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Original Research

The Validity and Reliability of Knee Joint Position Sense Measurement Performed with Image-Capture Technique in Stroke Patients

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Abstract

Objectives: The sense of joint position, which is one of the sub-parameters of proprioception, plays a very important role in initiating and stimulating voluntary and involuntary movements. The ImageJ software program is a free computer program used to make certain measurements on the material photographed in basic medical science laboratories. Angular measurements are also made in the program. In this study, we aimed to use the angular measurement tool to evaluate the sense of joint position in stroke individuals. For this purpose, it is investigated the intraexaminer and interexaminer reliability, criterion-related and construct validity of this program in stroke patients. **Materials and methods:** 50 stroke patients and 51 healthy control groups were included in the study. All stroke patients were assessed in four sessions, with three days intervals. Two fixed physiotherapists performed measurements at different times for the ImageJ software program. The isokinetic measurements were performed on all stroke patients session one. ImageJ software program measurements were carried out once on healthy people with three trials in a session. **Results:** The ImageJ software program showed good intraexaminer and interexaminer reliability. In measurements on the stroke patients significant correlations were observed between isokinetic equipment and ImageJ software program for the right and left knee ($r=0.77$, $r=0.77$, $p<0.001$). Measurements of ImageJ software program on both right knee and left knee showed difference between the groups ($p=0.045$ and $p=0.058$, respectively). **Conclusion:** ImageJ software program is a reliable and valid method to evaluate the knee joint position sense in stroke patients.

Keywords: *knee; joint position sense; proprioception; stroke.*

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Introduction

Proprioception consists of somatosensory information that from muscles, tendons, and skin. Proprioception, including kinaesthesia and joint position sense, enables us to perceive movements and spatial awareness of our bodies (Gandevia, Refshauge, & Collins, 2002; McCloskey, 1978). Kinesthesia is the perception of joint movement, while the joint position sense is a proprioceptive process that enables the detection of the localization of body segments in space (Rand, 2018). The joint position sense protects our body from dangerous movements and also affects joint stability, normal joint coordination and learning of new movements (Hwang, Lee, Cho, Han, & Kim, 2010). Joint position sense and kinaesthesia have an significant role in motor control and learning processes (Marini, Ferrantino, & Zenzeri, 2018). Additionally, studies on plasticity have shown that proprioceptive feedback plays an important role in the reorganization and recovery of the neuromotor system (Schwenkreis, Pleger, Höffken, Malin, & Tegenthoff, 2001; Xerri, 1998; Xerri, Merzenich, Peterson, & Jenkins, 1998).

Somatosensory deficits and impaired proprioceptive function of the lower limbs are commonly seen in patients with stroke (Gorst, Freeman, Yarrow, & Marsden, 2018). Impaired joint position sense of the lower limbs is associated with changed postural control and increased risk of falls, making it difficult to regain the ability to walk independently in post-stroke (Berthoz, 2000; Gorst et al., 2018; Lemoyne, Coroian, Mastroianni, & Grundfest, 2008; Rand, 2018). Therefore, the clinical evaluation of proprioception with both forms is important for evaluation and treatment in stroke patients (Doyle, Bennett, & Dudgeon, 2014).

Specialized and automated equipment is used for proprioception measurements in stroke and neurological populations (Kwon & Lee, 2013; Lin, 2005; Wingert, Burton, Sinclair, Brunstrom, & Damiano, 2009). Studies have shown that these devices such as isokinetic equipments, inclinometer, electrogoniometer, etc. be able to usaged as a tool for measuring lower extremity joint position sense (Bronner, Agraharasamakulam, & Ojofeitimi, 2010; Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004; Hwang et al., 2010; Taylor, Sanders, Howick, & Stanley, 1991). However, the use of clinical practices of these devices is limited due to the high cost, difficulty of use and being unportable (Connell & Tyson, 2012). Therefore, clinically available measurements for assessing joint position sense are clearly needed.

The ImageJ software program is a simple, cost-effective, and easily administered measurement tool for assessing joint position sense (Kim, 2015). To evaluate joint position

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sense with ImageJ software program, photo shoot is performed and the angular value of joint is measured on the photograph (Relph & Herrington, 2015a). Good intraexaminer (ICC=0.96) and interexaminer reliability (ICC=0.98) of the ImageJ software program have beeen reported in healthy people (Relph & Herrington, 2015b). However, reliability of the ImageJ software program has not yet been systematically examined in stroke patients. The aims of this study are to investigate the intraexaminer and interexaminer reliability of ImageJ software program with stroke patients and criterion-related and construct validity of the ImageJ software program.

Material and Methods

Participants

Stroke patients and healthy controls were included in the study. Inclusion criteria for stroke patients were a diagnosis of stroke by specialist physicians; having stroke at least 6 months before the study; having stroke-related hemiplegia or hemiparesis for the first-time; having no problems in knee joint range of motion; sufficient cognition to participate in the study, that is, a Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) Score of ≥24. Exclusion criteria were having made the botulinum toxin administration within 6 months; having stroke that have affected both halves of the body; having neglect syndrome and having defined higher point than 2 on the Modified Ashworth Scale (Gregson et al., 1999). Inclusion criteria for the control group were being at a similar age and sex with stroke patients, having no orthopedic and neurological deficit that could affect knee joint movement and sense. This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from Nevşehir Hacı Bektaş Veli University Non-interventional Clinical Researches Ethics Board. Signed consent was obtained from all subjects before the study.

Calculation of sample size

Sample size was calculated according to the significance testing of Pearson correlation coefficient to assess concurrent validity of Image J using $|\rho|=0,40$ (Gorst et al., 2018) as the effect size. Minimum required sample size was 46 patients to test the significance of Pearson correlation coefficient at 0,05 alpha level with 80% power. Since the loss of measurement rate was predicted to be 10%, the number of patients required was 51. To assess construct validity, known-groups method was used. Hence, above mentioned sample size was sufficient for Student's t test with Cohen's (Cohen, 2013) large effect size at 0,05 alpha level and 70% power. Therefore, equal number of individuals was included in the control group. In addition, all

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patients were examined by the same and a second examiner to access intraexaminer and interexaminer reliability respectively using test-retest method. Sample size was calculated using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2009).

Procedures

Demographic data which including information of gender, age, height, weight, duration of stroke, lesion type and affected side were recorded at the physical therapy center. The joint position sense was evaluated by active joint repositioning test. The joint position sense evaluation angle was 30 degrees (Co, Skinner, & Cannon, 1993). At each measurement, the participants were asked to repeat the target angle three times. The error value was calculated by averaging these three angular values. The eyes were closed with tape during the test to prevent visual access.

All stroke patients were assessed in four sessions, with three days intervals. Two fixed physiotherapists who have more than five years of clinical experience (Examiner 1 and Examiner 2) performed measurements. Examiner 1 conducted first two sessions and examiner 2 conducted last two sessions for the ImageJ software program. All the tests were recorded two examiners independently. They had been previously trained to perform the ImageJ software program on the basis of the standardized instructions. Also, each examiner was blinded to the other's result. The isokinetic measurements were performed to all stroke patients by Examiner 1 on session 1. ImageJ software program measurements were carried out once on the healthy controls with three trials in a session. Their data were used to determine known-groups validity between stroke patienst and healthy controls.

Measurements

ImageJ Software Program

The ImageJ software program was developed by the US National Institutes of Health as an image processing and analysis software program. It is a program that can be used on most operating systems. The ImageJ software program has the function of calculating the angle between two parts and a digitizing function for calculating the 2D coordinates (X, Y). ImageJ is a valid and reliable program for joint position sense, motion measurement, and lower extremity kinematic analysis (Kim, 2015; Lee & You, 2016; Maeoka, Fukumoto, & Sakaguchi, 2008; Relph & Herrington, 2015a, 2015b). For ImageJ measurements, photos were taken with an Apple Iphone 6 (1334 x 750 pixels resolution) connected to remote control tripod. Markers were placed on the greater trochanter of the femur, the femoral lateral epicondyle, and lateral malleolus. The phone camera was placed on a tripod at a distance of 1m to the lateral aspect of

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the patient. Participants were asked to stretch their knees from the initial position until the knee arrived the 30 ° target angle, as in isokinetic measurements. The 30 ° target angle was shown 3 times; then the participants were asked to repeat this angle 3 times and press the control attached to the camera when they reached the target angle. The angular value of the photographs was measured in the ImageJ software program.

Isokinetic measurements

Isokinetic equipment (Biodex System Pro 3,Biodex Medical System, Inc., NY ,USA) was used for joint position sense. Biodex uses a special software package with a dynamometer, built-in electro-goniometer, various motion set switches and several limb attachments for testing. Biodex is a valid and reliable tool (Drouin et al., 2004; Taylor et al., 1991). For isokinetic measurements, the subjects sat upright on the chair in the isokinetic equipment and the knee tested was leveled with the dynamometer axis. The thigh was secured with a tape. The tibia was fixed with a tape 3 cm above the lateral malleolus. In studies measuring joint position sense using an isokinetic equipment, 90 ° knee flexion was used as the initial position and evaluation of knee joint sense was started in 90 ° flexion position (Moezy, Olyaei, Hadian, Razi, & Faghihzadeh, 2008). Participants were asked to extend their knees from the initial position until they reached the 30 ° target angle. After waiting for five seconds in this position, the participants returned to their initial positions. Target angle was shown three times in the same way. After than, participants were inquired to reconstruct the perceived angle as truly as feasible and were asked to repeat the target angle three times.

Statistical analysis

Kolmogorov-Smirnov normality test was used for assessing normality assumption when sample size was equal or higher than 50. Otherwise, Shapiro-Wilk normality test was used. Descriptive statistics, including mean±standard deviation for normally distributed variables; median (interquartile range [IQR]) and median (minimum-maximum) for non-normally distributed variables were reported. Patient and control groups were compared in terms of demographic variables. In case of two independent groups, Student's t test or Mann-Whitney U test was used for comparisons, depending on whether the parametric test assumptions were met or not. Frequency and percentage (n, %) were used to describe categorical variables. Pearson Chi-square test was used to test independence when test assumptions were met. Otherwise Fisher's exact test or Fisher-Freeman-Halton exact test was used depending on the contingency table size.

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In order to evaluate the reliability of the ImageJ program, intraexaminer and interexaminer reliability were assessed in the stroke patients by using intraclass correlation coefficient, i.e. ICC (3, k) (Portney & Watkins, 2009), and its 95% confidence interval. This ICC (3, k) formulation is used by considering the effect of the examiner as fixed while the effect of subject is random. In addition, the measurements used to calculate ICC (3, k) are either sum or mean of "k" measurements obtained from the same examiners. The degree of the reliability indicated by ICC (3, k) values was interpreted as: good (0.76–1.00), moderate (0.51–0.75), fair (0.26–0.50) and poor if ICC (3, k) is less than or equal to 0.25. The same categorization is used for interpreting the correlation coefficients in the study.

Criterion-related validity of ImageJ software program was assessed in terms of both concurrent and predictive validity. Concurrent validity was analyzed by using Spearman's rho correlation coefficients between measurements obtained from isokinetic equipment and ImageJ software program itself. In addition, Bland–Altman analysis was used for evaluating the concurrent validity. Hence, Bland-Altman plots with 95% limits of agreement were generated for both knees in R with using "BlandAltmanLeh" (Lehnert) and "ggplot2" (Wickham, 2016) packages. Predictive validity was assessed by simple linear regression analysis with 10-fold cross validation using "caret" package (Kuhn et al.) Results were presented as Root Mean Square Error (RMSE), R-squared (R^2) and Mean Absolute Error (MAE) for both knees.

To assess the construct validity, known-groups validity (Davidson, 2014) method was used to determine whether there is a statistically significant difference between stroke patients and healthy controls in terms of degree obtained from ImageJ software program with Mann-Whitney U test due to the violation of parametric test assumptions. The level of significance was set at $p < 0.05$ for all analyses. The analyses were performed using IBM SPSS Statistics version 23 for Windows and Rx64 3.5.3 software.

Results

50 stroke patients, with a mean age of 56.5±14.8 years, 29 men and 21 women, and 51 healthy controls, with a mean age of 53.3±12.6 years, 22 men and 29 women, were included in the study. When stroke patients and healthy controls were compared, the two groups had similar features in terms of demographic characteristics such as age, height and weight (p=0.242, p=0.579 and, p=0.206, respectively). In addition, gender distribution was homogeneous within each group (p=0.135). Table 1 summarizes participants' characteristics.

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Table 1: Demographic and clinical characteristics of the participants

	Stroke patients (n=50)	Healthy controls (n=51)	p
Gender n (%)			
Male	29 (56.9)	22 (43.1)	0.135
Female	21 (42.0)	29 (58.0)	
Age (year)	56.5±14.8	53.3±12.6	0.242
Height (cm)	167.0±8.0	165.9±7.6	0.579
Weight (kg)	75 (67-77)[d]	75 (67-85)[d]	0.206
Duration of stroke (month)	42 (12-87)[d]	NA[e]	NA
Type of lesion (n) (hemorrhagic/ ischemic)	7/43	NA	NA
Hemiplegic side (n) (right/left)	16/34	NA	NA

[a] Body-Mass Index; [b] Mini- Mental State Examination; [c]Modified Ashworth Scale; [d]median (IQR); [e]not applicable.

ICC(3, k) values with 95% confidence intervals are presented in Table 2 to evaluate intraexaminer and interexaminer reliability of the ImageJ software program. High ICC(3, k) values indicate that the ImageJ software program is reliable for measuring degree in stroke patients.

Table 2: Intraexaminer and interexaminer reliability of the ImageJ software program for joint position sense in stroke patients

	Examiner		T1[a]	T2[b]	ICC [c](95% CI[d])
Stroke Patients n=50 (degree)	**1**	**Right**	6.91±4.081	6.73±4.018	0.975 (0.955-0.986)
	2	**Right**	6.79±4.182	6.65±4.175	0.988 (0.979-0.993)
	ICC (95% CI)		0.958 (0.926-0.976)	-	-
	1	**Left**	6.77±3.994	6.65±4.124	0.972 (0.951-0.984)
	2	**Left**	6.24±3.656	6.05±3.756	0.961 (0.931-0.978)
	ICC (95% CI)		0.923 (0.865-0.956)	-	-

[a]first ImageJ measurements; [b]second ImageJ measurements; [c]intraclass correlation coefficient ICC(3,k); [d]confidence interval.

Concurrent validity of Image J software program was examined with correlation analysis and results are presented in Table 3. Statistically significant and positive correlations between measurements, which are obtained from isokinetic equipment and ImageJ program, were observed for the right and left knee in the stroke patients ($p<0.001$). Accordingly, the results indicated that Image J program is a valid alternative to isokinetic equipment. However, the agreement between two measurement methods for the left knee was lower than the right knee.

Table 3: Correlations between ImageJ and Biodex measurements in Stroke patients

Group	Side	r_s[a]	p

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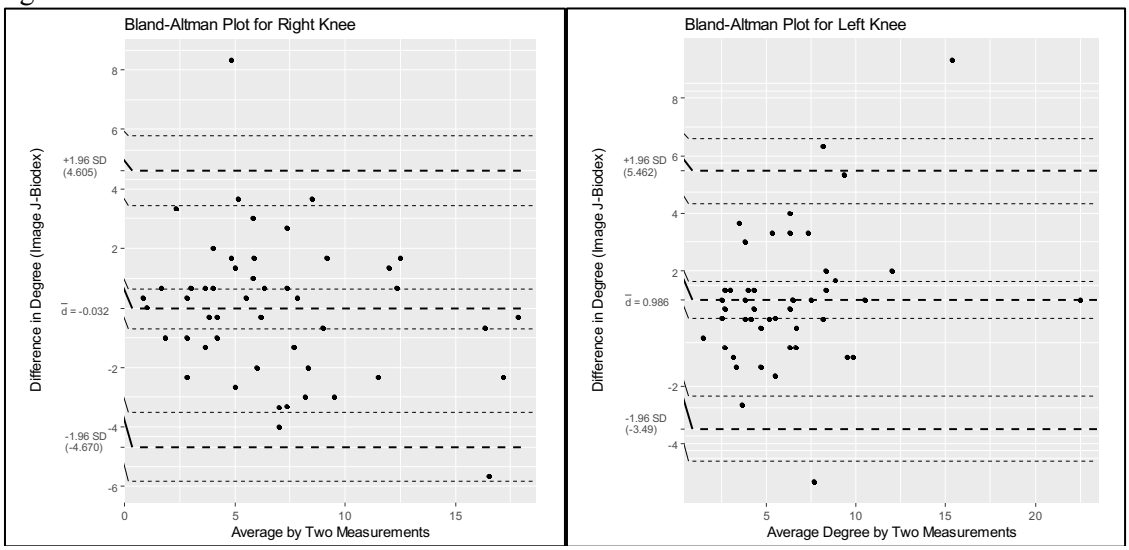
Stroke patients	Right	0.77	<0.001*
	Left	0.77	<0.001*

Notes:[a] Spearman´s rho correlation coefficients;*p <0.05.

In addition, there is no significant systematic error in ImageJ measurements of the right knee in stroke patients when the Bland-Altman plot is examined. Hence, majority of patients remained within the limits of agreement. When the Bland-Altman plot of the left knee was examined, the majority of stroke patients were within agreement limits though ImageJ measurements were obtained with approximately 0.986 degrees deviation in average from isokinetic measurements (Figure 1).

Fig 1: Overview of Bland-Altman plots of ImageJ software program and isokinetic equipment for right knee and left knee.



To assess predictive validity of ImageJ software program when measuring degree of the right and left knee in stroke patients, simple regression analysis was carried out. The results of the models with 10-fold cross validation are presented in Table 4.

The regression models indicated that ImageJ software program measurements could be used as a valid predictor of isokinetic measurements for both knees due to the fact that the models explain approximately 70% of the variability of the isokinetic measurements around its mean. Therefore, it could be said that ImageJ software program has a concurrent validity considering isokinetic measurements as a reference measurement method.

Table 4: Simple Linear Regression analysis results for predictive validity of ImageJ measurements

	Right knee	**Left knee**
Image J	0.9813	0.7017

	(p<0.001)	(p<0.001)
Constant	0.1579	0.9964
	(p=0.813)	(p=0.064)
F-statistic (p value)	133.5 (p<0.001)	108.6 (p<0.001)
RMSE[a]	2.2587	2.0466
R-squared	0.722	0.718
MAE[b]	1.824	1.536

[a]Root Mean Square Error; [b] Mean Absolute Error.

Lastly, construct validity was assessed by known-groups validity method that prior to the analysis significant difference between ImageJ software program measurements between stroke patients and healthy controls was foreseen. Therefore, after carrying out the analysis, the expected structure was observed and there was a significant difference between the groups, the level of significance was 5% for the right knee and 10% for the left knee. (p = 0.045, p = 0.058, respectively) (Table 5).

Table 5: Known-groups validity analysis of ImageJ measurements results

ImageJ measurements	Stroke patients (n=50)	Healthy controls (n=51)	p
Right knee	5.8 (1.0-17.7)[a]	4.0 (0.67-27.3)[a]	0.045[**]
Left knee	5.3 (1.3-23.0)[a]	5.0 (1.0-14.3)[a]	0.058[*]

[a]median (min-max); [**]p <0.05, [*]p <0.10.

Discussion

Insufficient proprioceptive information from the extremities delays the return of motor functions after stroke. In order to improve motor functions, proprioceptive information from the affected extremity must be accurate and sufficient (Doyle et al., 2014). Motor and proprioceptive losses should be examined with this purpose, rehabilitative approaches aiming the improving of proprioception should be used in stroke treatment (Findlater et al., 2018). On the other hand proprioception measurements are usually performed in the laboratory and with expensive equipment, so it is not practical for use in clinics. Cost-effective, and easy-to-use ImageJ software program has the advantage of evaluating in any clinical setting for measuring joint position sense. Thus, loss of joint position sense can be easily evaluated with ImageJ software program and sensory training can be started from the early period after stroke. In addition, the photos taken for this program can be stored and used to monitor the patient in the long term.

Since there is no accepted a gold standard test for measurements of joint position sense,(Relph & Herrington, 2015a) isokinetic equipment which is one of the standard measurement methods was made use of for validity. In addition, inclinometer is also one of the

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methods that can be used for validity. The use of both equipment reason extra sensorial inputs in the patient as it requires contact with the extremity. Considering the fact that have impaired sensory functions in stroke patiens, we think that extra sensorial inputs for measurements joint position sense may affect the accuracy of the measurement. On the other hand, the measurements of ImageJ software program do not reason extra sensorial input and can be provide more accurate measurements of joint position sense.

Excellent intraexaminer and interexaminer reliability of ImageJ for both sides was found in stroke patients in this study, which is consistent with Relph et al. who reported excellent intraexaminer (ICC(3, k)=0.96) and interexaminer (ICC(3, k)=0.98) reliability in healthy people (Relph & Herrington, 2015b). Standardized procedures and environment, clear instructions, two fixed examiners, and sufficient rest between trials to avoid the effects of learning and fatigue are all together believed to provide excellent reliability obtained for ImageJ software program in this study.

In our study, there was a statistically significant and good correlation between the two measurement methods in stroke patients (right knee and left knee r_s=0.77, p=0.000). This results were in line with a previous study reporting that in the evaluation of knee joint position sense with ImageJ software program and isokinetic equipment in healty individuals, there was a significant correlation between the two measurement methods (r_s=0.70, p=0.016) (Relph & Herrington, 2015a). Therefore, the use of ImageJ software program, which is simpler, faster and cheaper, is recommended in the clinic.

Joint position sense measurements for both right and left knee were different between stroke patients and healthy controls. Therefore, the joint position sense examination of stroke patients should be performed on the nonaffected side as well as on the affected side. Because of the lack of adequate low cost and simple clinical testing to measure the joint position sense, it is difficult to do joint position sense measurements in clinic. As a result, it makes it difficult to establish a treatment program for proprioceptive functions and to follow up the patient. This situation suggests that the importance of ImageJ software program which is simple and accessible as a method of assessing joint position sense.

This study has several limitations. Results of this study is current just to stroke patients satisfying the inclusion criteria of this study, therefore they cannot be generalized to a all the stroke patients. In addition, the majorities of patients included in the study were left-sided stroke patients and had ischemic type stroke. In future studies, muscle strength, gait and balance parameters may be examined regarding joint position sense.

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Conclusions

This study is the first to research the intraexaminer, interexaminer reliability, concurrent and criterion-related and, construct validity of the ImageJ software program in stroke patients. The results of our study provide a significant contribution to the literature for the evaluation of joint position sense without creating an extra sensory input in stroke. The study results showed that ImageJ software program can be easily administered and is a clinically available assessment tool for assessing knee joint position sense.

Conflict of Interest

No conflict of interest.

Funding

No one to report.

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