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Comparison of the Modified Ashworth Scale (MAS) and Angle of Catch Measurement with Inertial Sensor and Goniometer

관성센서와 고니오미터로 측정한 수정 애쉬워스 척도 및 캐치 각도의 비교

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ABSTRACT

Comparison of the Modified Ashworth Scale (MAS) and Angle of Catch Measurement with Inertial Sensor and Goniometer

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Objectives: Spasticity causes major disabilities in activities of daily living of stroke survivors. While modified Ashworth scale (MAS) and modified Tardieu scale (MTS) are most commonly used methods for measuring spasticity, there are fundamental limitations of ambiguity and reliability. These drawbacks are especially due to inconsistency of manual or goniometer-based measurement of angle of catch (AoC). We developed inertial measurement unit (IMU) sensors to quantitatively measure a joint angle during passive range of motion (ROM). In this study, we investigated to compare the MAS measurement of spasticity with IMU and goniometer. Also, we aimed to examine the reliability of IMU-based measurement of AoC.

Methods: Patients with post-stroke spasticity were recruited. Those with co-morbidity or with serious cognitive impairments were excluded. An experienced physiatrist measured the MAS score in the pre-test clinic. The test protocol was based on the dynamic part of the MTS measurement of spasticity. Two examiners measured the spasticity using goniometer and the IMU for twice, respectively.

From the time-angle curve, we reviewed the pattern of curves that were scored as MAS 2 in the pre-test clinic. AoC was defined as the maximal deceleration point. Test-retest and inter-rater reliability of AoC measurement for both digital goniometer and IMU data were calculated with interclass correlation coefficients (ICC).

Results: A total of 23 stroke patients with 29 spastic elbows were included. In 8 spastic elbows measured as MAS grade 2, pattern of AoC could be classified into following three groups: (A) one patient showed marked catch at the end of ROM; (B) five patients showed marked catch after a half of the full ROM; (C) two patients showed marked catch before a half of the full ROM. The test-retest reliabilities of AoC measurement using digital goniometer were excellent (ICC 0.970, 95% CI: 0.936 - 0.986 for examiner A and ICC 0.968, 95% CI: 0.923 - 0.983 for examiner B), and inter-rater reliability was good (ICC 0.770, 95% CI: 0.510 – 0.892). For IMU sensor method, both test-retest (ICC 0.964, 95% CI: 0.923 - 0.983 for examiner A and ICC 0.949, 95% CI: 0.890 - 0.976 for examiner B) and inter-rater reliabilities (ICC 0.933, 95% CI: 0.858 – 0.969) were excellent.

Conclusion: Spastic limbs with MAS grade 2 had heterogeneous pattern of AoC indeed, which means that goniometer-based scoring of MAS is not accurate. Post-stroke spasticity measurement using IMU sensors is reliable and accurate, especially in AoC measurement. It showed greater inter-rater reliability than the digital goniometry method. Further studies should be needed to investigate a new spasticity measuring scale using IMU sensor.

Keywords: Muscle spasticity, Stroke, Inertial sensor, Reproducibility of results, Modified Ashworth Scale, Angle of Catch

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ABBREVIATIONS

AoC=Angle of catch

CI=Confidence interval

CT=Computed tomography

ICC=Interclass correlation coefficient

IMU=Inertial measurement unit

MAS=Modified Ashworth scale

MRI=Magnetic resonance imaging

MTS=Modified Tardieu scale

ROM=Range of movement

SD=Standard deviation

SDD=Smallest detectable difference

SEM=Standard error of measurement

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INTRODUCTION

Stroke is an important public health burden due to increasing portion of aged population in Korea.[1] About half of the stroke survivors will have significant functional impairment and frequently experience numerous clinical symptoms related to the damaged brain area.[2] Among those, pyramidal tract damage leads to upper motor neuron syndrome.[3] Typical features of upper motor neuron syndrome includes muscle weakness, muscle hyperactivity, muscle spasticity and other problems related to voluntary motor control.[4]

Spasticity was first defined by Lance in 1980: “a motor disorder characterized by a velocity dependent increase in tonic stretch reflexes with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflexes (muscle tone), as one component of the upper motor neuron syndrome”.[5] In 1990, Lance restated this definition by adding that “spasticity does not include impaired voluntary movement and an abnormal posture”.[6] On the contrary, a more recent study showed that tonic stretch reflex and tendon jerks do not correlate with each other.[7] This tells us that there are more underlying mechanisms of increased resistance to passive stretch other than increased reflex activity, such as changes in muscle properties.[8]

According to previous studies, about 40% of stroke survivors have spasticity.[9, 10] Post stroke spasticity can present as a debilitating condition that is often desperate. It may cause stroke survivors to experience disabilities to perform activities of daily living, as well as reductions in health-related quality of life.[11] Many therapeutic interventions such as muscle relaxants, intrathecal baclofen, and intramuscular botulinum toxin A injection target on the reduction of spasticity to achieve better function.[12] For the medical decisions regarding therapeutic planning and evaluation of the treatment effect, identification and measurement of spasticity is essential.

However, the measurement of spasticity has been criticized by its subjective and inaccurate nature. Modified Ashworth Scale (MAS) (**Table 1**)[13] is the most prevalently used measurement tool in clinical setting.[14] The validity is not consolidate because it does not consider velocity-dependence.[15] Also, its reliability is poor due to the ambiguity between the score "1", "1+", and "2".[16] Modified Tardieu Scale (MTS), first suggested by Tardieu et al.[17], considers velocity dependence of spasticity. An increase in muscle tone reflex is elicited in the fast stretch and can be felt as a 'catch'. The joint angle where this 'catch' happens, is called as the 'Angle of Catch' (AoC). However, the reliability of the Tardieu Scale and measurement of AoC has also been doubtful.[18, 19] The inaccuracy is caused by repositioning the joint into the angle where the catch occurred.[20]

Table 1. Modified Ashworth scale (MAS).

Score	Description
0	No increase in muscle tone
1	Slight increase in muscle tone, with a catch and release or minimal resistance at the end of the range of motion when an affected part(s) is moved in flexion or extension
1+	Slight increase in muscle tone, manifested as a catch, followed by minimal resistance through the remainder (less than half) of the range of motion
2	A marked increase in muscle tone throughout most of the range of motion, but affected part(s) are still easily moved
3	Considerable increase in muscle tone, passive movement difficult
4	Affected part(s) rigid in flexion of extension

Inertial measurement unit (IMU) is a small sensor that contains accelerometer, magnetometer, and gyroscope.[21] It is a wearable device that can show the time-joint angle curve in the sagittal plane with gyroscope in real-time. Velocity and acceleration can be calculated by differentiating the curve. Therefore, the examiner can conduct and quantify the usual MAS and MTS measurement simultaneously with the IMU put on the examinee without repositioning the joint for measurement.

In this study, we aimed to compare human- and IMU-based measurement of spasticity and construct evidence for IMU-based measurement. Patients with post-stroke spasticity were recruited and IMUs were attached to their extremities for the quantification of usual MAS and MTS measurement. We compared the IMU- and human-generated data of MAS and evaluated the test-retest and inter-rater reliability of the AoC by reviewing the time-joint angle curve.

MATERIALS AND METHODS

Participants

Study participants were recruited from Seoul Metropolitan Government (SMG)-Seoul National University (SNU) Boramae Medical center. Inclusion criteria of our study were: (1) age 19 years or older; (2) diagnosed as stroke with clinical and radiologic (CT or MRI) evidence; (3) presence of MAS grade 1, 1+, and 2 spasticity in at least one elbow joint; and (4) ability to understand study information and requirements and to sign on their agreement paper. Patients with contracture in the spastic elbow joint and those who were considered as ineligible for this study due to medical conditions (e.g. acute medical illness, severe cognitive dysfunction) were excluded.

This study was approved by the Institutional Review Board (IRB) of SMG-SNU Boramae Medical center, South Korea (IRB No. 02-2017-6).

Instrumentation

The measurements were performed using both of instrumentations (**Figure 1**): (1) a digital goniometer (200mm Digital Angle Ruler Meter Goniometer, Bluebird Inc., Seoul, Korea) and (2) the range of motion (ROM) sensing function of IMU-based system (Human Track, R-biotech Co., Ltd., Seoul, Korea). Joint motion tracking was performed by attaching two IMU sensors to proximal and distal of the joint of interest. Using Velcro tapes and straps, a sensor was placed at the ventral side of the upper arm. The other was placed at the dorsal side of the lower arm, just proximal to the distal radial head.

Figure 1. Instruments used in the study. (A) Digital Goniometer, (B) Inertial sensors and their placement.

A

B

Procedure and measurements

In the pre-test clinic, an experienced physiatrist evaluated the MAS grade of elbow joint. The testing protocol was based on the principle of the Tardieu scale according to Boyd and Graham.[22] The Tardieu scale engages 2 stretch actions, one at a slow speed (V1) and one at the fastest speed possible for the examiner (V3). V1 is a speed of "as slow as possible as or slower than the natural drop". Under V1, the examiner measures the passive range of motion. During a slow stretching movement, the examiner determines the angle of movement arrest, either due to patient discomfort or a mechanical resistance that could not be overcome without jeopardizing the integrity of the joint. V3 is a speed of "as fast as possible as or faster than the rate of natural drop of the limb segment under gravity". According to the Tardieu scale instructions, V3 should be chosen such that the range of motion (ROM) in the fast measurement can be reached within 1s.[23]

Two physiatrists (examiner A and B) performed the measurements on the same day. Participants were examined in the supine position. They were informed that the examiners would move their lower arm at different speeds and told not to do anything voluntarily. At the starting point of a measurement, the examiner kept the involved limb in the anatomical and neutral position. During a measurement, the examiners stabilized the limb with one hand and passively flexed or extended the elbow with the other hand.

One trial consisted of a passive ROM and AoC measurement with the IMU sensors attached. For the measurement using goniometer, the examiner repositioned the limb manually to the angle where the catch was felt after the joint extension.

Since IMU sensor is attached to the Tardieu trial using a goniometer, the results of both IMU and goniometer could be obtained simultaneously. The two examiners independently performed two trials of a participant with at least 5 minutes between repetitions. The order was randomized using computer-generated randomization. The examiners were blinded from each other's performance.

Data analysis of IMU measurements

For IMU sensor-based measurements, the angles of full ROM and acceleration rate of the movements were calculated using MATLAB 7.0.2 (The MathWorks, Inc., Natick, MA, USA). AoC was the main parameter of outcome. It was defined as the joint angle at the maximal deceleration point of lower arm in the sagittal plane and calculated by subtracting the joint angle at the initial position from that at the maximal deceleration point.

Statistical analysis

From the time-angle curve, we classified the patterns of curve that correspond to the MAS grade 2. The test-retest and inter-rater (examiner A and B) differences of AoC were done by comparing the mean values of each trial with the paired *t*-tests. Two-sided *P* value of < .05 was considered statistically significant. Test-retest and inter-rater reliability of AoC measurement for both digital goniometer and IMU data were calculated with intraclass correlation coefficient (ICC). Values less than 0.5, between

0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability according to Terry and Mae.[24] Standard error of measurement (SEM) and smallest detectable difference (SDD) was calculated to determine the contribution of error to the variance. Statistical analysis was done by using SPSS version 19.0.0 (SPSS, Inc., an IBM Company, Armonk, NY, USA).

RESULTS

Total of 23 stroke patients with 29 spastic elbows were included in the study. Their mean age was 58.6 years and 13 patients (56.5%) were male. Eight patients (34.8%) experienced hemorrhagic stroke and the others were ischemic stroke patients. **Table 2** shows the demographic and clinical data, and AoC of each measurement. **Figure 2** shows the typical curves for MAS 1 and 1+.

IMU-based measurement of catch in patients with MAS grade 2

In 8 spastic elbows measured as MAS grade 2 by an experienced physiatrist, three distinct patterns of AoC were shown: (A) one patient showed marked catch at the end of ROM; (B) five patients showed marked catch after a half of the full ROM; (C) two patients showed marked catch before a half of the full ROM (**Figure 3**). Pattern A is compatible with the definition of MAS 1, and pattern B is compatible with MAS 1+. However, pattern C could not be defined by classic definition of MAS.

Test-retest reliability

Table 3 shows the two examiners' (examiner A and B) test-retest reliability for the AoC measurements with both goniometer and IMU. There was no significant difference in AoC measurements, irrespective of examiner and instrument. The ICCs of both goniometer and IMU were 'excellent' (0.970 and 0.964 for examiner A;

0.968 and 0.949 for examiner B).

Inter-rater reliability

The results of inter-rater reliability of both goniometer and IMU are shown on **Table 4**. There was no significant difference between the two examiners. However, the goniometer showed ‘good’ reliability (0.770), whereas the IMU method showed ‘excellent’ reliability (0.933).

Table 2. Demographic, clinical and measurement data.

Patient ID	Gender	Age	Diagnosis	Laterality	Extensor/ Flexor	MAS	AoC (Examiner A)	AoC (Examiner A)	AoC (Examiner B)	AoC (Examiner B)
1	M	48	Ischemic stroke	Left	Flexor	1+	79.4	76.6	62.4	61.8
2	F	74	Ischemic stroke	Left	Extensor	2	68.3	72.8	74	77.6
3	F	77	Hemorrhagic stroke	Right	Flexor	1+	95.1	99.4	107.8	114.9
4	M	57	Ischemic stroke	Left	Flexor	1+	92.1	89.3	81.8	95.2
5	M	64	Hemorrhagic stroke	Left	Flexor	1+	93.9	85.6	89	100
6	F	46	Hemorrhagic stroke	Left	Extensor	1+	73.3	71.8	76.8	63.3
7.1	M	59	Ischemic stroke	Right	Flexor	1+	73.5	73.5	67.4	68.9
7.2				Right	Extensor	1+	77.2	81.7	74.2	69.7
8	F	56	Ischemic stroke	Right	Flexor	1	90.7	98	93.3	96.3
9.1	F	54	Ischemic stroke	Left	Flexor	2	80.8	83.1	72.8	81.9
9.2				Left	Extensor	1+	78.3	88.5	72.6	82.7
10	M	61	Hemorrhagic stroke	Left	Extensor	2	74.8	75.4	87	91.4
11.1	F	61	Hemorrhagic stroke	Right	Flexor	1+	94.9	100.8	75	78.7
11.2				Right	Extensor	1+	88.8	91.8	75.6	75.2

Table 2. Demographic, clinical and measurement data (Continued).

Patient ID	Gender	Age	Diagnosis	Laterality	Extensor/ Flexor	MAS	AoC (Examiner A)	AoC (Examiner A)	AoC (Examiner B)	AoC (Examiner B)
12	M	61	Ischemic stroke	Left	Flexor	1	95.3	93.2	70.4	89.3
13	M	62	Ischemic stroke	Left	Flexor	1	106.7	89	103	87.4
14	F	71	Ischemic stroke	Right	Flexor	1+	71.9	71.1	63.3	71.6
15	M	40	Hemorrhagic stroke	Right	Extensor	2	54.1	57.1	54.7	62.1
16	F	75	Ischemic stroke	Right	Flexor	1+	89.2	82.8	86.4	85.4
17	M	37	Hemorrhagic stroke	Left	Extensor	2	54.3	61.4	64.3	66.5
18.1	F	51	Ischemic stroke	Left	Flexor	1	84.3	80.6	81.2	78.4
18.2				Left	Extensor	2	72.6	72.8	68.7	73.9
19.1	M	82	Ischemic stroke	Right	Flexor	1+	83	80.8	80.7	87.7
19.2				Right	Extensor	1	101.4	104.6	108.1	120.1
20.1	M	47	Ischemic stroke	Right	Flexor	1+	79.3	92.1	87.4	81.1
20.2				Right	Extensor	2	49.5	46.8	46.9	43.4
21	M	80	Ischemic stroke	Left	Flexor	1	101.5	99.4	107.3	112.9
22	F	65	Hemorrhagic stroke	Left	Flexor	2	57	55.3	55.2	53.9
23	M	23	Ischemic stroke	Left	Extensor	1	114.5	122.3	128.3	114.3

Figure 2. Typical curves. (A) MAS 1 and (B) MAS 1+. Asterisk: AoC (shown as the point of slope change on the curve, where the stretch reflex occurs).

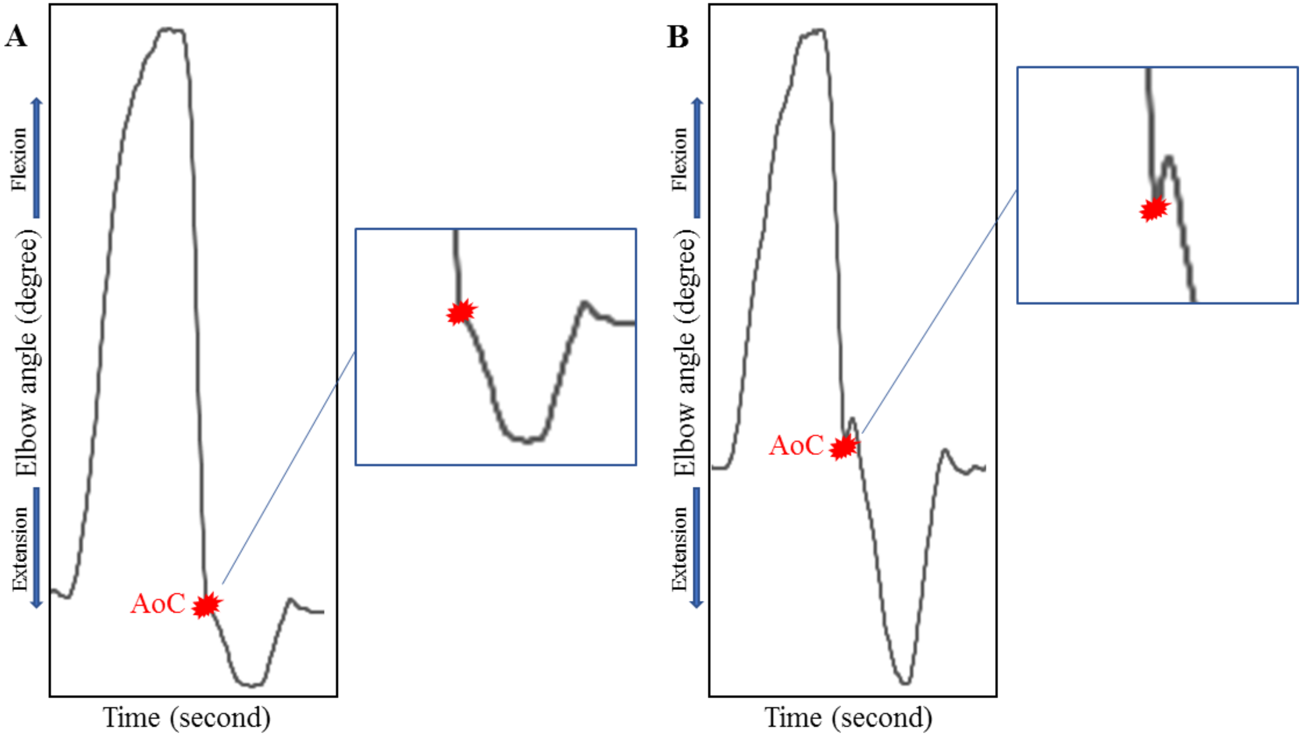

Figure 3. Pattern of IMU-measured AoC in patients scored as MAS 2. (A) Marked catch at the end of ROM, (B) Marked catch after a half of the full ROM, (C) Marked catch before a half of the full ROM.

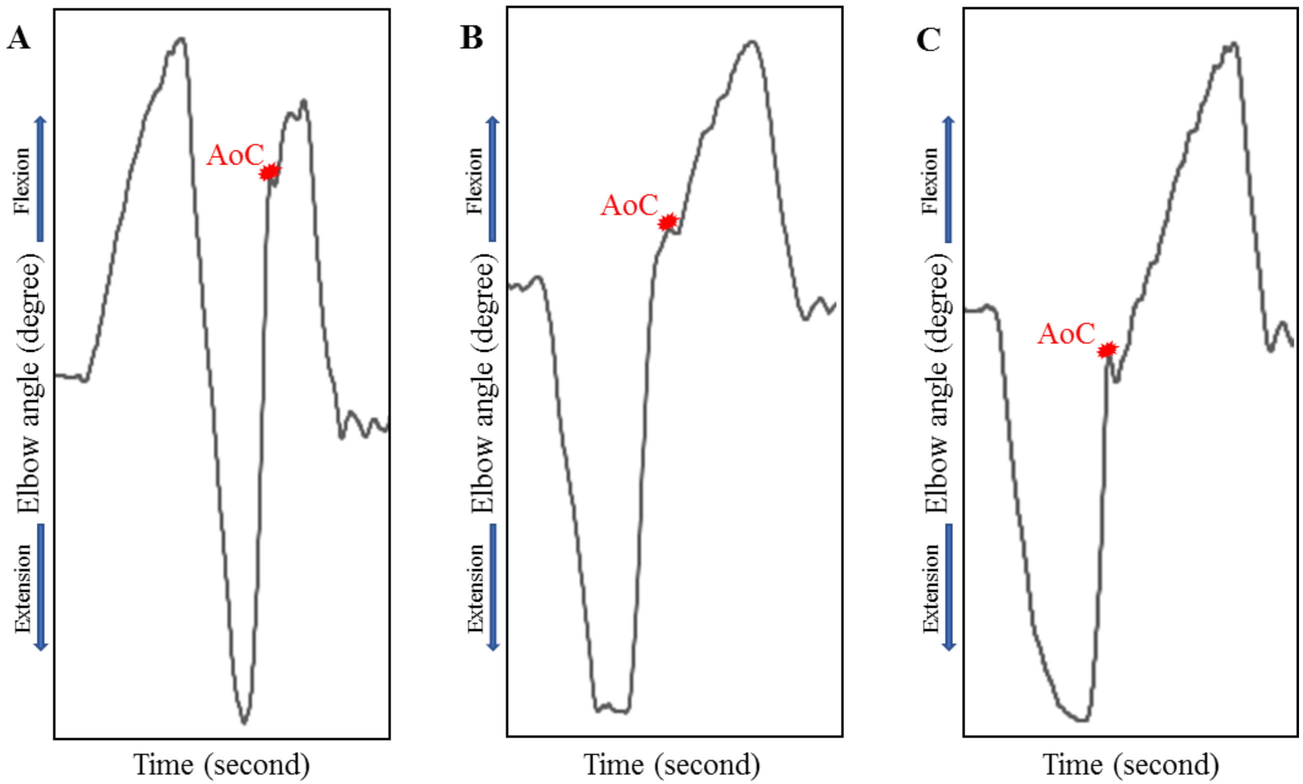

Table 3. Test-retest reliability for the angle of catch (AoC) measurement.

Examiner A test-retest	Test Mean (SD)	Retest Mean (SD)	*p*	SEM	SDD	ICC (95% CI)
Goniometer	84.228 (15.570)	85.662 (18.364)	0.194	3.153	8.74	0.970 (0.936-0.986)
IMU	81.921 (16.056)	82.676 (16.209)	0.507	3.035	8.413	0.964 (0.923-0.983)
Examiner B test-retest	Test Mean (SD)	Retest Mean (SD)	*p*	SEM	SDD	ICC (95% CI)
Goniometer	79.876 (15.543)	81.359 (14.947)	0.147	2.707	7.503	0.968 (0.932-0.985)
IMU	79.848 (18.295)	82.262 (18.621)	0.123	4.141	11.478	0.949 (0.890-0.976)

CI, Confidence interval; IMU, Inertial measurement unit; SD, Standard deviation; SDD, Smallest detectable difference; SEM, Standard error of measurement

Table 4. Inter-rater reliability for the angle of catch (AoC) measurement.

Inter-rater	Examiner A Mean (SD)	Examiner B Mean (SD)	*p*	SEM	SDD	ICC (95% CI)
Goniometer	84.945 (16.775)	80.617 (15.011)	0.101	7.638	21.171	0.770 (0.510-0.892)
IMU	82.298 (15.847)	81.055 (18.002)	0.437	4.354	12.069	0.933 (0.858-0.969)

CI, Confidence interval; IMU, Inertial measurement unit; SD, Standard deviation; SDD, Smallest detectable difference; SEM, Standard error of measurement

DISCUSSION

The results of this study revealed that the AoC patterns of those with spasticity graded as MAS 2 were heterogeneous. Some patients had to be scored as MAS 1 or 1+, and others could not be classified according to the definition (**Table 1**). Also, test-retest reliability of both goniometer- and IMU-based AoC measurement was excellent. Inter-rater reliability of traditional goniometer-based measurement was inferior to the IMU-based measurement.

Eight patients who were clinically assessed as MAS 2 could be divided into three categories (**Figure 3**). According to the definition of MAS, pattern A should be assessed as MAS 1, pattern B as MAS 1+, and pattern C could not be defined. Discordance on grades 0, 1, 1+, and 2 is in line with the results of previous studies.[13, 25, 26] Grades 1 and 1+ are distinguished mainly by the ratio of AoC followed by increase of resistance and entire ROM angle (see **Table 1**). However, the definition, 'at the end of the ROM' (in the definition of grade 1) and 'minimal resistance throughout the remainder - less than half' (in the definition of grade 1+) are subjective and seems to prone to error. Moreover, there is no category for the AoC that appears before the half of entire ROM. Also, inaccurate measurement of AoC and full ROM with goniometer might have affected to the discordance. Therefore, we suggest the need to revise the MAS definition. This revision must contain the score for the AoC that appears before the half of ROM. Moreover, further upgrade of our IMU system to automatically rating the MAS could be considered in future.

Li et al. reported that the overall test-retest reliability using goniometer was 0.71, which was lower than our study.[27] They also reported that inter-rater reliability using goniometer was about 0.78, which was similar to our study. The reason of higher test-retest reliability in our study might be due to shorter 'refresh period' between the test and retest. Examiners could have reproduced the angle of the initial measurement with the remaining memory of previous trial.

Lower inter-rater reliability of goniometer-based measurement may be explained by two facts. First is the misalignment of the goniometer to the joint. Flexion and extension movement of elbow joint is not done alone. The movement of elbow is a mixture of internal/external rotation, natural cubitus valgus/varus, and flexion/extension.[28] Therefore, the exact positioning of goniometer in proximity to the joint is inevitably inaccurate and can cause difference between examiners. Second, individual variance in repositioning the goniometer to the AoC might have affected. Van den Noort et al. showed that the repositioning of joint angle overestimates the AoC.[20] They compared the measurement with repositioning and without repositioning and concluded that the examiners are not able to reposition the segment exactly in the position where the catch appears. However, because the IMU-based system measures the angle by sensing the 3d-orientation without repositioning, it can overcome these problems and thus can lower the inter-rater differences.

There are several limitations to this study. First, our study did not evaluate the validity. For a measurement tool to be used widely, not only the reproducibility but the exactness of the result has to be guaranteed. In previous studies, validity of spasticity measurement was done with comparing electrophysiological evaluation results and goniometer-based measurement of MTS.[29] It showed relatively poor validity of goniometer-based MTS measurement. Similar method can be used to our IMU-based MTS measurement and its validity have to be examined in the future study. Second, as aforementioned, the 'refresh period' between the measurement sessions were relatively shorter than the previous studies. This might have affected to relatively higher test-retest and inter-rater reliability in our study, compared to previous studies. Lastly, joints other than the elbow were not evaluated in this study. Lower limb spasticity is directly related to gait function[30] but measuring it with goniometer is known to unreliable.[31] Reliable method of measuring lower limb spasticity is crucial in identifying patient's functional status and deciding the timing of anti-spasticity interventions. Therefore, reliability of IMU-based measurement of lower limb spasticity should be studied in future.

In conclusion, AoC measurement using IMU sensors is reliable in post-stroke patients. It showed greater inter-rater reliability than the digital goniometry method. Also, MAS grading done by human with goniometer was inaccurate. In detail, spastic elbows with MAS grade 2 showed heterogeneous pattern of catch that actually correspond with MAS 1 and 1+. Further studies are needed to examine the validity of this new IMU-based AoC measurement and to investigate a new spasticity grading system using IMU sensor.

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요약 (국문초록)

목적: 뇌졸중 생존자에 있어서 경직은 일상생활 수행의 주된 장애를 유발한다. 경직을 측정하는 도구로는 수정 애쉬워스 척도 (modified Ashworth scale, MAS)와 수정 타디우 척도 (modified Tardieu scale)이 가장 흔하게 사용되나, 정의 상의 모호함과 낮은 재현성으로 인해 근본적인 제한점이 많은 것이 사실이다. 이러한 한계는 인력으로 또는 고니오미터 (goniometer)를 이용한 캐치 각도 (angle of catch) 측정의 비일관성 때문으로 추측된다. 이를 극복하기 위해 우리는 관성 측정 도구 (inertial measurement unit, IMU)를 개발하여 가동 중인 관절의 각도를 측정할 수 있도록 하였다. 이번 연구에서는 각각 관성 측정 도구와 고니오미터를 이용하여 수정 애쉬워스 척도를 측정한 뒤 이를 비교하였다. 또한, 관성 측정 도구를 이용한 캐치 각도 측정의 재현성에 대해 평가하고자 하였다.

방법: 보라매병원의 입원/외래 환자 중 뇌졸중 후 경직이 있는 환자들을 대상으로 분석하였다. 의무기록과 문진을 통해 중증 기저질환이 있거나 심한 인지기능 저하가 있는 환자들을 확인 후 제외하였다. 숙련된 재활의학과 의사가 본 실험 전 외래에서 대상 환자의 경직을 수정 애쉬워스 척도로 측정하였다. 실험 프로토콜은 수정 타디우 척도의 역동적 측정 부분을 기반으로 설계되었다. 두 명의 검사자가 고니오미터와 관성 측정 도구를 이용하여 각각 두 번씩 경직을

측정하였다.

캐치각도는 시간-관절각도 곡선을 분석하여 감속이 최대가 되는 지점으로 정의하였다. 본실험 전 외래에서 수정 애쉬워스 척도 2점으로 평가된 환자들의 시간-관절각도 곡선을 분석하여 캐치각도 패턴을 확인하여 비교하였다. 고니오미터와 관절 측정 도구를 이용한 캐치각도 측정의 반복성 및 평가자간 신뢰도는 급내상관계수 (interclass correlation coefficient, ICC)를 이용하여 계산하였다.

결과: 23명의 환자에게서 29개의 경직이 있는 주관절을 측정하였다. 수정 애쉬워스 척도 2점으로 평가된 8개의 주관절을 분석하였을 때, 세 가지의 캐치 발생 패턴을 확인할 수 있었다. 1개의 주관절에서 관절가동범위의 끝에서 캐치가 발생하였고, 5개의 주관절에서 관절가동범위 절반 이상에서 캐치가 발생하였으며, 2개의 주관절에서만 실제로 관절가동범위 절반 이하에서 캐치가 발생하였다. 고니오미터를 이용한 캐치각도 측정의 반복성 신뢰도는 excellent로 평가되었고 (검사자 A, 급내상관계수 0.970, 95% 신뢰구간: 0.936 - 0.986; 검사자 B, 급내상관계수 0.968, 95% 신뢰구간: 0.923 - 0.983) 검사자간 신뢰도는 good으로 평가되었다 (급내상관계수 0.770, 95% 신뢰구간: 0.510 - 0.892). 관성 측정 도구를 이용한 캐치각도 측정의 반복성 신뢰도는 excellent로 평가되었고 (검사자 A, 급내상관계수 0.964, 95% 신뢰구간: 0.923 - 0.983; 검사자 B, 급내상관계수 0.949, 95% 신뢰구간: 0.890 - 0.976) 검사자간 신뢰도 또한 excellent로

평가되었다 (급내상관계수 0.933, 95% 신뢰구간: 0.858 – 0.969).

결론: 수정 애쉬워스 척도 2점의 주관절 경직은 실제로 캐치각도의 패턴이 다양하게 나타났고, 이는 고니오미터를 이용한 수정 애쉬워스 척도가 정확하지 않음을 시사한다. 반면, 관성 측정 도구를 이용한 뇌졸중 후 주관절 경직 평가는 정확하고 재현성이 있는 것으로 나타났으며, 특히 캐치 각도 평가에 있어서 그러하였다. 이를 토대로, 관성 측정 도구를 이용하여 비교적 정확하게 뇌졸중 후 경직을 측정할 수 있음을 알 수 있었다. 추후 연구를 통해 관성 측정 도구를 이용한 새로운 경직 측정 척도의 개발이 필요하다.

색인: 경직, 뇌졸중, 관성 측정 도구, 재현성, 수정 애쉬워스 척도, 캐치 각도

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감사의 글

설렘과 꿈을 안고 12층 재활의학과 전공의실에 들어섰던 것이 엊그제 같은데, 벌써 4년이라는 시간이 흘러 전공의 생활과 석사 과정의 말미에 있습니다. 너무나 부족한 제가 의학도로서 정진할 수 있었던 것은 서울대학교병원 재활의학교실 교수님들의 애정 어린 가르침 덕분이었습니다. 특히 다사다망한 가운데에도 제자의 연구를 시작 단계에서부터 지켜봐 주시고 연구 및 논문 작성 과정에서도 결정적인 조언을 해 주신 이시욱 교수님께 깊은 감사를 드립니다. 또한, 실질적인 부분에서 항상 따뜻하게 지원해주신 이상윤 교수님께도 감사드리지 않을 수 없습니다. 바쁘신 가운데에도 논문 심사를 위해 시간을 내어 주신 이상형, 권형민 교수님께도 깊이 감사드립니다.

같은 길을 걷고 있는 동료가 있다는 것이 저에게는 큰 힘이 되었습니다. 석사 과정을 같이 밟으며 제가 놓치고 있는 것이 있으면 옆에서 꼼꼼히 챙겨주었던 재현이, 같은 지도교수님 아래서 연구를 진행하면서 서로 많은 상의를 하며 발전적인 방향으로 나아갈 수 있도록 도와줬던 성민이가 아니었다면 여기까지 오기가 힘들었을 것이라 생각합니다. 또한, 이 논문의 데이터 측정에 있어 아주 큰 부분을 차지하셨던 도휘재 선생님께도 깊은 감사를 드립니다. 이외에도 전공의실에서 4년 간 동고동락하며 제가 앞으로 나아갈 수 있는 원동력이 되어주었던 여러 선후배 동기들에게 감사를 표합니다.

항상 무뚝뚝한 아들임에도 응원해주시는 부모님이 없었다면 지금 이 자리의 저는 없었을 것이라 생각합니다. 앞으로도 묵묵히 한걸음씩 나아가서 자랑스러운 아들이 될 수 있도록 노력하겠습니다.

이외에도 여기에 미처 적지 못한 많은 분들께, 저를 이끌고 깨우쳐 주시어 감사드립니다. 2년 간의 결실을 함께 나눌 수 있기를 바랍니다.