ORIGINAL REPORT

RELIABILITY AND ACCURACY OF JOINT POSITION SENSE MEASUREMENT IN THE LABORATORY AND CLINIC; UTILISING A NEW SYSTEM

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Abstract- Measurement of the joint angles is used to assess the joint position sense (JPS). The aim of this study was to introduce a simple, fast, less expensive and objective method of measurement for JPS. In the current research, the accuracy and reliability of a system, consist of digital photography, nonreflective markers and manual analysis were evaluated. For this purpose, digital photos were taken from 72 angles of the knee positions of twenty four healthy subjects. The angles were measured by using transparent sheets and goniometers as manual method. AutoCAD software was used to evaluate the accuracy of the manual results. The values of Pearson correlation coefficient (*r*), and intraclass correlation coefficients were used to establish reliability. It was noted that the AutoCAD measurements, as a new system, was reliable and precise enough so it could be utilised for evaluating the JPS.
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Key words: Proprioception, digital photography, manual analysis of angle, angle analysis with AutoCAD

INTRODUCTION

Angular measurements have been used by researchers to assess one of the submodality of proprioception, joint position sense (JPS) (1-7). Various methods have been used in order to measure the conscious submodalities of proprioception *i.e.* JPS, kinaesthesia and tension sense (8, 9). For evaluating the JPS in the knee joint, the testing angles and the replicated ones are measured in two positions of sitting and standing and in the forms of active and passive (10-16). In doing so, a variety of techniques have been used, such as electrogoniometry (6, 17), isokinetic dynamometer (18, 19), automatic two dimensional computer analysis from the video images (20, 21), kinematic analysis system (22), visual estimation for remodelling the angles tested (for example in a goniometer, joint model or computer monitor) (23), the combination of videography and goniometry (24), and combined photography and goniometry (25, 26).

Electrogoniometer, which is a strain gauge, can not be used for all the body joints especially for the hip and the ankle joints. The results may be affected by abnormal sensory feedbacks while the axis of goniometer and the joint center of rotation are not coincided (1). Also in cases where the abnormal activity of proprioceptors due to imposed pressure from the holding straps and fixators, is present. The other limiting factor is the lack of inter-rater reliability and the fact that angular changes of less than 10º may provide invalid results (27). Clapper and Wolf proposed that the use of a computerized electrogoniometer, for measuring the angular positions during the weightbearing activities, is less reliable than the universal goniometer and may result in abnormal movements (28).

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The main problems with isokinetic dynamometer are the abnormal sensory feedbacks due to limb fixators and the inability of the evaluation of the JPS in functional or weight bearing position. Weight bearing tests are more functional and involve all of the cutaneous, articular and muscular receptors that act in concert during normal everyday activities (29-31).

In the method of computer analysis of video images, the test and the replicated angles are measured with the aid of a video camera and a two dimensional automatic digitizing system. For ease of visualizing, some markers are attached to the limb to reflect the ordinary or infrared lights (20, 21). Measuring the angles by this method is costly, time-consuming and sophisticated (32).

Kinematic research is the study of motion variables, ignoring the causing source, or in other words, it is the study of linear or angular displacement, velocity and acceleration (33). Kinematic measurements are accomplished by tracking the displacement of specific body segments during motion. Various tools are utilised in this method, such as high speed cameras (34), electromagnetic tracking systems (35), electrogoniometer (36), and accelerometer (37). However, high speed cameras and spherical reflective markers, which are placed on the limb, are used more than other tools. The main difficulty with high speed cameras is that it requires so much time to analyze the video images (9). In addition, employing the visual analogue responses is not adequately consistent and precise (38).

There are limited studies on the evaluation of JPS, using the combination of videography and goniometry or photography and goniometry together with the placement of markers (10, 39-41). Skin markers do not cause any limitation for movement and are easy to use (40, 41). Goniometric evaluation for measuring the angle accompanied by video films are adequately accurate (40) and the photographic and goniometric methods have been used in some research studies (25, 26), but non-digital photos have been expensive and lingering. Herrington used digital photography and goniometry on printed images to evaluate the JPS of the knee (42). Although, angle measurement is easy via these two methods, their precision and reliability are not clear.

The aim of this study was to investigate the following issues: 1) evaluating the accuracy and reliability of angles measurement using a system of digital photography, nonreflective markers and AutoCAD analysis in the laboratory, and 2) reliability evaluation of knee joint angles measurement using a manual analysis and comparing the results with the one obtained by AutoCAD in clinic.

MATERIALS AND METHODS

First section

Following the method of Linden *et al* (43), which was similar to the ones of Scholz (44) and Haggard and Wing (45), in first section of this research a system of digital photography, nonreflective markers and AutoCAD analysis was used and the accuracy and reliability of the angle measurement was evaluated.

Four sets of four square markers, each with the side length of 4 cm, were attached vertically on the corners of an 80 cm by 90 cm board hung on the wall. This was used to calibrate the system. Two 4-cm markers were attached on each arm of 18-cm standard plastic goniometer with units of 1º. Then the goniometer was fixed on the board on two locations of *A* and *B* with its stationary arm stuck on the board (Fig. 1).

In location *A*, the pivot point of the goniometer had a 21.5 cm distance from top edge and 37 cm from the right edge. The stationary arm of the goniometer was horizontal. The pivot point of goniometer at location *B* was 28.5 cm and 60 cm far from top and right edges respectively. The stationary arm was placed at the slope of 40º.

Digital video camera (Canon 8 M pixel, MV750i) was located 2 meters far from the board and elevated 65 cm from the ground, with its lens pointing towards the center of the board. Nine reference angles were chosen from 20º to 180º with 20º increments.

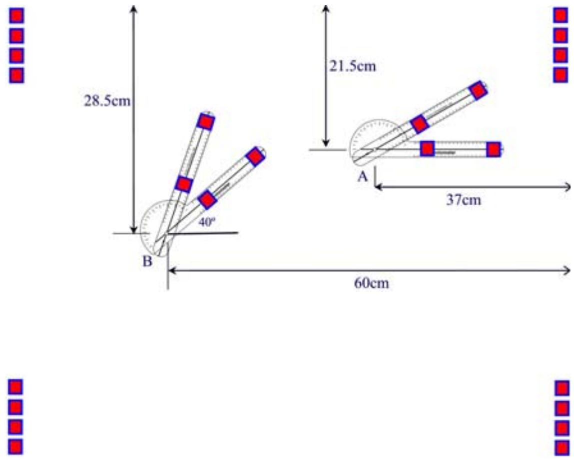

Fig. 1. Two locations of goniometer (*A* and *B*) in the limit of a calibration board.

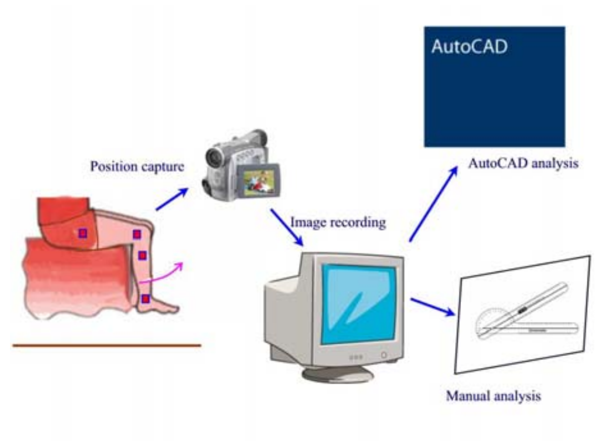

Fig. 2. Schematic diagram of knee angle measurement using a system of digital photography, nonreflective markers and manual or AutoCAD analysis. Digital video camera view is perpendicular to the knee motion plane.

While the stationary arm was attached to the board, the moving arm was moved and three photos were taken from each position. Then the change in each angle was quantified with the help of AutoCAD software.

Second section

In second section, reliability of manual analysis for measuring the angles was assessed with the aid of transparent sheets and nonreflective markers and then the comparison was made between this manual method and the AutoCAD analysis. For this purpose, 24 healthy adults (15 males and 9 females) aged between 20 and 47 (28.12 ± 9.30) from the students and staffs of Rehabilitation Faculty were tested. The only criterion was to make sure that the subject had a complete range of motion of knee joint. Right knees of the participants were tested.

First, each subject was asked to lay down on the couch on his/her back. Four colourful squared markers, each with the side of 4 cm, were attached to each limb at the following locations: the greater trochanter was palpated (for some subjects it was better to locate the limb in adduction position) and the tip of greater trochanter was connected to the middle of lateral joint line by a measuring tape. The markers were respectively placed over the 1/4 proximal to this distance, the neck of fibula and finally over the proximal of lateral malleolus. Then, the subject sat on the treatment couch and bent his/her knee at 90º angle.

The fourth marker was attached over the iliotibial tract adjacent to the superior border of the patella (Fig. 2). Choosing the locations of markers was based on the research studies conducted by Lafortune *et al.* (46), Cappozzo *et al.* (47), Lamoreux (48) and Tully and Stillman (49). To calibrate the system, 28 centimetres standard goniometer, with two 4 cm by 4 cm markers attached on each arm, was stuck on the couch's adjacent wall. Digital video camera was placed at the same distance as stated before for the calibration board, with its view perpendicular to the plane of the knee rotation.

Each subject was asked to extend his/her leg and make three angles arbitrarily from the resting position (90º) to the full extension. Photos were taken, while they kept their leg at each position for few seconds. After completing the procedure for the whole volunteers (taking 72 photos), the angles were measured manually. Transparent sheets were then placed on computer monitor and the corners of four squared markers were transferred by a very fine pen. Subsequently, the center of each squared marker was determined using the intersections of diagonals. Centres of two markers of the leg were joined to the centres of the two markers of the thigh, and then the angles between each two lines were measured by a universal goniometer. The primary investigator (hereafter referred to as PI) did these procedures. Two trained physiotherapists (PT1 and PT2) also measured the angles using a similar method.

After 10 days, joint angles were measured again. In order to exclude the following errors of manual method and to compare the evaluated angles, AutoCAD software was also used: 1) error due to the slippage of the transparent sheet on the monitor, 2) errors in drawing the diagonals of each square, 3) errors in drawing the connector lines between each two squares' centres, and 4) errors due to placing the goniometer on each intersection and error in reading the angles.

In measuring the angles by AutoCAD, the only error was possibly due to placing of the corners of each square on the computer monitor. Squared markers were used because it was believed that there would be more errors (in finding the center of each marker) if circular markers were used.

Data Analysis

All the collected data were analyzed by a statistical program, SPSS (Ver. 11.5). Descriptive statistics was used to calculate the mean and standard deviation. $P < 0.05$ was considered for the statistical significance of the tests.

For *first section* (the accuracy and reliability of the system), intraclass correlation coefficient or ICC was considered to evaluate the reliability of measurement at two goniometers' locations (*A* and *B*) at each reference angle. The accuracy of the system was evaluated at each angle considering the variability of three repeats of photography and AutoCAD analysis by taking into consideration the standard deviation from the mean values. Linear regression was also calculated using these mean values of three repeats for locations *A* and *B* and reference angles.

In *second section*, in order to evaluate the reliability of knee joint angles measurements, (*i.e.* employing the manual analysis and comparing it with AutoCAD analysis in 72 angles of 24 healthy subjects), Pearson product-moment correlation coefficient (r) was considered to find a relation between the results obtained by the PI (1st and 2nd measurements), the PT1, and the PT2 and also to evaluate the effect of the gender.

In fact, intraclass correlation coefficient or ICC [2.1] was a means for estimating the inter-rater reliability of three investigators' manual analysis (combination of two repeats of the PI and also the PT1 and the PT2 results). Whereas ICC [3.1] was utilised for evaluation of the intra-rater reliability of repetitions of the PI's manual analysis, and Paired *t* test for comparing the manual measurements of all investigators. Furthermore, Pearson product-moment correlation coefficient was used to find the relation between manual and AutoCAD analysis and the paired *t* test for comparing these two methods.

RESULTS

In *first section* (the evaluation of accuracy and reliability of the system), ICC for two locations (*A* and *B*) was 1. This showed that the system of digital photography, nonreflective markers and AutoCAD analysis, gave similar results for the two locations of goniometer on the board. Mean and standard deviation values of three repeated measurements for each given angle in two locations of *A* and *B* are shown in Table 1. Figure 3 shows the difference between each reference angle and the mean angles at locations *A* and *B* in terms of reference angle.

In location *A*, there was no error at 140º angle. Maximum error was -0.67º for two angles of 60º and 180º and only at 100º angle the system had calculated the angle +0.25º more.

In location *B*, minimum error (+0.01º) was at 140º angle and the maximum (-0.73º) at 180º (see Table 1 and Figure 3). Standard deviations of three repeats from the mean values or the variability of the system at locations *A* and *B* are shown in Table 1 and Figure 4.

Table 1. Mean and standard deviation values of three repeated measurements for each given angle in two locations of A and B. The values are in degree.

Reference angle	Location *A*	Location *B*
20	19.68 (0.104)	19.64 (0.060)
40	39.52 (0.087)	39.46 (0.073)
60	59.33 (0.201)	59.55 (0.110)
80	79.94 (0.096)	79.70 (0.006)
100	100.25 (0.055)	99.80 (0.140)
120	119.77 (0.147)	119.43 (0.757)
140	140.00 (0.050)	140.01 (0.110)
160	159.72 (0.020)	159.94 (0.155)
180	179.33 (0.171)	179.27 (0.077)

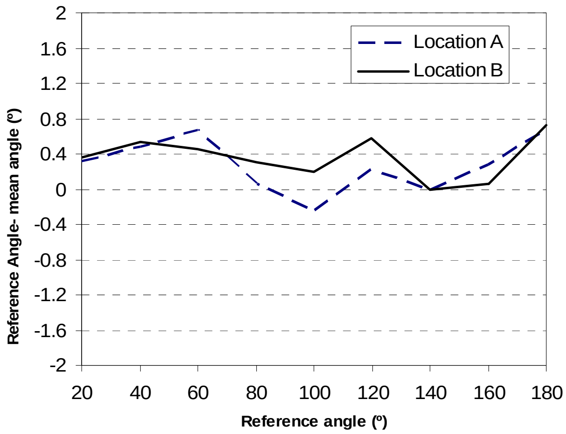

Fig. 3. The difference between the reference angle and the mean angles of locations *A* and *B* in terms of reference angle.

Variability from the mean values at location *A* was from 0.02 to 0.2 at 60º and 160º respectively. However, for location *B* the minimum and maximum deviations were 0.006 for 80º and 0.76 for 120º (See Table 1 and Fig. 4).

The variability from the mean, excluding the 120º in location *B*, was less than 0.2º for all other angles and for both *A* and *B* locations.

The slope of the linear regression equations for the mean values of the three measurements of the system and reference angles at location *A* was 1.000 and at location *B* was 1.001 (P = 0.000). The intercepts for locations *A* and *B* were 0.249 and 0.066 respectively. Hence, they were not statistically different from zero while P was greater than 0.05.

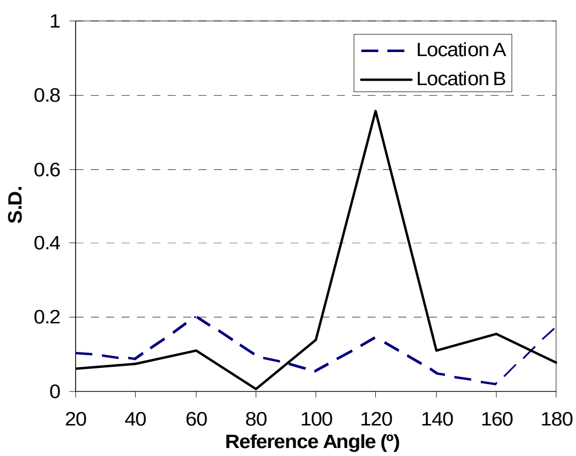

Fig. 4. Standard deviations ($\pm$1) of three repeats from the mean values at locations *A* and *B*, in terms of the reference angle.

The correlation coefficient (r^2) for the linear regression equations was 1 (P = 0.000) at two locations.

In *second section*, the mean and standard deviation of three angles in healthy knee joints of each subject, measured by the PI, the PT1 and the PT2 for section 2 (analyzing the reliability of manual analysis and comparison with AutoCAD analysis) are shown in Table 2. Correlation coefficient, r, for the first and second knee angles of 24 subjects was recorded as follow:

- 0.999 between the first measurement of the PI and the measurement of the PT1 (P = 0.000),
- 1 between the second measurement of the PI and the measurement of the PT1 (P = 0.000),
- 1 between the two measurements of the PI (P = 0.000),
- 1 for all angles obtained by the PI and the PT2 (P = 0.000),
- 1 between measurements of the PT1 and the PT2 (P = 0.000).

Table 2. Mean values and standard deviations, and standard errors in manual analysis of three angles of the 24 healthy knee joints. Results were obtained by 2 repetitions of the Primary Investigator (PI), first physiotherapist (PT1) and second physiotherapist (PT2)

		Mean value	**Standard deviation**	**Standard error**
First angle	PI's first measurement	34.45	13.82	2.82
	PI's second measurement	34.45	13.76	2.80
	PT1	34.54	13.60	2.77
	PT2	34.50	13.72	2.80
Second angle	PI's first measurement	23.25	14.13	2.88
	PI's second measurement	23.22	14.10	2.87
	PT1	23.33	13.96	2.85
	PT2	23.35	10.04	2.86
Third angle	PI's first measurement	26.93	16.79	3.42
	PI's second measurement	26.85	16.84	3.43
	PT1	26.97	16.70	3.41
	PT2	26.93	16.79	3.42

The value of *r* was also 1 for the third angle (P = 0.000) for all measurements. To figure out the effect of the gender, *r*-values were obtained as follow:

- 1 in manual analysis of all males and females' first angle (P = 0.000),
- 1 for second and third angles of all females,
- Minimum 0.999 (P = 0.000) for all males measurements.

ICC [2.1] was 0.999 (P = 0.000) for the mean values of the PI's two measurements and the PT1 and the PT2 (for all three angles). 95% confidence intervals were recorded as (0.9998, 0.9999) degrees for the first and second angles, and (0.9999, 1) degrees for the third angle.

Besides, ICC [3.1] was 0.999 (P = 0.000) for all the three angle values of the PI's two measurements with 10 days interval. 0.95% confidence intervals were recorded as (0.9998, 1) degrees for the first angle, (0.9997, 0.9999) degrees for the second angle, and (0.9998, 1) degrees for the third angle. The mean differences between two repetitions of angle measurements were 0º, 0.02º and 0.08º for the first, second and third angles respectively.

Paired *t* test showed no significant differences between the results obtained by the PI, and the two other physiotherapists and also between the PT1 and the PT2 (P > 0.05). Comparing the manual results (4 measurements of 3 investigators) and AutoCAD results, *r* was 1 for all three angles (P = 0.000).

The mean difference of two methods in three angles was approximately 0.8º. Paired *t* test showed significant differences between manual and AutoCAD results for all three angles (P < 0.05).

DISCUSSION

The purpose of this study was to evaluate the reliability and accuracy of the system of digital photography, nonreflective markers and AutoCAD analysis in the laboratory and to compare it with the manual analysis in the clinic.

The reliability of the system at two goniometer's locations of *A* and *B* was 1. This means that measurement in the limit of calibration board was consistent and did not depend on the location of the goniometer. The reliability of the measuring system in the clinic is important especially while the limb or joint's position in the limit of camera's image is changed.

Table 1 and Figure 3 show that the mean values of the measured angles were a little smaller than the references angles, except at 100º of location *A* which was 0.25º more and at 140º of both locations that similar results were obtained. Maximum differences at locations *A* and *B* were respectively -0.67º (for 60º and 180º) and -0.73 (for 180º).

For both locations and for all angles, the difference range was -0.73º to 0.25º. The main reasons might be the light reflection from the markers and error in finding the exact location of the corners of the markers. However, this difference was less than what obtained by Scholz *at al.* (44) and Linden *at al.* (43) which were based on reflective spherical markers (with motion analysis system).

The variability of the system for angle measurements in location *A* was less than the one of location *B*. Since, the camera distance and all its settings and the light intensity were the same for two locations and for the three repetitions, the following parameters might be the reasons for this difference: the change of the slope of the stationary arm of the goniometer, higher light reflection from the markers and error in finding the corners of the markers.

In motion analysis systems with reflective spherical markers, more variation is seen and more errors are produced (43). This is due to this fact that the markers' images change whenever the markers move and there is an error in finding the markers' centres by the software. However, this error does not exist in present method. Clinically it is not important to have minor errors in mean measured values of the system and reference angles and also in standard deviation values.

The slopes of regression equations were respectively 1 and 1.001 (P = 0.000) for locations *A* and *B*. Values of intercepts were 0.249 and 0.066 in that order (P > 0.05 for both). For both locations, r^2 = 1 (P = 0.000) and this shows that the introduced system is able to predict the actual angle values between 20º and 180º.

Manual analysis has been utilised for the measurement of the joint angle in some research studies. In most of them, angles were measured by using either a goniometer or a hinged protractor placed on television screen, while the desired film is paused. Therefore, several errors may arise during measurements as follow: the measurement tool may slip on TV screen, measurement may not be accurate when TV screen is not flat and a good contact between the measuring tool and the screen is not provided, and it is difficult to find the centres of the markers and also the coordinate center (where the axis of measuring tool is placed). Hence, such methods are not precise and reliable. But the present method, which was also used by Stillman (32), produces fewer errors.

Correlation coefficient in manual analysis of knee joint measurement was between 0.999 to 1 (P = 0.000). Although the colour of markers was not in large contrast with males' skin colour which might produce imprecision, this coefficient was 0.999 (P = 0.000). Intra-rater and inter-rater reliabilities were high between the PI's two measurements and between the PI's measurements and the ones of the PT1 and the PT2 respectively for all three angles measured.

In current method, since the goniometer is in direct contact with the transparent sheet, there would be no error due to slippage on TV screen or computer monitor. However, there might still be some errors due to finding the markers' corners and transferring these on the transparent sheet, plotting lines, and placing the goniometer. The reliability of the manual analysis reported in the present study was higher compared to the one obtained by Wilson *et al.* (50) and Jeng *et al.* who mainly used a combination of videography and goniometry on TV screen (40).

In the study of Herrington, the reliability of repeated measurements was 0.98 by using the combination of three skin markers, digital photography and goniometer on printed images (42). t test showed no significant differences between two repeated measurements. Mean difference between two measurements was 0.5º (± 0.3) with 95% confidence interval of 0-1.1 degrees.

The present study gives better results and has the reliability of 0.999 and means differences of 0º, 0.02º and 0.08º for first, second and third angles, respectively, for the two repetitions of the PI. There were also not significant differences in manual analysis of knee joint angles between two repeated measurements of the PI, between the results of the PI and the other two physiotherapists and also between the ones of the PT1 and the PT2. Besides, AutoCAD that is engineering software and is rarely used in medical studies was used for the measurements of the angles for the first time. This software was also utilised to evaluate the results obtained by manual analysis and to reveal any errors that might be produced due to tracing lines on transparent sheets and also due to the goniometry. To compare these two methods, the mean values of four measurements of three investigators were used. The mean difference was almost 0.8º for all three angles, noting that the manual analysis gave greater angles.

In studies of Foley *et al.* (51), Kadaba *et al.* (52), Smith (53), Karkouti and Marks (1), and Selfe (54), test-retest reliabilities of the measuring angles with manual analysis were also high. Therefore, the manual analysis is adequately precise, considering this fact that there are always some errors in rounding the values read by a goniometer. The goniometer used had a unit of 1 degree and was not as precise as AutoCAD software that was set to use up to two decimal points for the values. The results show that the investigators were willing to round up and if the value of 0.7 or 0.8 is subtracted from all manual values, then the results are almost similar in two methods. It is noteworthy to mention that although Stillman used circular markers and the centres of the markers were found not as precise as the present method, there were not significant differences between the results obtained by the manual analysis and by automatic computer analysis (32). Therefore, based on the results of this study, a system of digital photography, nonreflective markers and manual or AutoCAD analysis is a reliable and precise method to measure the joint angles. This method can be used in laboratory investigations and also in clinical environments to evaluate the JPS. In addition, the present method is objective, less expensive, fast and simple in comparison to other methods. Furthermore, it is not dependent to the interaction of investigator and computer program, to ensure that data are not contaminated by computer errors. This may occur in measurement of angles greater than 180º (knee hyperextension) or when the markers hide or move rapidly. In these situations, the investigator must actively correct the computer errors (43). It is necessary to mention that the errors would be much less in the two methods of manual and AutoCAD measurements if we consider the following points: higher colour contrast between the skin and the markers, reducing the reflection of the light, more precise settings of the camera, keeping the knee motion in a plane perpendicular to the camera view, and choosing a standard goniometer.

In conclusions, ordinary methods for evaluating the JPS are measuring the joint angle by electrogoniometer, visual estimation, isokinetic dynamometer, and automatic two dimensional computer analyses from the video images. Before using any method or system in the clinical or laboratory studies, the reliability and accuracy of it should be evaluated. In addition to these two main characteristics, it is very important in clinical physical assessments that the method used is objective, fast, accessible, simple and less expensive. The introduced system in this research, comprised of digital photography, AutoCAD analysis (or manual analysis) has all these characteristics. Furthermore, this method enables us to evaluate the JPS with the following advantages: it can be used in weight bearing positions; it has no limitation in joint motion, and produces no abnormal sensory feedback.

In this system, it is more important to measure the joint angle in just one session, rather than doing it through repetitions with short or long intervals. In evaluating the JPS, the test and replicated angles are compared at the same time. Besides, if it is necessary for some reasons to remove a marker, one can re-measures the exact location of the marker by a measuring tape and hence increase the reliability of the measurement.

Conflict of interests

We have no conflict of interests.

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