less painful. Goniometers of 360° constructed of flexible transparent plastic material, were used for testing (20.5 cm arms with 1°markings) (fig 1). Each patient was positioned supine on the examination table with the lower extremity undressed. As starting position the leg was positioned in maximal extension with the heel supported by a towel, the thigh and the back well supported. Maximal extension of the knee was measured (photographic or goniometric) (fig 2). For the assessment of the flexed knee the participant was asked to flex the knee maximally (fig 3). Each observer performed four goniometric measurements. The observers were two orthopaedic surgeons with 20 years and 16 years experience respectively, one senior resident, and one medical student. The observers followed specific written directions defining the knee's position and goniometer alignment according to Norkin and White (*11*) (fig 3). The goniometers were blinded on one

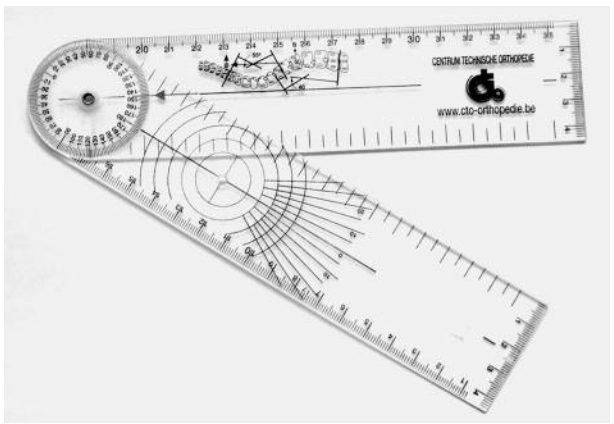

Fig. 1. — Goniometers of 360 degrees constructed of clear flexible plastic, were used for testing (20.5-cm arms with 1°markings).

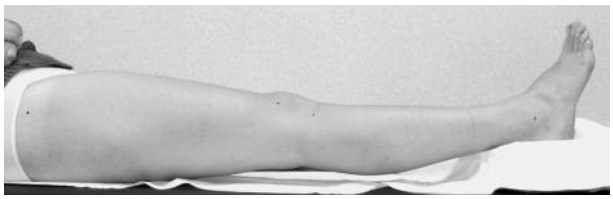

Fig. 2. — Photographic setup with the knee in maximal extension.

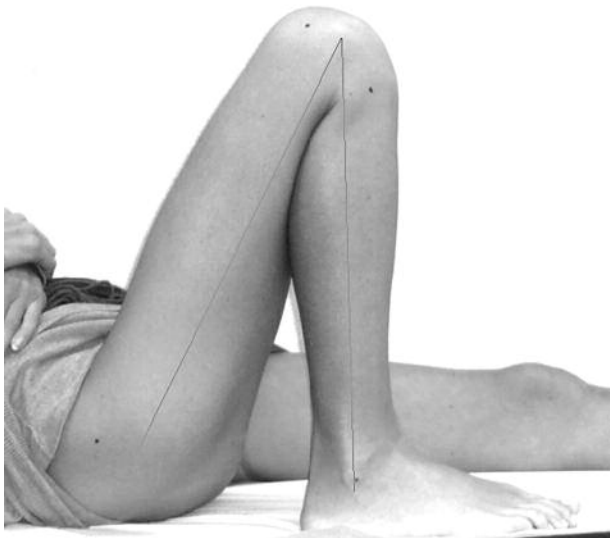

Fig. 3. — An angle measurement software program was used (Vectorworks 2008) on an Apple Macbook G4, here shown with a measurement setup with the knee in maximal flexion.

side so that the observers could not estimate their measurements, to avoid learning effects. After each measurement, the blinded goniometer was handed over to an independent registrator, who read the measured degrees and noted them without communicating with the observers. All assessments were made in a one-day session. Photographs of the lateral side of the lower extremity were taken, using a Canon Ixus 40 camera placed on a tripod. The photographs were taken focused on the lateral condyle of the knee, perpendicularly, with a distance of 130 centimetres from the camera focus to the subject. In the second part, each of the four observers measured one photograph in flexion and one in extension. The photographs were blinded and randomized, to prevent the observers from visualising or estimating their results. They measured both photographs twice, in a separate measuring session with the program Vectorworks 2008- on an Apple Macbook G4. The computer screen was partially covered to prevent the observers from visualising or estimating their results. The measured result was controlled by an independent registrator and noted without communicating with the observers. This measuring session was conducted individually, during approximately one hour. The results of the first and second half of the included subjects were compared, to investigate a lower reliability towards the end of the experiment due to a decrease in concentration. The order of measurements was counterbalanced to avoid order bias. The practicality of a digital photograph was assessed, and the influence of education and experience of an observer on a goniometric measurement was evaluated (*9*). The intra- and interobserver reliability for each ROM measurement was assessed simultaneously on 49 patients using the 8 repeated measures (4 observers, 2 replications per observer). In the calculations, observers were considered as a random sample. Two indices of reliability are reported, i.e. the intraclass correlation coefficient (ICC) and the standard error of measurement (SEM) (*5*). A practical description of the approach can be found in Hayen *et al* (*6*). Both measures are related ; however, they define distinctly different properties. The magnitude of the ICC defines a measure's ability to discriminate among subjects, and the SEM quantifies error in the same units as the original measurement. Most of the statistical methodology addressing reliability presented in the physical therapy literature focuses on the ICC (*13*). Reliability was determined for the photographic and goniometer measurements and for flexion and extension measurements separately. All analyses were performed with the statistical software SAS (version 9.1) using the procedure PROC MIXED to obtain appropriate variance components from a mixed model. Intra-observer agreement was also quantified per observer. A likelihood-ratio test (LRT, based on maximum likelihood) was used to verify if the intra-observer agreement differed between the observers comparing the original mixed model with a mixed model where the variance due to respectively the two replications and methods was allowed to be observer-specific. Further, a LRT is also used to compare the SEM between both methods and between the first and second half of the included subjects. A Bland-Altman plot (Bland and Altman, 1999) based on the mean over the 8 repeated measures is used to visualize the inter-method agreement (*1*). Paired Wilcoxon tests have been used to test for systematic differences in measurement between the two methods.

RESULTS

The maximal range of motion of the knee varied from 53° to 165°. The age varied from 17 to 84 years. The standard error of measurement (SEM) for flexion ($p < 0.0001$) and extension ($p = 0.005$) measured with the digital method was consistently lower than for the goniometric measurement (table I). The intra- and inter-observer reliability of both methods, expressed as intra class correlation coefficient or inter class correlation coefficient (ICC) was consistently lower for extension than for flexion (table I). We observed a systematic difference between digital imaging extension and goniometric extension measurements ; the goniometric assessments showed less hyperextension or extension deficit measurements. We compared the SEM from the first half and the second half of the digital measurements, this showed no significant difference for flexion from 1.54 to 1.62 ($p = 0.63$) but a significant difference for extension from 1.28 to 2.12 ($p < 0.0001$).

DISCUSSION

The measurement of ROM of the knee is an important outcome parameter following knee arthroplasty. We propose a measuring method with which we observed a higher reliability than with traditional goniometry (table I) (fig 4 & 5) (*3,4,9*). With a goniometer the observers measured more extension deficit, or less full extension or hyper-

Table I. - Standard error of measurement (SEM) and intra class correlation coefficient (ICC) of goniometric and photographic measurements in flexion and extension. Overall results are shown in the first column, per observer – results can be viewed in the numbered columns. The P-value is shown in the far right column.

	overall	1	2	3	4	P value
gon flex ICC intra	0.955	0.954	0.967	0.966	0.94	
dig flex ICC intra	0.993	0.992	0.994	0.99	0.994	
gon flex ICC inter	0.927					
dig flex ICC inter	0.966					
gon Flex SEM intr	3.28	3.85	2,71	2.83	3.53	< 0.001
dig flex SEM intra	1.58	1.69	1.38	1.78	1.42	0.31
gon ext ICC intra	0.819	0.864	0.777	0.837	0.795	
dig ext ICC intra	0.838	0,807	0.944	0.783	0.827	
gon ext ICC inter	0.642					
dig ext ICC inter	0.651					
gon ext SEM intra	2.13	1.74	2.28	1.99	2.44	0.0888
dig ext SEM intra	1.73	1.49	0.89	1.83	2.37	< 0.001

Gon : goniometry ; SEM : standard error of measurement ; flex : flexion ; ext : extension ; ICC : intra class correlation coefficient.

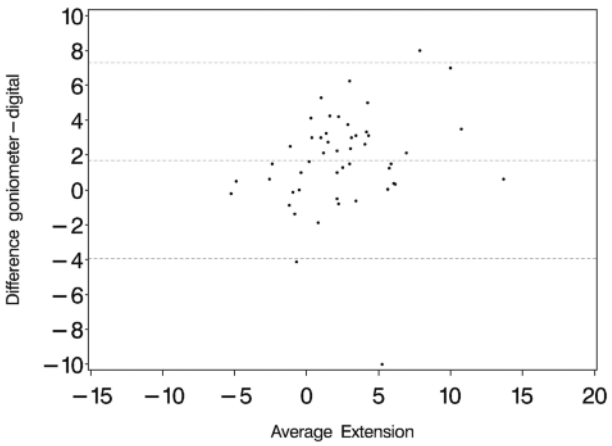

Fig. 4. — Results for extension data. Inter method agreement visualized in Bland-Altman plots, the upper and lower dotted lines indicate the upper and lower limits of agreement. The horizontal axis shows the average extension, the vertical axis shows the difference between goniometric and digital measurements.

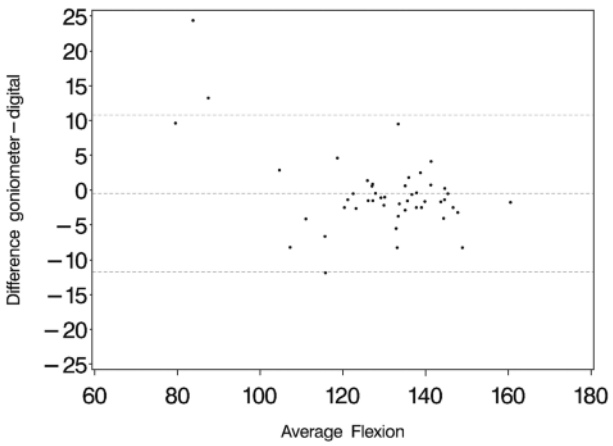

Fig. 5. — Results for flexion data. Inter method agreement visualized in Bland-Altman plots, the upper and lower dotted lines indicate the upper and lower limits of agreement. The horizontal axis shows the average flexion, the vertical axis shows the difference between goniometric and digital measurements.

extension. The low values of the Intraclass Correlation Coefficients (ICC) for all the extension measurements with both methods are explained by the low variability in this group. The ICC improves however with the digital method, thus showing that goniometry is less reliable in ranking for differences. The higher reliability could be valuable for future research applications. As expected, the intra-observer reliability is consistently higher compared to the inter-observer reliability. The major advantage of digital photographs is that one clinician can measure and re-measure the standardized image at each time. This could be useful in a setting where different clinicians measure the ROM.

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