足指・足爪の機能改善による虚弱高齢者の歩行能力の計測

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Measurement of Ambulatory Ability by Improvement Function of Toe and Toenail for the Elderly

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Abstract: The medical foot care, which removes the interference from thickening of the nail, improved the angle of ankle, the knee elevation, the moving of greater trochanter and double stance phace, it seems that it is effective to improve the walking ability of the aged. It is suggested that the medical foot care of the aged has possibility to prevent the fall.

1. はじめに

高齢者の多くは足指・足爪に異常を抱えており，歩行に影響があると予測される．足指・足爪の異常は転倒リスク増加の 1 つの要因となると考える．そこで本研究では，高齢者の足指・足爪の異常を改善することによる歩行能力の変化について調べた．その結果，次の 4 点が明らかになった．(a) 足関節動作範囲が小さくなる，(b) 歩行中の蹴りだしの力の減少から膝関節の高さの低下，(c)歩行中の身体重心位置の変動量の増加，(d) 両足支持時間の増加を確認した．以上，足指・足爪異常の改善は，歩行能力の向上に寄与し，転倒リスク低減に有効であることが示唆された．

2. 実験方法

2.1 対象者

対象者は特別養護老人ホームに住む高齢者 10 名（平均年齢 80.6±6.1 歳，76～96 歳）で自立歩行可能，心疾患および脳血管疾患の未経験者とした．対象者には実験前に計測内容の説明を行い，十分な理解を得た．

2.2 メディカルフットケア

対象者の足指・足爪異常の判断は，メディカルフットケア（以下，フットケアとする．）技術を有するフットケアワーカーが行った．フットケアの内容は，皮膚と足爪の状態を観察し，足部を洗い角質を除去する．さらに，足爪は爪切りやニッパーを用いて巻き爪や肥厚した爪を切る[1]．フットケアの頻度は月に 1 回とし，週，曜日を決めて一年間実施した．

2.3 計測項目

(a) 足関節動作範囲

中高年者の歩行中の足関節動作範囲は，若年者と比較して約 50 % 小さくなり足関節の可動性の衰えを表す．我々は，足指・足爪異常が歩行中の足関節動作範囲を小さくすると考える．本研究では歩行中の足関節動作範囲を計測するために，Fig.1 中の対象者の B.膝関節外顆，C.足関節外果，D.踵，E.第 5 中足骨粗面に取り付け，デジタルビデオカメラから得られたデータから，歩行中の足関節角度 θ_σ を求めた．Fig.1 の θ_1 は足関節動作範囲の基準とし，$\theta_{2\,max}$ を足関節伸展角度，$\theta_{3\,min}$ を屈曲角度とする．足関節角度 θ_σ は，式(1)より求めた．

$$\theta_\sigma = (\theta_{2\,max} - \theta_1) + (\theta_1 - \theta_{3\,min}) \quad \cdots (1)$$

(b) 膝関節の高さ

足指・足爪の異常は，下肢筋力と姿勢制御能が低下し，立脚相後期から遊脚相への蹴りだしの力が低下すると考えられる．本研究では，蹴り出しの力が膝関節の高さと比例関係にあることから膝関節の高さに着目した．本研究では，動画解析のためのマーカ位置を Fig.1 の B.膝関節外顆に取り付け，デジタルビデオカメラから得られたデータより，歩行中の膝関節の高さを求めた．Fig.1 の f_y は膝関節の高さの基準とし，f_{ymax} を膝関節の高さの最大値とする．膝関節の高さ f_δ は式(2)より求めた．膝関節の高さは正規化のため，式(3)より求めた f_δ を各対象者の踝から膝関節外顆までの長さで除した．

$$f_\delta = f_{ymax} - f_y \quad \cdots (2)$$

(c) 大転子の変動量

人間の歩行中の重心位置は上下，左右方向に変動する．歩行中の上下の重心位置の変動量は，小さく滑らかになることで歩行の安定性が向上するとされる[2]．我々は足指・足爪異常が歩行中の安定性を低下させ，重心位置の変動量が大きくなると考える．本研究では，重心位置の変動量を調べるため，人間の重心位置の近くにあるとされる Fig.1 の A の位置，すなわち大転子に

マーカを取り付けた．計測ではビデオ撮影から得られたデータより歩行中の大転子の変動量 F_{δ} を求めた．Fig.1 の F_y は大転子の位置の基準とし，F_{ymax} を大転子の最大値，F_{ymin} を大転子の最小値とする．大転子の変動量 F_{δ} は式(3)より求めた．

大転子の変動量は正規化のため，式(2)より求めた F_{δ} を各対象者の下肢長で除した．

$$F_{\delta}=|F_y - F_{ymin}|+|F_{ymax} - F_y| \quad \cdot\cdot\cdot(3)$$

(d) 両脚支持時間

先行研究では，高齢者の歩行の特徴の一つとして，片足支持時間が減少し，両脚支持時間の割合の増加がみられると報告している[3]．本研究では，足指・足爪異常の改善により両脚支持時間が減少すると考える．計測では，ビデオ撮影から得られたデータより両脚支持時間を求めた．

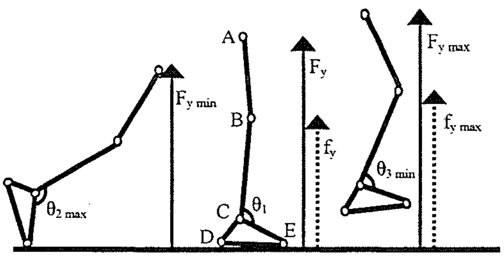

Fig.1 Measurement of rotation range of ankle joint and the knee elevation , moving distance of greater trochanter

3. 結果および考察

Fig.2 に動画計測から得られた各歩行能力の結果を示す．Fig.2 (a)の足関節動作範囲はフットケア前と比較してフットケア 3 ヵ月後で 161%の向上が得られ，5%以下の危険率で有意差が確認された．Fig.2 (b)の膝関節高さはフットケア前と比較してフットケア 1 ヵ月後で 120%の向上が得られ，1%以下の危険率で有意差が確認された．Fig.2 (c)の大転子の変動量はフットケア前と比較してフットケア 4 ヵ月後で 60%の低下が得られ，1%以下の危険率で有意差が確認された．Fig.2 (d)の両脚支持時間はフットケア前と比較してフットケア 3 ヵ月後で 19%の低下が得られ，1%以下の危険率で有意差が確認された．

これらの結果より，次の 4 つのことが推測される．

(1) 足関節動作範囲は，フットケアを行うことで維持・向上の兆しが考えられる．
(2) 膝関節の高さは，フットケア開始 1 ヵ月後で 120%改善し，立脚相最周期の蹴り出しの力を向上させる傾向にあった．
(3) 大転子の変動量は，フットケア開始 4 ヵ月後で 60%低下し，改善する傾向にあった．
(4) 両脚支持時間はフットケア開始 3 ヵ月後で 19%低下する傾向にあった．

足指・足爪異常は，長期的に足部に無関心になることで形成されると考える．効果的に歩行能力を向上するためには足指・足爪に着目し，フットケアを推進することが重要である．

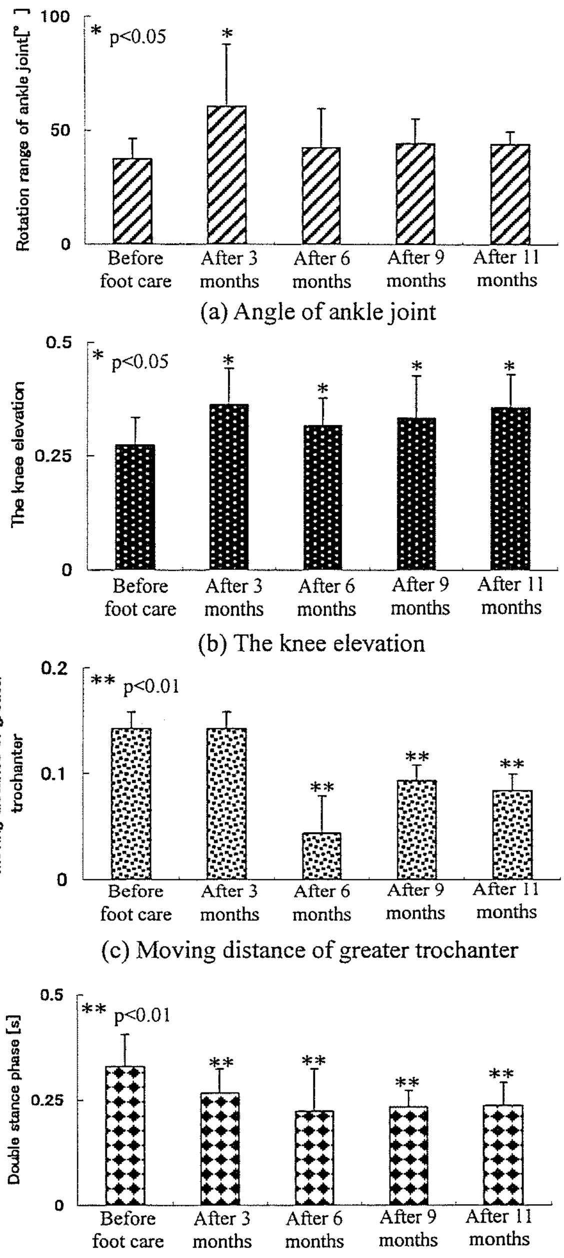

Fig.2 Results of walking ability

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The Role of Toe-gap Force for the Evaluation of Falling Risk on the Elderly

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Abstract— **This paper was proposed a toe-gap force measurement to estimate the lower limb muscular power. In the proposed method, the clipping toe-gap force is measured between the great toe and the digitus secundus. The toe-gap force in this situation, is muscles of the lower limb, which are supposed to have roles in the effort against falling. This study was used three experiments to determine whether or not the use of the toe-gap force measurement was useful from a practical viewpoint. First, the aging change in toe-gap force was examined by using the developed measuring device for 361 people included the elderly with physical weakness. Second, to examine the relation between the toe-gap force and falling, we were examined falling experience in a year for 82 healthy volunteers. Third, to examine the relation between muscular power and the toe-gap force, the results of the toe-gap force were compared to the result of the 10 m walking time for 153 healthy volunteers. We found following results: 1. the toe-gap force reflected the lower limb muscular power decrease rapidly from 65 years old. 2. The non-faller group demonstrated the factor of 1.3 greater toe-gap force compared with the faller group. The subjects who have less toe-gap force have experienced many falls. 3. the measured toe-gap force is closely related negative correlation to walking ability. This implies that the lower limb muscular power is reflected on the toe-gap force measurement. It is thus concluded that, the proposed method can be a practically useful method for evaluating quantitatively the lower limb muscular power of the elderly against fall.**

Keywords— **Toe-gap force, lower limb muscular power, elderly, falling prevention**

I. INTRODUCTION

Falling is one of the most common and serious problems because advancing age has been associated with muscle weakness, reduced cutaneous sensation and deterioration of postural control system. Falling causes the hip fracture and the bed-bound, and increases national medical expenses for the aged. About 1% of falls cause hip fracture and 5% result in any type of fracture[1].

Decade from now with the graying of the baby-boom generation, it is indicated that fall-related problems such as hip fractures will quadruple over the next 40 years[2]. It is easy to assume that the fall-related problems will heavily task the health care systems, as the medical expenses for the elderly, unless effective approaches to prevent falls and develop new method and device about prevention falls.

The some of falling factors are reported the decrease of lower limb muscular power and ability of postural control[3-5]. However, the technique and device which evaluate quantitatively lower limb muscular power and ability of postural control are not developed. This paper proposes a toe-gap force measurement as an evaluation of the lower limb muscular power for this purpose.

The major design goals were focused on portability, economy, effectiveness, and convenience which are considered as the result can be clearly shown, in the evaluation of lower limb muscular power. The proposed device was developed so that these conditions might be fulfilled.

The aim of this paper was examined the aging change of lower limb muscular power focused fore part of the feet by the toe-gap force for 361 people (mean 65.1 years old, 3 to 95 years old) included the elderly with physical weakness. Second, we was examined the experience falling for one year, and referred the relation to the toe-gap force. Third, to examine the relation between the toe-gap force and walking ability, the results of the toe-gap force were compared to the results of the 10 m walking time.

II. MATERIALS AND METHODS

A. Measurement device of toe-gap force

Fig.1 shows the measuring device for toe-gap force. In the proposed method, the clipping toe-gap force is measured between the great-toe and the digitus secundus. This device has a structure similar to the grip dynamometer, and the toe-gap force is displayed by a mechanical structure.

Fig.2 shows one example of the usage. When the toe-gap force measurement device is used, the subject is seated in front of the device. It is safe because there is no danger of a falling accident during the measurement process. And it can be easily to measure only one person.

Fig.3 shows the muscles have effects in generating the clipping force. Muscles of directly related to the toe-gap force are the transverse head of adductor hallucis and the plantar interossei[6]. The movements of the toe are generated by collaborative actions of flexor-tensor muscles, such as the flexor hallucis brevis, the flexor digitorum longus, the floxor digitorum brevis, etc.. These muscles compose the lowest part of the feet. Thus, the measurement of the toe-gap force is the general assessment of muscular power in the lower limb.

Analogous to the fact that the grip of hands is generated by the collaborative actions of the distal muscles of upper extremity[4], it is considered that the toe-gap force reflects the muscular power in the lower limb.

These muscles play the important roles in fixing the great-toe as well as in walking, in final term of stance phase[5]. Degradation of these flexor muscles force and the tibialis anterior will produce stumbling, which is the main cause of falls. These muscles also enhance the function of all constituents of the plantar arch. The arch of foot works as a shock absorber and functions of the postural control. The toe-gap force measurement can be used to evaluate these flexor muscles of the lower limb.

B. Aging change in the toe-gap force

The aging change in muscular power by the toe-gap force, was examined by using the developed measuring device. Young healthy participans (male: n=29, age:15.0±10.5(3-35 years old) , female: n=45, age:19.1±9.9 (3-44 years old)) , middle age healthy participants (male: n=8, age: 56.9±6.0 (46-64 years old), female: n=13, age:57.5±6.2 (46-64 years old)), elderly healthy participants (male: n=43, age:77.1±5.3 (69-90 years old), female: n=166, age:79.1±6.2 (65-95 years old)) and elderly participants in the physical weakness (male: n=23, age: 79.5±7.3 (66-94 years old, female: n=34, age: 79.9±6.5(69-92 years old)) were recruited from the volunteer.

c. Relationship between toe-gap force and falling experience for one year

There are many reports that a correlation between the experienced fall and the falling risk, so it is important to estimate the falling risk in the future. To examine the relation between toe-gap force and falling, we examined the falling experience for one year. The subjects were 82 healthy volunteers (mean 82.0 years, age range from 72 to 95 years old) in this experiment.

D. Relationship between toe-gap force and walking ability

The toe-gap force was compared with the basic physical function as the walking ability, because there are many reports such as a risk of fall which have relationship between the 10 m walking time and the experience of fall[3-5]. The subjects were 153 healthy volunteers in this experiment.

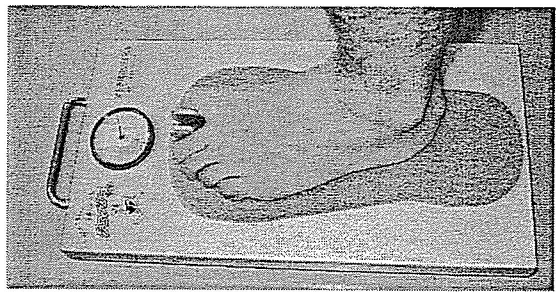

Fig.1 The measurement device of toe-gap force

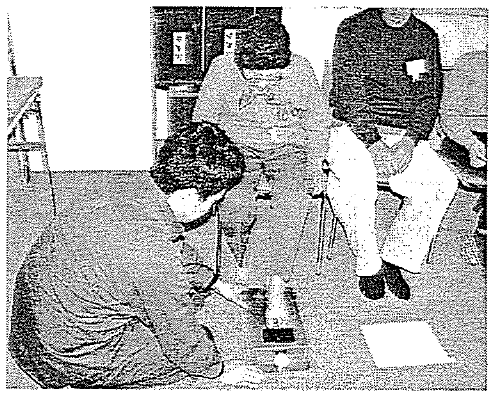

Fig.2 Example of how the device is used

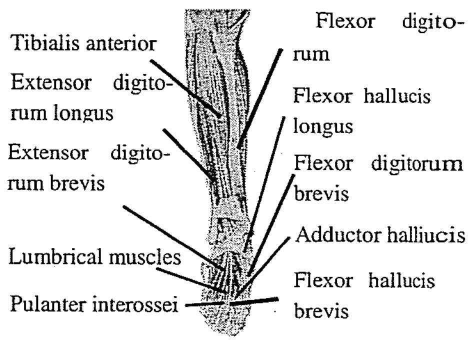

Fig.3 Anatomy view of lower limb

For the assessment of lower limb muscular power, the subjects were divided into two age group as young old (age range from 65 to 74 years old, mean 71.2±2.0 years old, 9 males and 20 females) and old old (age range from 75 to 95 years old, mean 81.8±5.0 years old, 13 males and 111 females).

The comparisons of toe-gap force between faller and non-faller were made using One-factor ANOVA. The results of toe-gap force and 10 m walking ability were made using Wilcoxon sign-ranks test.

III. Results

A. Aging change in the toe-gap force

Fig.4, 5 show the results of aging change in the toe-gap force. As the result, the decrease because of the aging of the toe-gap force was confirmed both male and female.

On an average of toe-gap force in twenties, male is 6.3 kgf, female is 3.9 kgf. On an average from 45 to 64 years old, male is 5.9 kgf (right) and 5.0 kgf (left), female is 3.9 kgf (right) and 3.7 kgf (left). For the young old, male is 3.9 kgf (right) and 3.8 kgf (left), female is 2.8 kgf (right) and 2.9 kgf (left). For the old old, male is 4.0 kgf (right) and 3.8 kgf (left), female is 2.5 kgf (right) and 2.4 kgf (left). For the elderly with physical weakness, male is 2.1 kgf (right) and 1.9 kgf (left), female is 1.9 kgf (right) and 1.6 kgf (left).

It was suggested that the toe-gap force as well as the lower limb muscular power decrease rapidly from 65 years old.

B. Relationship between toe-gap force and falling experience in one year

Fig.6 shows the result of the toe-gap force the relationship between the faller group and the non-faller group. The faller group consists of 22 subjects, the non-faller group consists of 60 subjects.

As the result, the non-faller group demonstrated the factor of 1.3 greater toe-gap force compared with the faller group. It found that there are relationship at 8 % under of the risk rates between the toe-gap force and the experienced fall.

C. Relationship between toe-gap force and walking ability

Table 1 shows the results of the relationship between toe-gap force and 10 m walking time as well as lower limb muscular power and walking ability.

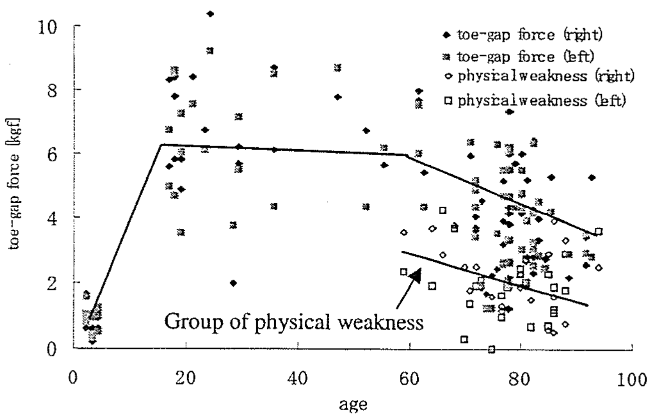

Fig.4 Aging change in the toe-gap force (male)

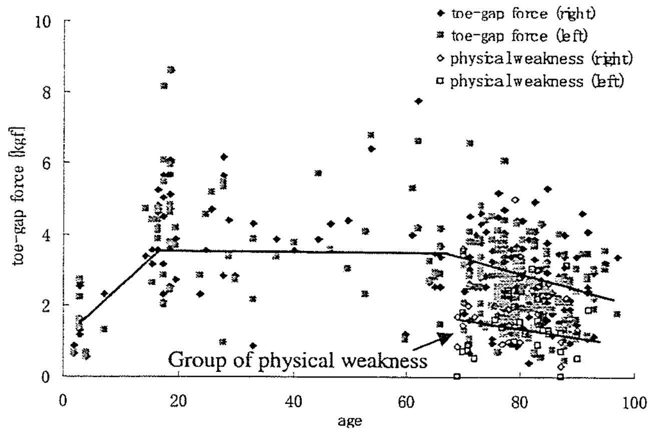

Fig.5 Aging change in the toe-gap force (female)

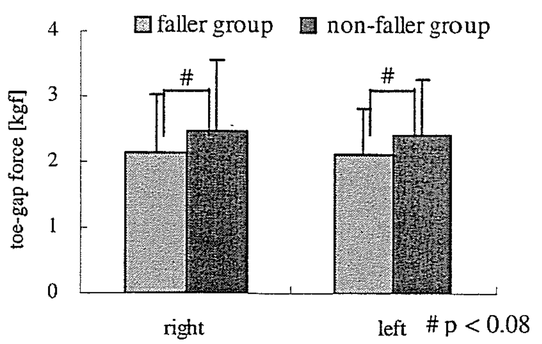

Fig.6 Relationship between toe-gap force and falling experience for one year

Table 1 Relationship between toe-gap force and walking ability

	under 75 years	75 years and over	average	test (R,L)
toe-gap force (right) [kgf]	3.1± 1.2	2.6± 1.1	2.7± 1.2	
toe-gap force (left) [kgf]	3.2± 1.2	2.5± 1.0	2.7± 1.1	
10 m walking normal speed [s]	8.77± 1.67	10.91± 3.02	10.49± 2.9	-*, -**
10 m walking maximum speed [s]	6.57± 1.50	7.89± 1.95	7.62± 1.93	-**, -**

* $p < 0.01$, ** $p < 0.005$

As the results, it is seen that the measured toe-gap force is closely related negative correlation to the lower limb muscular power and walking ability. The method of measurement of 10 m walking time is semi-quantitative measurement technique, and a lot of disturbances as the psychological hallmark in the subjects, are often generated. And there is a falling risk during the measurement.

On the method of toe-gap force measurement, there is no danger of the fall for this measurement process by the seating. And it is possible to measure it quantitative, safety, everywhere and anytime to use. Moreover, it is a feature that the result is simple and comprehensible.

IV. Discussion and Conclusions

In this study, in order to the validity of the toe-gap force measurement device for estimation of risk of fall, were compared with aging change, falling experience and walking ability.

As the results of aging change in the toe-gap force, the aging change is confirmed both male and female. Especially, the toe-gap force decrease rapidly from 65 years old. It is reported that the lower limb muscular power, ability of ambulatory and postural control decrease rapidly from 65 years old. The result similar as for the toe-gap force measured in the fore feet was obtained.

As the results of relationship between toe-gap force and falling experience for one year, the non-faller group demonstrated the factor of 1.3 greater toe-gap force compared with the faller group. The subjects who have less toe-gap force have experienced many falls. It is suggested to be able to use the toe-gap force measurement device when the falling risk is presumed from the viewpoint of the lower limbs muscular power.

As the results of relationship between toe-gap force and walking ability, walking time is declined, it could presume that the toe-gap force was also declined. The toe-gap force is generated by work of the tibialis anterior which play important roles in final term of stance phase on walking. In the results, it is considered that as for the toe-gap force is declined, the walking speed becomes slow in relation to a kick of a walk becoming weak.

It is thus concluded that, the proposed method can be a practically useful method for evaluating quantitatively the lower limb muscular power of the elderly against fall.

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