

*Original Article***Reliability and minimal detectable change of Quantified Paralysis Performance Assessment (QPPA) using a three-dimensional motion analysis device**

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**ABSTRACT**

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**Purpose:** We developed a quantitative evaluation method for motor impairment in hemiplegia using a three-dimensional motion analysis device, the Quantified Paralysis Performance Assessment (QPPA). As a pre-clinical study, we verified the reproducibility and minimal detectable change of the method.

**Methods:** Sixty-six patients who had the first stroke [39 males, 27 females; aged  $60 \pm 12$  years (mean  $\pm$  standard deviation)] were studied. QPPA measurement was conducted two times to obtain one set of data. The following measurements were performed; upper limb function (arm; QPPA-UE) and lower limb functions (hip joint; QPPA-Hip, knee joint; QPPA-Knee, and ankle joint; QPPA-Ankle). The lifted distance and maximum velocity for each marker were used as the typical values. From the typical values obtained from one set, the intraclass correlation coefficient (ICC) and 95% confidence intervals of minimal detectable change (MDC<sub>95</sub>) were calculated.

**Results:** In the case that two sets of data were obtained from the same acute stage patient at an interval of over

two weeks, the two sets were analyzed individually. With a total of 91 sets of measurements, the ICCs of the QPPA indices ranged from 0.956–0.989, and MDC<sub>95</sub> ranged from 4.56–6.79%.

**Conclusion:** The typical values of QPPA showed high reproducibility. In addition, the minimal detectable change was small, suggesting that this method captures clinical changes with higher sensitivity than evaluation methods using ordinal scales.

**Keywords:** three-dimensional motion analysis, hemiplegia, interval scale

**Introduction**

In Japan, the total number of stroke patients was estimated to be 1,235,000 in 2011 [1]. As a consequence, stroke survivors have to lead a social living affected by paralysis and various impairments. Therefore, rehabilitation during the acute phase, convalescent phase and maintenance phase plays an important role.

To conduct rehabilitation effectively and efficiently, first and foremost an accurate diagnosis is necessary. The International Classification of Impairments, Disabilities and Handicaps (ICIDH) proposed to stratify disablement into three levels: impairment, disability, and handicap [2]. Post-stroke hemiplegia is classified under impairment. Therefore, it is important to evaluate paralysis by the level of functional impairment and to aim at achieving functional improvement.

The evaluation of hemiplegia was attempted in as early as the 1950s, as described in the detailed report by Twitchell [3]. Subsequently, several evaluation methods were proposed. Saitoh and Chino [4] broadly divided evaluation methods for stroke-related functional impairment into (1) evaluation of muscle weakness and (2) evaluation of movement pattern impairment

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called synergy-decomposition. Evaluation methods (1) include manual muscle testing (MMT) and motricity index calculated from the upper and lower limb MMT scores [5]. Evaluation methods (2) include the Brunnstrom Stage [6]. The Brunnstrom approach graded the upper extremity, fingers and lower extremities into 6 stages (stage 1 to stage 6) according to whether certain movement patterns can be executed. Other comprehensive evaluation methods of functional impairment, including findings other than hemiplegia, have been proposed, such as the Fugl-Meyer scale (FMA) [7] and Stroke Impairment Assessment Set (SIAS) [8]. The FMA consists of upper and lower extremity evaluations by synergy, tendon reflex and coordinating movements, together with sensation and range of motion (ROM). On the other hand, SIAS is a more comprehensive evaluation method, which rates performance on scales of 0 to 5 or 0 to 3 for motor function, tendon reflex, sensation, as well as pain, ROM, truck control, the sound side, and higher brain function. However, these methods assess and grade according to physical examination or visual observation, and therefore can only be categorized as subjective ordinal scales.

As described above, evaluations used in rehabilitation medicine are mostly ordinal scales, which raises an issue of the possibility that correct interpretations of the results may not be arrived [9, 10]. Conversion of ordinal scales to interval scales using Rasch analysis or other methods, or development of novel quantitative evaluation methods are recommended. Evaluation of impairment by objective interval scale using quantitative measurement device is expected to detect clinical changes with higher sensitivity than the conventional ordinal scales. The purpose of the present study was to develop a quantitative evaluation method of hemiplegic motor impairment using a three-dimensional motion analysis device, and to evaluate its reproducibility and minimal detectable change. We named the novel method "Quantified Paralysis Performance Assessment (QPPA)".

### Subjects

The present study was performed prospectively. The entry criteria were patients with the first stroke (unilateral supratentorial lesion) capable of maintaining a sitting position in the wheelchair, and capable of executing instructed movements. Exclusion criteria were patients with uncontrolled hypertension, heart failure, or respiratory failure, and patients with severe aphasia or severe dementia not capable of executing instructed movements.

Sixty-six patients gave informed consent to participate in the study, comprising 39 males and 27 females, aged  $60 \pm 12$  (mean  $\pm$  standard deviation) years. Stroke was caused by cerebral infarction in 34 patients, cerebral hemorrhage in 30, and subarachnoid

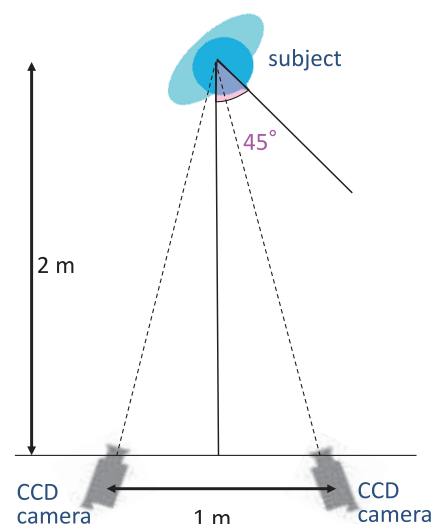
hemorrhage in 2. The lesion was on the left in 34 patients and on the right in 32. The initial measurement was performed 173 days on average after onset. Written informed consent for participation in this study was obtained after the patients and their families were given explanations including the risk involved and that they would not be disadvantaged even if they withdrew from participation during the course of the study. This study was approved by the ethical committee of our hospital (No. 08-098).

### Methods

Four movements were measured by a three-dimensional motion analysis device. The assessment items were upper limb function (arm: QPPA-UE) and lower limb functions (hip joint: QPPA-Hip, knee joint: QPPA-Knee, and ankle joint: QPPA-Ankle).

#### Measurement device

The three-dimensional motion analysis device used was KinemaTracer<sup>®</sup> (Kissei Comtec Co. Ltd., Matsumoto, Japan). This system has a simple configuration, consisting of several CCD cameras connected by IEEE1394 to a computer for recording and analysis. Calibration was conducted using a control object. After attaching markers to the subject, measurement can start. Measurements were made at a sampling frequency of 60 Hz. The control object was a conventional 120×60×50 cm frame. Standard 30-mm spherical markers were used. For simplicity, all measurements were conducted in a sitting position. At least two CCD cameras are needed for three-dimensional data acquisition. The cameras were fixed



**Figure 1.** Measurement environment.

Two CCD cameras used for filming are fixed by a frame at a distance of 1 m from each other. The distance between the subject and the frame is 2 m. The paralytic side (measurement side) is filmed at an angle of 45 degrees from the front.

by a frame. The measurement environment is shown in Figure 1. To allow filming of the upper and lower extremities under the same conditions, the distance between two cameras was set at 1 m, and the distance between the subject and the camera frame at 2 m. To facilitate the visualization of markers and analysis, the paralytic side (measured side) was filmed from the front at an angle of 45 degrees.

### Method of measurement

The instructed movements were selected by reviewing conventional hemiplegia evaluation methods. Finally, the instructed movements were designed according to the movements of SIAS-Motor (SIAS-M), because the SIAS-M movements are simple tasks, and match our condition of filming in a sitting position during evaluation.

For QPPA-UE, a serial task was designed. First the SIAS knee-mouth test was executed, in which the hand touching the contralateral knee was lifted to the mouth by abducting the shoulder and flexing the elbow. From this condition, the hand was lifted upward and then returned to the mouth. In addition, the movement of lifting the hand from the mouth as high as possible and returning to the mouth was repeated as fast as possible five times.

For evaluating lower limb functions, initially serial movement consisted of a combination of movements was examined, but the movement were too complicated and difficult to execute by the subjects. Eventually, following SIAM-M, hip joint function (QPPA-Hip), knee joint function (QPPA-Knee) and ankle joint function (QPPA-Ankle) were assessed individually. For QPPA-Hip, from a 90° flexed position, the patient flexed the hip joint as high as possible and as fast as possible five times. For QPPA-Knee, from a 90° flexed position, the patient extended the knee joint as far as possible and as fast as possible five times. The patient was instructed not to lift the thigh from the chair while performing the movement. For QPPA-Ankle, with the heel resting on the floor and from a 10° plantar flexed position, the patient dorsiflexed the ankle joint as much as possible and performed dorsiflexion/plantar flexion as fast as possible five times.

The markers were set at positions that most effectively reflect the instructed movements. A wrist marker (center of dorsal wrist) was used for evaluating QPPA-UE, a knee joint marker (lateral epicondyle of femur) for evaluating QPPA-Hip, ankle joint marker (lateral malleolus of fibular) for evaluating QPPA-Hip, and a toe marker (fifth metatarsal bone) for evaluating QPPA-Ankle. The marker positions during filming are shown in. Figure 2

Two QPPA indices were evaluated: the displacement of each marker in a vertical direction (lifted distance) and the maximum velocity of the movement (lifting velocity). For each index, the mean value for three of the five movements was used for analysis. When five

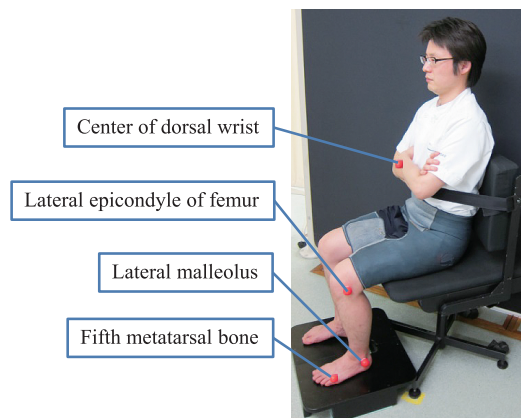


Figure 2. Filming scene and marker positions.

movements could not be executed due to severe paralysis, the largest value among the movements executed was used. To correct for difference in physique, the lifted distance was corrected by the corresponding limb length measured on the images during KinemaTracer® analysis. The lifted distance was divided by the arm length (outer edge of acromion to styloid process of radius) for QPPA-UE, by the length of upper leg (greater trochanter to lateral epicondyle of femur) for QPPA-Hip, by the length of lower leg (lateral epicondyle of femur to lateral malleolus) for QPPA-Knee, and by the distance between the lateral malleolus to the fifth metatarsal bone for QPPA-Ankle.

For QPPA-Knee measurement, a preliminary study in healthy persons showed that the hip joint was flexed during knee extension, resulting in overestimation of the lifted distance. Therefore, when evaluating QPPA-Knee, the knee joint marker lifted distance was corrected for the hip joint flexion. Moreover, the measured values were divided by the respective upper limits of measurement measured in healthy persons (QPPA-UE: 1.9, QPPA-Hip: 0.9, QPPA-Knee: 0.9, QPPA-Ankle: 0.7), multiplied by 100, and expressed as percentage. The lifted distances were divided by the mean values measured in healthy persons (QPPA-UE: 214.1 cm/s, -Hip: 157.9 cm/s, -Knee: 268.8 cm/s, and -Ankle: 56.6cm/s), multiplied by 100, and expressed in percentage. Lifted distance was abbreviated as D and maximum velocity as V. Thus, the following eight indices were used: QPPA-U(D) and -U(V) for QPPA-UE, QPPA-H(D) and -H(V) for QPPA-Hip, QPPA-K(D) and -K(V) for QPPA-Knee, and QPPA-A(D) and -A(V) for QPPA-Ankle. The instructed movements, marker positions, and indices are shown in Table 1.

### Statistical analysis

For each subject, QPPA measurement was performed two times on two different days. Measurement was performed using the three-dimensional motion analysis device KinemaTracer®. Following the methods described above, QPPA-UE, -Hip, -Knee,

**Table 1.** Instructed movements, marker positions and indices used in Quantified Paralysis Performance Assessment (QPPA).

Assessment	Instructed movement	Marker position	Index
QPPA-UE	Lift the hand that is placed on the contralateral knee to the mouth by abducting the shoulder and flexing the elbow. Consequently lift the hand upward and return to the mouth as fast as possible 5 times.	Center of dorsal wrist	Lifted distance = U(D) Maximum velocity = U(V)
QPPA -Hip	From 90°flexed position, flex the hip as far as possible. Repeat movement as fast as possible and as high as possible 5 times.	Lateral epicondyle of femur	Lifted distance = H(D) Maximum velocity = H(V)
QPPA -Knee	From 90°flexed position, extend the knee as far as possible. Repeat movement as fast as possible and as high as possible 5 times. Do not lift the thigh from the chair.	Lateral malleolus	Lifted distance = K(D) (correct according to lifted knee position) Maximum velocity = K(V)
QPPA -Ankle	With the heel touching ground and from 10° plantar flexed position, dorsiflex the ankle as much as possible. Repeat dorsiflexion/plantar flexion as fast as possible 5 times.	Fifth metatarsal bone	Lifted distance = A(D) Maximum velocity = A(V)

Lifted distance = Mean lifted distance of 3 of 5 trials (cm) × 100/each limb length (cm)/upper limit of measurement [Limb length for U(D): acromion outer edge–styloid process of radius; for H(D): greater trochanter–lateral epicondyle of femur; for K(D): lateral epicondyle of femur–lateral malleolus; for A(D): lateral malleolus–fifth metatarsal bone. Upper limit of measurement for U(D): 1.9; H(D): 0.9; K(D): 0.9; A(D): 0.7]

Maximum velocity = Mean maximum lifting velocity of 3 of 5 trials [cm/s] × 100/mean value of healthy young adults [cm/s]

[Value of healthy young adults for U(V): 214.1 cm/s; H(V): 157.9 cm/s; K(V): 268.8 cm/s; A(V): 56.6 cm/s]

-Ankle were filmed. The second measurement was performed within 3 days of the first measurement in acute to subacute patients (within 180 days after onset), and within 7 days in chronic patients (181 days or longer after onset). On the same day of measurement, SIAS-M was evaluated by a person other than the QPPA assessor, to confirm whether there was any change in paralysis. In acute to subacute patients, if repeated measurements were possible from the same patient after an interval of 14 days or longer, the data were analyzed as a different data set. A total of 91 data sets were analyzed.

Using the data from two measurements, intraclass correlation coefficient (ICC) and 95% confidence interval of the minimal detectable change (MDC<sub>95</sub>)

were calculated. Since the study was designed to examine intra-assessor reliability using the same device, ICC (1, 1) was used. To obtain MDC<sub>95</sub>, first of all the standard error of measurement (SEM) was calculated, and MDC<sub>95</sub> was computed by the following equation:

$$MDC_{95} = SEM \times 1.96 \times \sqrt{2}$$

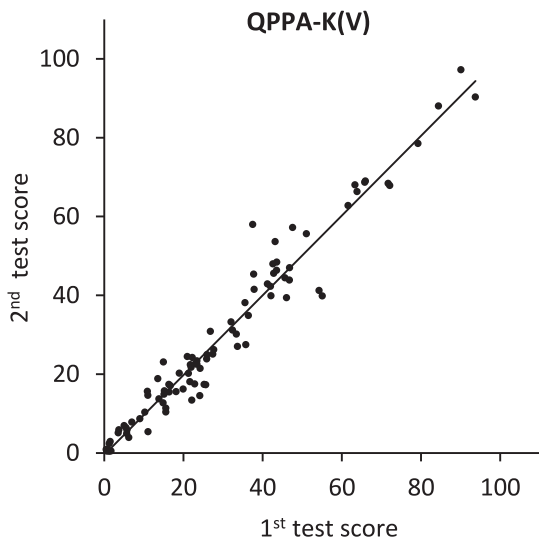
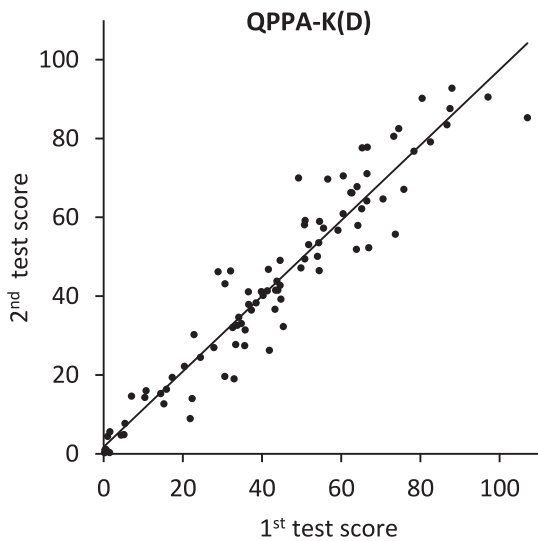
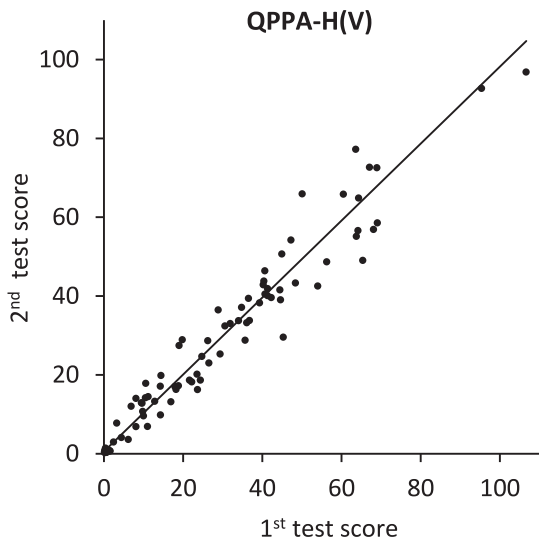
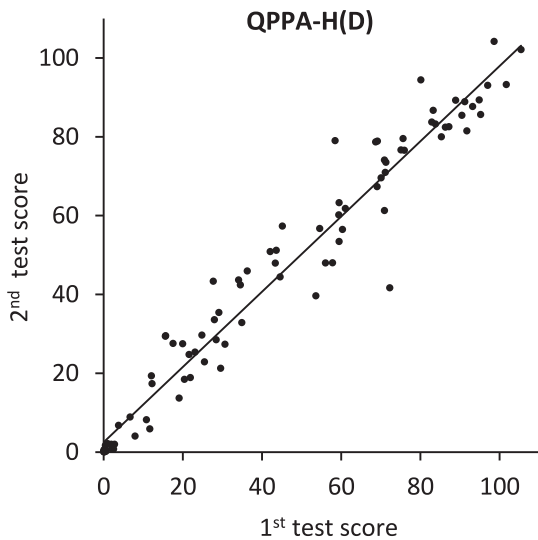
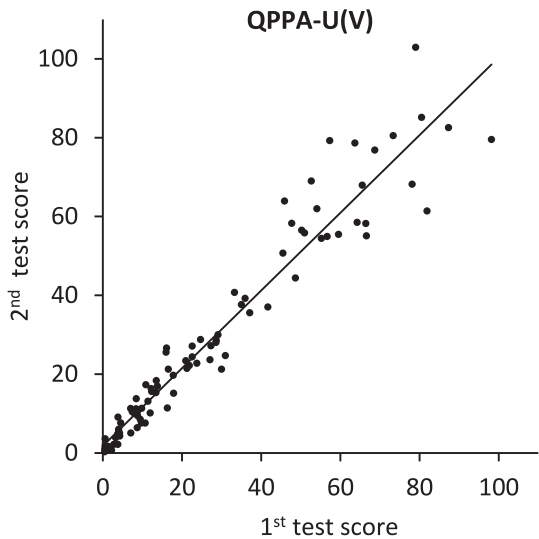
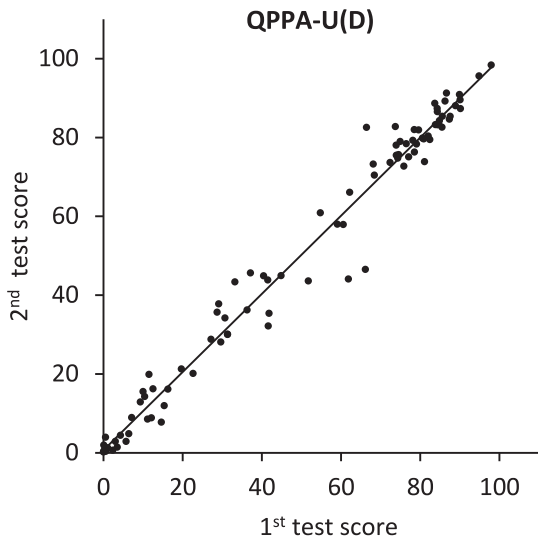
## Results

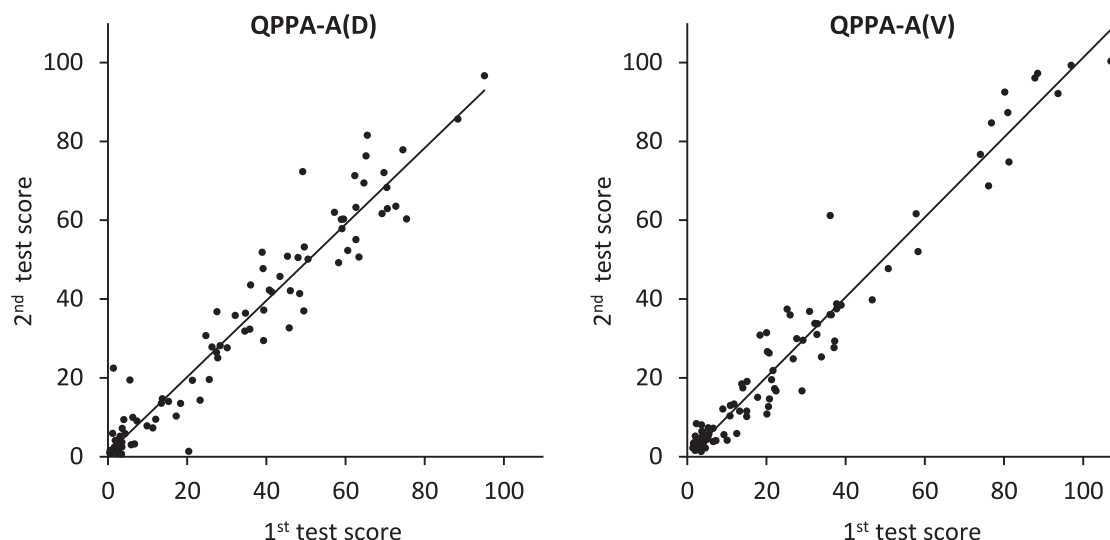
The SIAS-M scores at the time of measurement are shown in Table 2. The median score for U/E (proximal), L/E (proximal, hip) and L/E (proximal, knee) was 3, and that for L/E (distal) was 2. These results showed that the subject population had slightly more severe

**Table 2.** Stroke Impairment Assessment Set-Motor (SIAS-M) scores of subjects at the time of Quantified Paralysis Performance Assessment (QPPA) measurement.

	SIAS-M score						Total
	0	1	2	3	4	5	
U/E (proximal)	9*	16	11	23	21	11	91
L/E (proximal, hip)	4	15	21	19	17	15	91
L/E (proximal, knee)	4	7	19	27	25	9	91
L/E (distal)	18	12	17	24	10	10	91

Data are expressed as number of subjects.





**Figure 3.** Reproducibility of Quantified Paralysis Performance Assessment (QPPA) indices.

Scatter plots with the first measurement on the X axis and the second measurement on the Y axis are shown. All plots have ICC (1, 1) greater than 0.05, indicating high reproducibility. QPPA-UE lifted distance = U(D), maximum velocity = U(V); QPPA-Hip lifted distance = H(D), maximum velocity = H(V); QPPA-Knee lifted distance = K(D), maximum velocity = K(V); QPPA-Ankle lifted distance = A(D), maximum velocity = A(V).

**Table 3.** Intraclass correlation coefficient (1, 1) [ICC (1, 1)], standard error of measurement (SEM), and 95% confidence interval of minimal detectable change ( $MDC_{95}$ ) of QPPA indices.

	QPPA	ICC (1, 1)	SEM	$MDC_{95}$
-UE	U(D)	0.989	2.431	6.738
	U(V)	0.965	1.898	5.260
-Hip	H(D)	0.977	2.450	6.791
	H(V)	0.971	1.840	5.101
-Knee	K(D)	0.956	1.843	5.109
	K(V)	0.976	1.645	4.563
-Ankle	A(D)	0.965	1.911	5.299
	A(V)	0.978	1.994	5.528

L/E (distal).

Figure 3 shows the scatter plots of QPPA indices. The calculated ICC (1,1), SEM and  $MDC_{95}$  are shown in Table 3. The ICC (1,1) values ranged from 0.956 to 0.989, and were all higher than 0.95 showing high reproducibility. The  $MDC_{95}$  values ranged from 4.563 to 6.791. Since the QPPA indices are expressed as percentage, it is possible to speculate from the  $MDC_{95}$  of an index the smallest percentage of significant change among the total possible change which can be detected by this method.

### Discussion

Muscle weakness due to palsy should fundamentally be assessed by measuring muscular tension. However, as shown by the definition of manual muscle test (MMT) grade 3: “Full available range of motion

against gravity”, in practice muscle weakness is often evaluated by movements. Furthermore, in the evaluation of central paralysis, emphasis is placed on motor pattern; i.e. movement. Conventionally, these movements were scored subjectively by visual observation. The present study was conducted with the objective to quantify objectively the impairment associated with paralysis using three-dimensional motion analysis. Most of the previous studies on lower limbs using a motion analysis device examined gait [11], and few investigated the level of functional impairment [12]. For the upper limbs, most of the reports were on reach movement [13, 14], and many were either preliminary studies with small number of cases, or used as an indicator of special training effects such as training robots.

Fisher, one of the pioneers of inferential statistics, proposed ICC, and Shrout and Fleiss [15] presented formulas for different types of interclass correlation. There are different types of ICC: (1) intra-assessor reliability when one assessor assesses multiple subjects [ICC (1, 1)]; inter-assessor reliability when multiple assessors assess multiple subjects [ICC (2, 1)]; and (3) inter-assessor reliability when assessors with different skill levels (random factor) assess stroke patients (defined by age, gender, lesion, length of hospitalization, others) (random factors) [ICC (3, 1)]. Since the present study was designed to examine the intra-assessor reliability using the same device, ICC (1, 1) was therefore adopted. Studies evaluating the reproducibility of motion analysis include that of Wagner et al. [16]. Their study examined the reproducibility of kinematic indices of reaching in 14 patients with chronic hemiplegia, and reported high

reproducibility for reach extent (ICC = 0.93–0.99), peak velocity (0.74–0.95), and maximum change in joint range of motion (0.93–0.99). In the present study, we found high ICC values of 0.956–0.989, which are consistent with their results.

SEM and MDC are two of the indices of minimal clinical important difference (MCID) [17]. These evaluation methods have been used also in the field of rehabilitation. Hiengkaew et al. [18] investigated the  $MDC_{95}$  of various lower limb functions, and reported that the  $MDC_{95}$  of Berg Balance Scale was 5 points (10% of total) and that of the lower limb subscale of Fugl-Meyer Assessment Scale was 4 points (16% of total). For evaluation methods using ordinal scales, because reproducibility is not necessarily high and the number of grades in the scale is limited, MCID cannot be exceeded if clinically the subjective changes are not above a level that is perceivable. On the other hand, the  $MDC_{95}$  of the QPPA indices, which are an objective scale, was 4.563–6.791 (approximate % of total), suggesting that these indices are sensitive in capturing significant changes.

There were some limitations in the present study. First, measurements were simplified. In this study, we attempted to simplify the measurements by using the minimum number of cameras and using the same filming environment for both upper and lower limbs. However, these attempts did not shorten the time of assessment compared with conventional methods such as SIAS-M and Brunnstrom Stage, and it is necessary to further examine simplification of the automatic analysis of the device and the assessment methods. Second, finger function was not assessed. Because of the small magnitude of finger movements which are difficult to film under the same filming condition, finger function was not included in the present study. We are planning to develop finger function assessment in the future. Third, paralysis was assessed by movements. Assessment of severe paralysis not capable of joint movement is difficult, and may result in floor effect. Fourth, external validity was not verified. In the present study, good reproducibility and MDC of the method were verified, but whether this method assesses hemiplegia in the true sense remains unknown. Further verification of criterion-related validity with conventional hemiplegia evaluation tools such as SIAS-M and Fugl-Meyer Assessment are necessary.

If the above issues can be solved, QPPA would be utilizable for evaluating rehabilitation effects between treatment groups and between facilities, as well as giving detailed feedback on the changes of paralysis to hemiplegic patients, and would provide objective data for such purposes.

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