Study on differentiation factors for main disease identification of intermittent claudication

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Study on differentiation factors for main disease identification of intermittent claudication

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Abstract— **Intermittent Claudication [1] is a walking symptom. After a short time walking, patients suffer from pains at lower limbs. But if taking a rest, the pains can be relieved and they can walk again. Unfortunately, it arises from not one but mainly two kinds of diseases: LSS (lumber spinal canal stenosis) and PAD (peripheral arterial disease). Additionally, it is reported that symptom is similar and LSS groups is furthermore divided into two main groups: L4 and L5 groups. Therefore, it is clinically very important to differentiate which diseases the patients suffer from, PAD, L4 or L5. We aims at developing the system to differentiate them from short walking motion data. In our previous paper [2], we derived differentiation factors, but did not consider the difference between L4 and L5 and the results are limited. This paper focuses on biarticular muscles associated with the diseases, and derive new and effective differentiation factors. The results supports their effectiveness and validity.**

I. INTRODUCTION

Intermittent Claudication [1] is a walking symptom. After a short time walking, patients suffer from pains at lower limbs. But if taking a rest, the pains can be relieved and they can walk again. Recently there has been a marked increase in the number of patients who consult a doctor of orthopedic surgery due to the intermittent claudication [3], since the intermittent claudication is one of walking symptoms. Unfortunately, intermittent claudication comes from not one but mainly two types of diseases: LSS (lumber spinal canal stenosis) and PAD (peripheral arterial disease). Additionally, LSS can be divided into two groups: L4 and L5 radiculopathies based on the area where stenosis occurs. It is clinically very important to identify the main disease for intermittent claudication.

Toribatake at al. [1]–[3] pointed out that PAD and LSS groups have similar symptoms and emphasized the significance of their differential diagnosis. There are mainly two types of examination methods for differentiation. The one is simple but poorly precise and often fails to differentiate. The examples are touching or observing standing posture. The other is precise but invasive and high cost. The examples are angiography, myelography, MRI (magnetic resonance imaging), ABI (ankle brachial index) [4]. Furthermore, these examinations require high professionals and precision instruments. It is difficult to conduct such a high cost examination at small hospitals. If we can differentiate with minimum required simple instruments, it would be very useful, and even non-professionals can easily use at small hospitals. With this in mind, we developed another examination method in which analyzing 2D walking motion measured by commercially available cameras [2]. However, the difference between L4 and L5 was not considered and the obtained results are still limited. The derived differentiation factors were only with regard to one angle corresponding to uniarticular muscles. However, the muscles associated with PAD, L4 and L5 are not only uniarticular but also biarticular. It indicates the possibility of existence of factors associated with biarticular muscles, or combination of multiple angles. Then, this paper tries to extract another differentiation factors related with combination of multiple angles. In half a century, there are several researches concerning with walking motion analysis [5]–[8]. However, the differentiation of intermittent claudication by walking motion analysis has not been researched very well.

A. Participants

The participants are 13 normal healthy persons (5 males and 8 females), 10 PAD patients (9 males and 1 females), 10 LSS (L4) patients (6 males and 4 females), and 13 LSS (L5) patients (4 males and 9 females). Medical doctors among the authors comprehensively considered clinical features, radiological examinations, surgical findings, MRI, MRA, ABI, contrast enhanced CT, and effects of selective nerve root blocks and diagnosed the patients. Since patients with LSS mainly suffers from L5 or L4 radiculopathies, this paper focuses on L5 and L4.

B. Motion capture

Fig.1 shows the walking motion measuring system. We constructed the measurement system as much as simply such that at small hospitals, even a few non-professional medical staffs can use. Note that we do not aim at developing measurement systems with high accuracy, but extracting clinically convinced and useful differentiation factors from limited information (from simple instruments). We also suppose that measurement is conducted in narrow space and at not-controlled environment. Then, we measured gait pattern of participants with LED markers who walk on the treadmill

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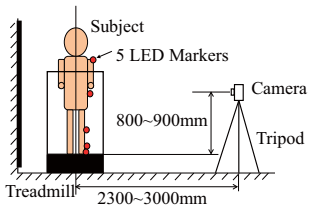
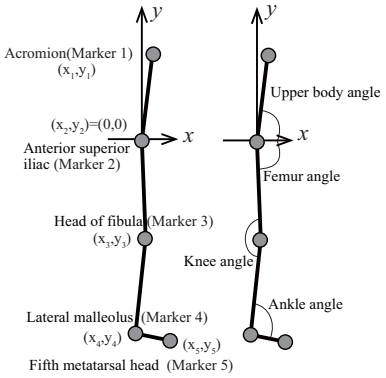


Fig. 1. Walking measurement system



(a) Marker positions (b) Angles

Fig. 2. Coordinate frame, marker positions, and angles

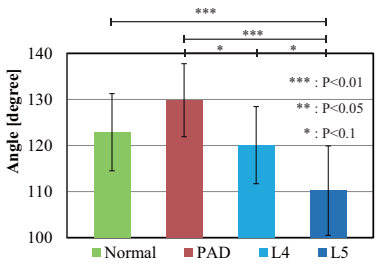


Fig. 3. Average of ankle angle

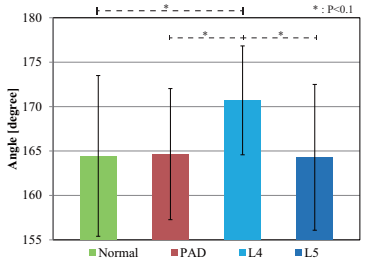


Fig. 4. Knee angle at stance phase start time (The dash lines show the case when conducting t-test for every pair)

in semidarkness such that LED marker positions can easily captured. Semi-darkness can transform not-controlled environment into controlled environment. Another purpose is to differentiate the groups with minimum required information. If the instruments are a few and simple, non-professionals can easily handle them and we can reduce measurement time, which is also comfortable for patients. Concerning this, we used the simple 2 dimensional motion capture system.

We put handmade LED markers on acromion, anterior superior iliac, head of fibula, lateral malleolus and the 5th metatarsal head of participant. Fig.2 (a) shows the definition of the coordinate frame and the marker positions. Note that the right side is forward in Fig.2. The LED markers were attached on the disordered leg. Before the experiment, the participants took a practice of walking on the treadmill. Its purposes are safety, calibrations, and setting of the treadmill speed.

We decided the speed so that the participant can normally walk. If the participant felt pain, we stopped the measurement. For the safety, medical doctors stand by watching the participant such that the medical doctors can immediately stop the treadmill and help the participant at accidents. The length per pixel of image was calibrated according to marker length attached on the treadmill. The used camera is commercially available product, and its frame rate was 30[frame/sec].

C. analysis

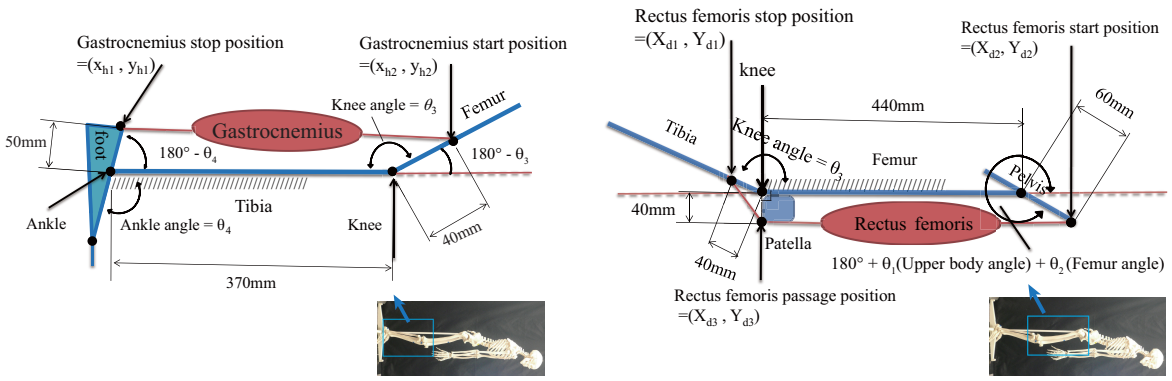
The used angles for analysis are shown in Fig.2 (b). We detected the marker positions by our own algorithm [2] based on LK filter [9]. From the marker positions, we derived the angles. Note that the angles do not identical to real ones since they are mapped on the sagittal plane, and then we call them with our own names. Analysis was conducted with regard to average one cycle data. The accuracy of this system depends on the resolution of camera and the distance between treadmill and camera. It was 2.97±0.23 [mm/pixcel].

II. Differentiation Factors

Frist, we describe the previously derived differentiation factors [2], in order to see how they change when considering L4 and L5 groups separately. Next we describe about new differentiation factors corresponding to biarticular muscles. Here, we focus on gastrocnemius muscle where is critical part for PAD group and quadriceps muscle where L4 group has sensation disturbance. After showing the results, we will discuss the results.

A. Previously derived differentiation factors [2]

Fig.3 and Fig.4 respectively show the results for previously derived differentiation factors. Let stance phase start time be the time when the x component of the marker position on the 5th metatarsal head is the largest. At the time the foot reaches its most forward position, and then the time is not always identical to the time when real stance phase starts (which is possibly before the stance phase start time). Therefore, we picked up knee angles at 4 frames before the stance phase start time and at the stance phase start time, and calculated their average, which is the knee angle at stance phase start time. From Fig.3, it can be seen that PAD group has large values while L5 group has small values, and there are statistical significant differences between PAD and L5 groups. Note that we used tukey-kramer method for statistics analyses. From Fig.4, it can be seen that the values



(a) gastrocnemius muscle (b) quadriceps muscle

Fig. 5. Reference models for biarticular muscle muscles

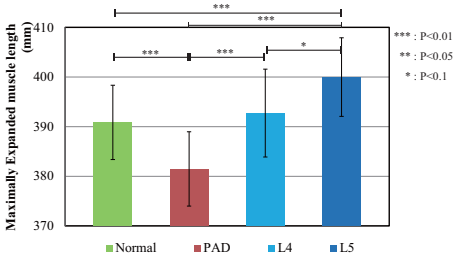


Fig. 6. Maximally relaxed muscle length of gastrocnemius muscle at the reference model

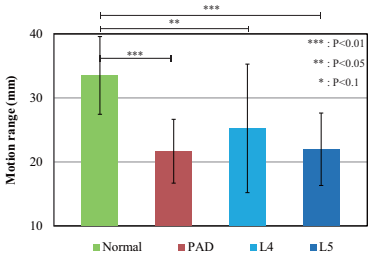


Fig. 7. Motion range of gastrocnemius muscle at the reference model

for L4 group is only large, although we did not get any significant differences. Note that if we conducted t-test for every pair, we got significant differences between L4 and the other groups, shown in Fig.4 with dash lines. The difficulty of differentiating L4 groups can be seen.

B. Factors associated with gastrocnemius muscle

Here we derive new differentiation factors associated with gastrocnemius muscle where is critical part for PAD group. There is individual difference for body size, and direct comparison of muscle lengths does not make sense. Then, we used reference model. We made it based on the bone size of the real human skeleton model in our lab. We decided the connecting positions between muscles and bones for the reference model based on the data of anatomia [10], [11]. Fig.5(a) shows the created reference model. If considering certain participant data, we calculated muscle length at the reference model regarding the knee and ankle angles for the participant as the knee and ankle angles for the model. Let the derived length be the muscle length for the participant. It is different from the real muscle length for the participant, but directly comparable. The comparable muscle length can be said to be normalized muscle length. Hereafter, we abbreviate *normaized* unless otherwise noted.

Utilizing this model and angle data, we calculated maximum relaxed and contracted muscle lengths, and motion range (See Fig.6 and Fig.7. Relatively effective factors are only shown). For maximum relaxed length, the value gets larger with the order of PAD, L4 and L5 groups except for Normal group. The difference was vivid and there are statistical significant differences between many groups. For motion range, the values for Normal groups are only large and there are statistical significant differences between Normal and the other groups.

C. Factors associated with quadriceps muscle

With the same way as gastrocnemius muscle, we created the reference model (Fig.5 (b) for quadriceps muscle associated with critical part for L4 group and derived comparable and normalized muscle length. Utilizing this model and angle data, we calculated maximum relaxed and contracted muscle lengths, and motion range (Fig.8 and Fig.9). For maximum contracted length, the value for L4 is small, although vivid differences could not be gotten. For motion range, the values of normal and L4 groups are large and there are statistical significant differences between L5 and the other groups.

D. Discussion

From Fig.3, previous factor [2], namely average angle of ankle is considered to be effective to differentiate PAD and L5 groups. From Fig.6, it can be seen that maximally relaxed muscle length of gastrocnemius muscle are effective to differentiate PAD and the other groups. Comparing with the previously derived factors, its high effectiveness can be seen.

Soleus muscle associated with ankle angle and gastrocnemius muscle belong to triceps surae muscle which is critical (the area where problems appear) for PAD group. PAD

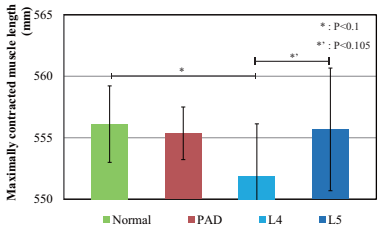


Fig. 8. Maximally contracted muscle length of quadriceps muscle at the reference model

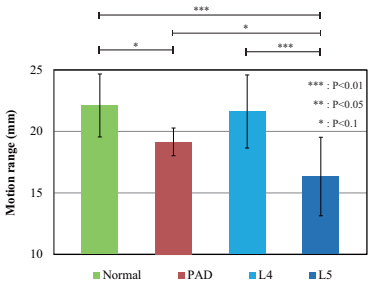


Fig. 9. Motion range of quadriceps muscle at the reference model

patients have to prevent collapse and stenosis of blood vessel inside the muscles. They would like to keep the radius of the blood vessel large in order to deliver the blood minimizing the loss of the blood flow, especially at the knee joint in spite of the decrease of the blood flow at the upstream due to stenosis, and keep enough large blood flow at crural muscle. Then, they keep the length of the gastrocnemius muscle large, and ankle angle large at any time. In reality, the factor associated with gastrocnemius muscle is related with the soleus and gastrocnemius muscles and then this might be the reason why this factor was more effective.

On the other hand, L5 group has sensation disturbance at tibialis anterior muscle and bottom side of foot. This causes the increase of risk of collisions between (tip area of) foot and ground. In order to decrease the risk, L5 patients tend not only to keep ankle angle small but also not to lift up their legs, which indicates their walking is close to shuffling. Small ankle angle, large maximally relaxed muscle length and small motion range support the hypothesis.

From Fig.9, it can be seen that motion range of quadriceps muscle are effective to differentiate L5 and the other groups. But, if seeing both Fig.8 and Fig.9, it can be seen that this factor is important for differentiation of L4 groups. From both figures, we can see that motion range for L4 group is similar to Normal group, but the contraction amount is largest. It indicates that L4 group walks keeping the quadriceps muscle contracted. For L4 group, quadriceps muscle is critical and there is sensation disturbance. This causes large unexpected bending/flexion of knee angle just after landing. In order to get smooth walking in spite of the unexpected bending/flexion, they tend to keep the quadriceps muscle contracted (small upper body, small femur and large knee angles), especially at the landing (see Fig.4). Motion range similar to Normal group might be due to the unexpected bending/flexion (If they could avoid the unexpected bending/flexion, motion range might be small). Note that the reason for small motion range at L5 group is considered to be the same as the case mentioned before.

Summarizing, by considering differentiation factors associated with biarticular muscles (combination of multiple angles), we got stronger differentiation factors for differentiating Normal, PAD, L4 and L5 groups (comparing with previously derived factors).

III. Conclusion

Intermittent claudication mainly comes from two kinds of diseases: LSS (lumber spinal canal stenosis) and PAD (peripheral arterial disease). LSS is also subdivided into L4 and L5 groups. The medical treatments for them are totally different, and then their differentiation is very important problem. In our previous paper [2], we derived differentiation factors related with unit angle. However, the obtained results were still limited. This paper presented new differentiation factors associated with combination of multiple angles, focusing on biarticular muscles. The results support the effectiveness of new factors. We also discussed why we got effective factors taking into account diseases characteristics. The derived factors are effective but a little bit large variances can be seen. The differentiation system concerning the variance might be our future work.

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