Evaluation of muscle thickness of medial gastrocnemius and ankle joint angle during walking in situ among hemiplegic patients

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***Abstract*—Most hemiplegic patients experience problems in maintaining proper body balance and postural control, which is one of the reasons for abnormal gait characteristics. These problems arise from damages of the central nervous system and lead to muscles' loss of functional capabilities. Methods that allow estimating the motor abilities and muscle properties of such patients could contribute to the efforts for their rehabilitation assessment. Ultrasonography is a promising approach to detect muscle morphological changes in both static and dynamic situations. In this paper, we carried out a new study using electronic angle gauge and ultrasonography to explore the ankle joint angle (AA) and the muscle thickness of the medial gastrocnemius (MTMG) during walking in situ among hemiplegic patients. Statistical data analysis procedure for hypothesis testing was used to get a reliable result. As a result, AA values show significant difference between the affected side with the unaffected side ($p<0.05$). However, MTMG values didn't show the same case ($p>0.05$). Besides, AA changes are not found linearly correlated with MTMC changes with both sides during walking in situ among hemiplegic patients.**

I. INTRODUCTION

Hemiplegia is a common manifestation after stroke and it is associated with impaired motor functions. There are several methods for clinical evaluation of the degree of disability of hemiplegic patients such as the functional scales [1, 2]. However, these methods require complicated operational procedures and are subjective. The adequacy of results highly depends on the experience of therapists, which is the reason why sometimes different physicians get different results for the same patients using the same scale. In order to make the evaluation more repeatable and objective, it is needed to explore methods for quantitative evaluation.

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To quantify the functional capabilities of hemiplegic patients, researchers have also made some evaluations in both kinetic and kinematic aspects, such as gait [3], foot-to-ground force [4], and the correspondence between the both [5]. According to the report by G. Kwakkel, there is a high risk of falling among the stroke patients [6]. Rehabilitation is usually conducted to preserve and recover motor functions and special attention is paid on fall risk assessment and corresponding treatment to improve the gait and the condition of lower limb muscles. It is well known that muscles are activated by the nervous system to generate forces and each of the muscles distributed all over the body fulfills a specific task [7]. At present, surface electromyography (EMG) has been shown to be a useful method to quantify superficial muscle activity. However, EMG signals from deep-lying muscles can be shadowed by those of superficial muscles and therefore it is hard to separate them non-invasively [8].

Sonomyography (SMG) can also reflect quantitative information of muscle activities. Application of SMG is of benefit for advancement of medical and engineering efforts to understand, diagnose or even treat musculoskeletal disorders. When investigating muscle activities, ultrasonographic systems are simple-to-operate, patient-friendly, highly-flexible and cheaper alternative of CT (Computed Tomography), MRI (Magnetic Resonance Imaging) and PET (Positron-emission Tomography) systems. For this reason they are preferred for estimation of skeletal muscle morphology under both static and dynamic conditions. English et al. validated that US allows for a reliable measure of muscle morphology, especially muscle thickness, in acute stroke patients at specific anatomical sites [9]. At present, SMG has been proved to allow accurate measurement of changes in muscle thickness (MT), fiber length, pennation angle and cross sectional area.

The biomechanics of the ankle joint during the gait cycle can provide a way to the hemiplegic patients to observe their recovery, and the researchers have evaluated AA quantitatively either by 3D motion model [10, 11] or inertial sensors [3, 12]. To quantify disability in patients, Guo et al. presented a practical method to measure knee and joint angles and gait cycles of hemiplegic patients during walking using Xsens MTx motion trackers attached on body segments [3]. They found that the extensibility of hemiplegic patient's affected limb was significantly lower than that of a normal subject's limb, and the hemiplegic gait had compromised balance level compared with normal gait. Besides, evaluating the correlation between the AA and other parameters have also been done by other groups, for example, the relationship between AA with pennetion angle and facial length of muscle

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by the study of L. L et al. [13], and the relationship between AA with force by the study of W. et al. [14]. Li et al. studied the thickness of anterior muscles during plantar flexion among hemiplegic patients by means of simultaneously captured SMG and EMG [15]. They found that the thickness of this muscle is linearly correlated with EMG RMS (root-mean-square), and they both are linearly correlated with muscle strength level. In this study, the AA and the MTMG are evaluated with the both sides, and in the end the correlation between those two parameters are explored during walking in situ.

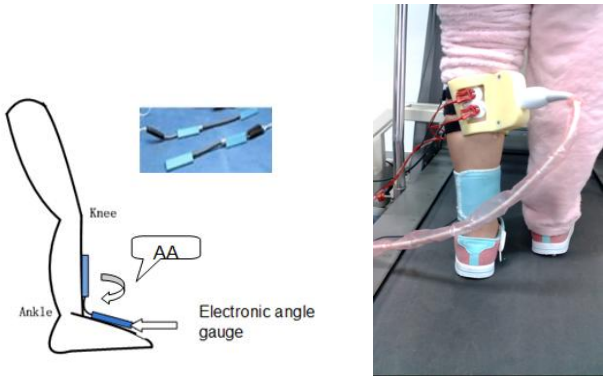
II. METHOD

A. Subjects

Fifteen hemiplegic patients from the physical therapy rehabilitation center of the Nanshan Hospital, Shenzhen, China, were recruited to participate in this experiment. For each of these patients an informed consent form was signed by the patient or by a patient's authorized legal representative. The group included ten males and 5 females. The study was approved by the institutional review board of Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences. The exclusion criteria included: (1) cognitive disorders that made patient incapable to follow the guidance of examiner; (2) severe motor dysfunctions that made the patients unable to walk on his own; (3) physical complaints that impeded the test, such as muscle pain.

B. Experimental setup

The multiparameter synchronous data collection platform incorporates hardware and software parts. The hardware units incorporate angle signal and SMG image acquisition modules; the software unit is controlled by Labview, thus the synchronized operation of data acquisition modules is guaranteed. A goniometer of type TSD130 (BIOPAC, USA) was used to measure the AA. In this experiment, the electronic angle gauges were attached on the two segments of the joint by means of adhesive tape as shown in Figure 1a, and the definition of AA can be seen from this figure.



(a) (b)

Figure 1. Experiment setup: (a) position of the electronic angle gauge and the defination of the AA; (b) ultrasound transducer.

SMG images were captured using a linear array ultrasound transducer by Sonostar Technologies Co., Ltd., Zhuhai, Guangdong, China. In addition, coupling gel was used to ensure the good contact between the transducer and the skin, and, consequently, the reliable acquisition of the sound wave. The US traducer operates at frequency of 7.5 MHz and has 70 mm depth of detection. The transducer was fixed on place to the limb using a customized device as shown in Figure 1b.

C. Experimental procedure

The experiments were performed on a treadmill. The most of the patients exhibited low balance ability during walking. In order to ensure their security, the subjects were asked to walk in situ. In order to guarantee the consistency of the experimental procedure among patients, all the subjects walked in situ to simulate walking in daily life. Following the examiner's 'start' instruction, the subjects began to walk in situ for 60 seconds. In some cases, in order to ensure the security, the patients were allowed to use the handrail. Following each test, the subjects took a rest for about 60 seconds. For each patient, the experimental procedure was performed for each of the lower limbs.

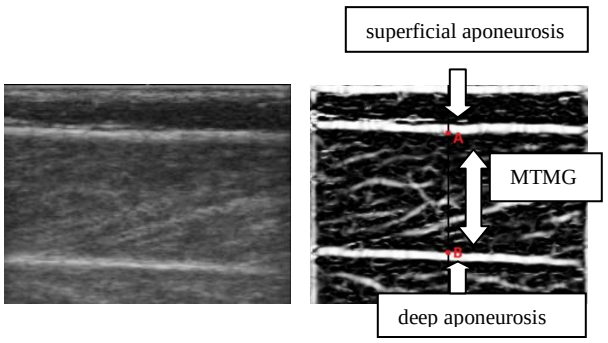
D. Data analysis

In every test, an angular signal was recorded synchronously. Considering high frequency noise which interferes with the angular signal, a low pass filter with cutoff frequency of 5 Hz and stopband frequency of 6 Hz was employed. Five gait cycles with relatively large amplitude ranges that correspond to large AA changes (AAC) were selected as a base for the study.

A total of 78000 SMG images (15 subjects ×1300 frames ×2 sides ×2 tests/side) with resolution of 251×431 pixels were acquired and all the images were cropped to keep the region of interest (ROI) only. SMG images were chosen to fall within the same time range as the selected angular signal. Visual inspection of the images for ten subsequent cycles of muscle thickness change was performed. Thus the frames which show the maximum and the minimum thickness of medial gastrocnemius were identified.

The quality of ultrasound images could be seriously affected [16] by speckle noises. Due to the higher efficiency of Multiscale Vessel Enhancement Filtering (MVEF) [17, 18] than Gabor Filtering [19], considering the similar enhancement result [20], MVEF was choosed to do the SMG image enhancement. As shown in Figure 3b, muscle thickness was approximated as the distance between the point A marked on the lower edge of superficial aponeurosis with point B on the upper edge of deep aponeurosis respectively. Figure 3a shows a raw cropped image. A vertical line was drawn at the center of every image using MATLAB, to make sure that in each frame the thickness at the same region of the muscle will be measured.

The SMG image enhancement was processed with programs written in Matlab (Version R2011b), and the statistical process was done with SPSS 19.0.



(a) (b)

Figure 2. (a) An SMG ROI; (b) The corresponding SMG image that was enhanced using MVEF, and the defination of MTMG..

III. RESULTS

Data from three subjects were discarded due to exercise failure; therefore only 12 subjects' data were valid. Five gait cycles were selected to get the average value of each parameter. For every cycle the maximum and minimum AA, as well as the maximum and minimum MTMG were collected.

AA values show significant difference between the affected side and the unaffected side. However, MTMG value didn't show the same case. As shown in Figure 4, it can be seen that the both in the minimum and the maximum situation, larger AA is shown in the affected side (123.3 versus 111.6 for the minimum AA, p=0.001; 138.1 versus 122.1 for the maximum AA, p=0.001). Besides, the affected side shows larger AA changes (AAC) during walking in situ (14.8 versus 10.5, p=0.07). In Figure 5, it can be seen that both in the minimum and the maximum situation, smaller MTMG is shown in the affected side in low degree(12.67 versus 14.42 for the minimum MTMG, p=0.1, 13.88 versus 15.32 for the maximum MTMG, p=0.2). However, the affected side shows larger MTMG changes (MTMGC) during walking in situ (1.21versus 0.9, p=0.22). The statistical results of AA and MTMG are shown in Table I and Table II respectively.

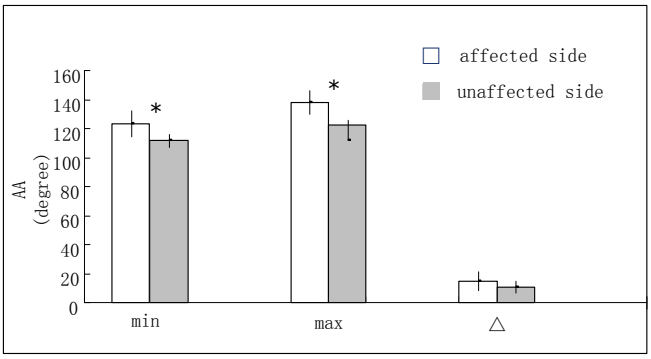


Figure 3. Minimum, maximum AA values and angle changes of the both sides during walking in situ. Min means the minimum AA, max means the maximmum AA, and △ means AAC.

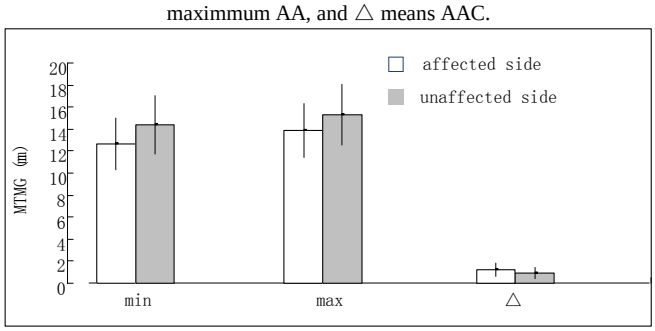


Figure 4. Minimum, maximum MTMG values and MTMG changes of the both sides during walking in situ. Min means the minimum MTMG, max means the maximmum MTMG, and △ means MTMC.

	A-min	*U-min*	*A-max*	*U-max*	*A-⊿*	*U-⊿*
Mean	123.3	111.6	138.1	122.1	14.8	10.5
SD	8.78	4.63	8.21	3.62	6.62	4.16

A means the affected side, and U means the unaffected side.

TABLE I. MTMG VALUE

	A-min	*U-min*	*A-max*	*U-max*	*A-⊿*	*U-⊿*
mean	12.67	14.42	13.88	15.32	1.21	0.9
SD	2.34	2.67	2.45	2.74	0.63	0.55

A means the affected side, and U means the unaffected side.

In the end, the correlation between the AAC and the MTMGC was also analyzed. From Figure 6, it can be seen that the degree of linear correlation is very low, and it is similar for both sides.

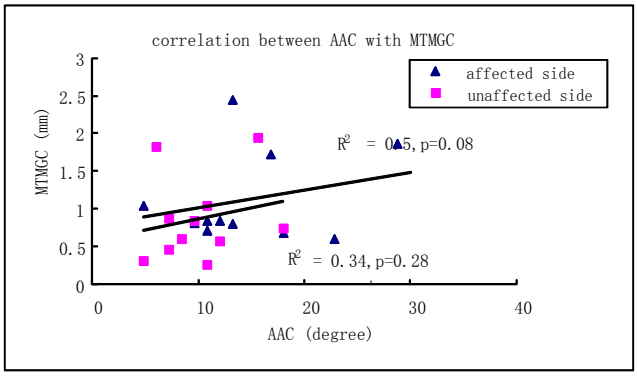


Figure 5. Correlation between the AAC and MTMGC..

IV. DISCUSSION

It has been reported that hemiplegic patients show less dorsiflexion than normal subjects [21]. In some cases ankle-foot orthoses were suggested to allow such patients to practice normal gait. Firstly, in this study, the affected side shows larger AA during walking in situ, implying more difficulty in dorsiflexion with hemiplegic patients. Since walking in situ demands less driving force which can be provided by plantar flexion during toe off, the dorsiflexion, which helps to keep the symmetry and consistency of walking is more needed in this experiment.

Secondly, considering comparison of the MTMG between the two sides of the hemiplegic patients, it can be found that

for the most of the subjects the value of MTMG of the affected side is lower than that of the unaffected side, which implies muscle atrophy. As a result, it is more difficult for the patients to use the activity of muscle to generate force during the daily life. Besides, according to Li et al [10], muscle strength level shows high degree of linear correlation with muscle thickness change. So, it is so significant to insist rehabilitation training, and thus the significance of the quantitatively evaluation which can help the physician to instruct the procedure and improve the confidence of the patients during the rehabilitation progress. At the same time, for the walking in situ of the hemiplegic patients, the affected side showed higher degree of motion, with larger range of AA change and MTMG change. It implies that for the affected side, for the lack of muscle strength, it is needed for larger range of muscle change to generate the similar force as the unaffected side.

In the end, for the correlation between the AAC with MTMGC the degree of linear correlation is very low, and it is similar for both sides. The safety concerns of the subjects in the experiments place limits to the range of AA. Therefore the range is significantly smaller than the one reported in normal subjects [3]. Limited to the smaller range of ankle motion during walking in situ, and due to the complicate adjustment in a small range of the body, it is needed to study the correlation between AAC with MTMGC in a larger range of motion of the ankle. Currently we are collecting more data from more subjects and will analyze corresponding results in future reports.

V. Conclusion

In this work we investigated the gait of walking in situ among hemiplegic patients. It is found that the affected side shows higher difficulty with dorsiflexion, and higher range of ankle joint is needed for this side to finish this activity. During the activity, muscle atrophy of the affected side is presented. a Further study with larger number of subjects and with more activities is needed to study the gait characters and muscle changes among hemiplegic patients.

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