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Effects of Muscle Strength Decline Associated with Older Adults on Effectiveness of Self-protective Measure on Falls using OpenSim

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ABSTRACT

Falling down is a common and unintentional phenomenon, and the caused body injury may lead to loss of body function or even death. It is estimated that one out of every three older adult individual report a fall at least once every year of which 20% have serious consequence. To predict injury accurately and have better-targeted treatment after falling down, it is necessary to study the damage caused by falling down. To obtain reliable results similar to those of previous high-cost dummy experiments, more effective falling simulation methods should be developed. In this study, by using the biomechanical analysis software OpenSim (open-source software) with the proposed multi-body models associated with older adults' declined muscle properties, we obtained the kinematic characteristics under different falling down situations for injury evaluation. Finally, the head peak acceleration under several falling down situations are served as the index to evaluate the injury and to obtain this influence of muscle strength decline. Regardless of aging, more positive self-protective can greatly help release the impact. And the declined muscle strength of older adults will higher the risk of fall injury under specific falling down posture.

1. Introduction

Falling down is a sudden, involuntary, and unintentional change in body position that hits the ground or a lower surface. Falls can cause broken bones such as ankle, hip, arm, and wrist fractures. Serious head injuries also happen widespread, which can lead to paralysis, cognitive function problems and even death. Besides, even many of those falls do not cause serious injuries, but the shock or pain at that time may cause the fear of falling. The fear may cause people decline their daily activities. When the physical exercise is cut down, weaker body would increase the possibility of falling and the risk of get injured.

As a major public problem, falls are the second leading cause of accidental injury deaths worldwide, and each year an estimated 684,000 individuals die from falls globally [1]. Specifically, as for the persons aged 65 years or older, the underlying disease and reduced physical activity or isolation may accelerate the loss of mobility and physical conditioning, leading to higher risk of

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injuries such as falls [2-6]. In order to prevent serious falls injury and have better-targeted treatment after falling impact, various factors are to be concentrated for better understanding how falling impact is determined.

In most published literature, such human body impact research was used to be operated by dummy experiment. However, the expensive equipment and effort it takes make the method hard to be accessed. OpenSim has also proved useful in sports analysis, prosthetic design, and metabolic analyses [7-10]. Vieira *et al.,* used OpenSim with the model "ToyLandingModel" including the head, two arms, torso, and the limbs to investigate effects of passive AFO, muscle reflexes, and muscle synergistic activation during ankle varus on the risk of injury [10]. The applicability of the OpenSim to obtain the biomechanical falling impact was validated.

In this study, we describe the effect of muscle strength decline associated with older adults on effectiveness of self-protective measure on falls. With proposed models and pre-set falling down motions, the kinematic results are obtained with the head marker of the model in the simulation. This paper is structured as follows: the dynamic simulation method with multi-body model is described in section 2. Simulation results and discussion with comparison between younger adult and older adult are concluded in section 3. Finally, the paper conclusions are proposed in section 4.

2. Multi-Body Dynamic Simulation Method using Opensim

2.1 The Proposed Model

The biomechanical analysis software OpenSim has been used to operate the forward dynamic simulation with the proposed multi-body models associated with the declined muscle properties of older adults. Since the objective of this study is the activation of muscles under arm support actions, "Adjusted_ULBmodel" [18] was chosen for our original model. The body structure of "Adjusted_ULBmodel" model contains the head, two arms, torso, and the limbs. What's more, the simplified upper body and lower body muscle configuration can help decrease the run time of the simulations. Without realistic strength, the actuators are necessary to provide the stress and strain effect properly.

Forward dynamic simulation offers the methodology for describing the causal relationship between muscle activation and multi-joint movement during body motions [19]. In contrast to inverse dynamic simulation, forward dynamic simulation is operated with controlled muscle activation and force to describe the coordinates and their velocities change. As for falling down cases, the impact between the model and the ground is required. In the proposed model (Figure 1), to create the proper contact as realistic as possible, there are totally 28 contact points have been added to the corresponding positions of the main body parts, and the ground is added to the model in the form of a contact square.

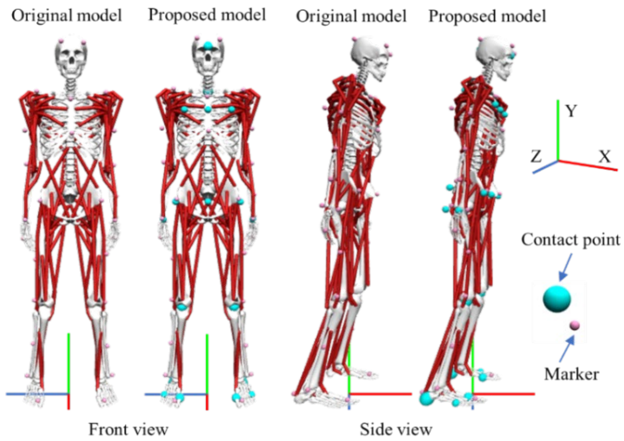

Fig. 1. Original model and the proposed model

When using OpenSim to simulate falling with various postures, the kinematic characteristics of each part of the model can be obtained by markers in the corresponding part. In this study, the position history of the head is tracked by the added marker in the mass center of head as shown in Figure 2.

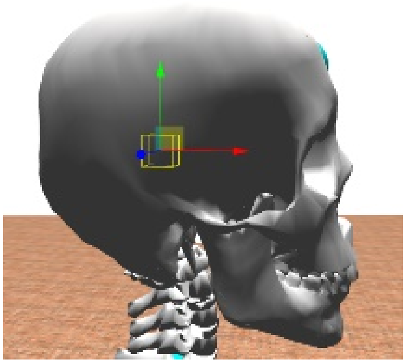

Fig. 2. Marker in the mass center of head

2.2 The Falling Down Posture and Motion

The structure of the human body determines the tendency of people to fall in the forward and backward directions when they lose their balance. In this study, the forward fall scenario is focused. When a forward fall occurs, people subconsciously extend their arms forward and cushion the impact on their body by bending their arms when their palms touch the ground, Figure 3 shows the falling down motion and how this self-protective measure works.

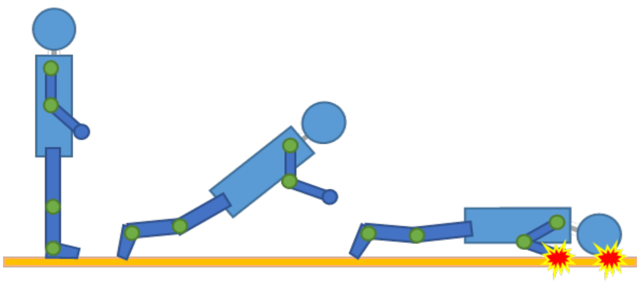

Fig. 3. Falling forward with self-protective measure

2.3 Rotational Stiffness of Joints

In the process of arm support, the arm will be passively stressed. In the forward dynamics simulation, such complex action effect requires the participation of a large range of muscle groups, but this not only increases the complexity of the simulation but also makes the accuracy of the results affected by many factors, so we simplified the procedures. Resemble with push-up exercise, muscle group of chest which is PECM (pectoralis major) is considered to be the most stressed part during arm support measure, shown in Figure 4.

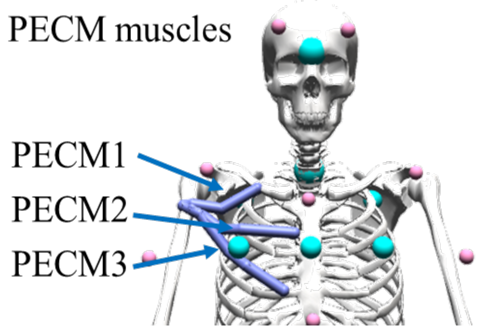

Fig. 4. PECM muscles in proposed model

To simplify the simulation, shown as Figure 5, rotational stiffness is set at the joints of the shoulder and elbow to allow the arms can cushion the impact during falling down, to obtain the realistic motion of self-protection measure of arm support. Finally, the activation status of PECM muscles during this action can be focused as the main objective in the simulation associated with muscle strength changes according to different age.

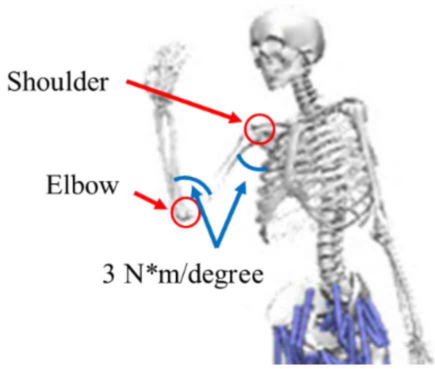

Fig. 5. Application of rotational stiffness

2.4 Muscle Strength Property – Stress and Strain Curve

During falling down process with arm support, muscles are stressed by the reaction force from the ground through body part that is in contact with the ground especially the two arms. In order for the muscles to react to the force, especially the PECM muscles, the muscle stress and strain curve of 20~29 years adult from published literature [19] is obtained. And with consideration of the age differences in the tensile properties of skeletal muscle tissue [19] as Table. 1.

Table 1
Age differences in the tensile properties of skeletal muscle tissue

	Age Group	
	20~29 years	60~69 years
	Ultimate Tensile Strength (g/mm^3)	
Ratio	15±0.6	9±0.3
	Ultimate Percentage Elongation	
Ratio	64±1.1	58±1.8

Eq. (1) calculate the ratio of ultimate tensile strength between older adult and younger adult, and the ratio of ultimate percentage elongation is as Eq. (2).

$$R_{UTS} = \frac{UTS_{older\ adult}}{UTS_{young\ adult}} \approx 0.6 \tag{1}$$

$$R_{UPE} = \frac{UPE_{older\ adult}}{UPE_{young\ adult}} \approx 0.91 \tag{2}$$

The obtained muscle stress and strain curves of younger adult and curve of older adult obtained by applying the ab element are shown in Figure 6. According to the aging caused difference, each curve includes the elongation changing with stress of fiber length of the BIC (biceps brachii) muscle, PECM muscles, and integration of other upper body muscles as the default set. The curves are applied in models of younger adult and older adult for simulation.

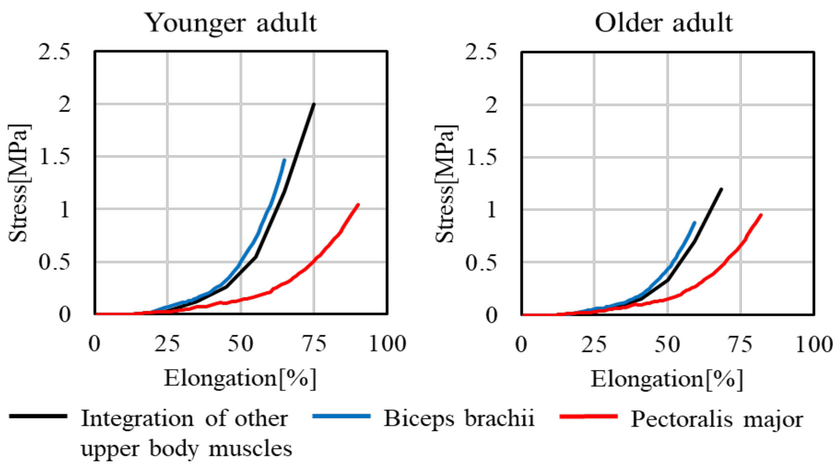

Fig. 6. Muscle stress and strain curve of younger adult and older adult

3. Simulation Result and Discussion

3.1 Falling Process of Simulation

With confirmed posture and motion, falling down simulations with the proposed younger and older adult models have been operated in the OpenSim environment. Figure 7 shows the process of falling forward simulation for obtaining the effect of muscle strength decline on the effectiveness of the self-protective measure.

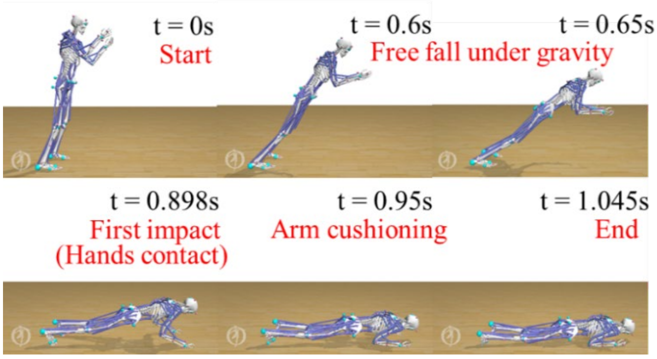

Fig. 7. Falling down process

The angle between the multi-body model and the ground makes the model unbalanced in its natural state, and the model first undergoes free fall at the beginning of the simulation under the effect of gravity. At 0.898s, the model's hands were the first body part other than the feet to contact the ground. Then, with the effect of rotational stiffness, the elbow and shoulder joints start to absorb the impact while flexing and transferred the ground reaction force to the PECM muscles. Finally, the impact is cushioned by the arm support acts as a self-protection measure, and the whole falling down process is finished.

3.2 Effect of Muscle Strength Decline on Falling Impact

As for the situation of falling forward with self-protective measures without default activation of PECM muscles, the head peak acceleration results of each model are recorded by marker of head mass center as Figure 8. Different with common sense, the value of head peak acceleration of older adult model which applied strength declined muscle is 18.1% lower than the value of younger adult model.

The specific falling down posture is considered to be responsible for changes in muscle strength that contrary to the trend in injury reduction capacity. Due to the difference of tensile properties of skeletal muscle tissue of older adult, more variation in muscle fiber length can be obtained with relatively smaller forces. The softer muscle allows the body to respond more actively to external forces through deformation under the same passive movement.

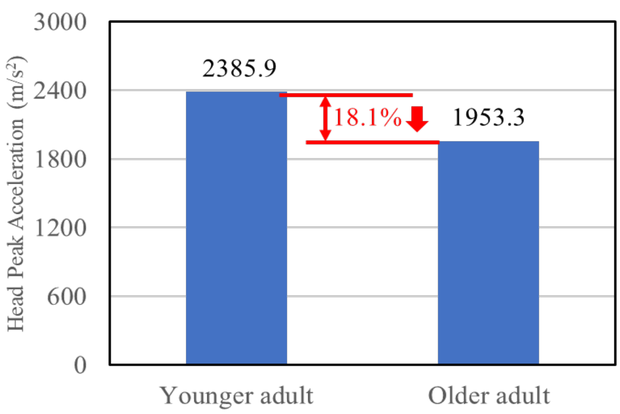

Fig. 8. Acceleration results of falling down without default activation of PECM muscle

3.3 Effect of Default Activation of PECM Muscles on the Effectiveness of Arm Support

The PECM muscles on the chest are considered to be the most active muscles in the implementation of active self-protection measures like arm support. The degree of pre-activation of the PECM muscles before the hands contact with the ground is an important factor influencing the impact cushioning effect of arm support. In order to apply muscle pre-activation in forward dynamics simulations, controllers were added to set the default activation of PECM muscle in the multi-body model.

For comparison, falling down simulations were performed with PECM muscles under different default muscle activations by controllers. The values of default muscle activation were from 0 to 0.5 with an interval of 0.05.

As for younger adult and older adult, of each the head peak acceleration results of falling down simulation under different default muscle activation of PECM muscle is shown in Figure 9 and Figure 10.

In Figure 9, the head peak acceleration of younger adult model changes with default activation of PECM muscles through the following phases: (1) Increases from 0 to 0.1. (2) General decrease between 0.1 and 0.35 with a brief increase at value of 0.3, reach to minimum at default activation value of 0.35. (3) Increases after 0.35.

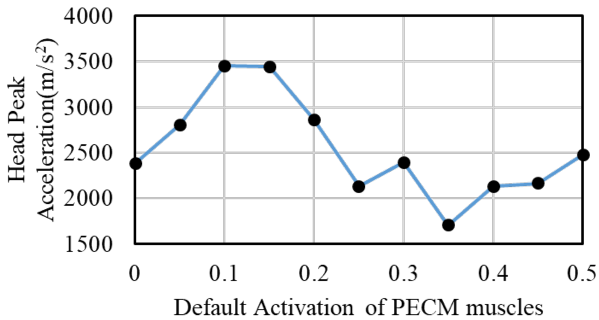

Fig. 9. Effect of default activation of PECM muscle on impact of younger adult

In Figure 10, the head peak acceleration of older adult model changes with default activation of PECM muscles through the following phases: (1) Increases from 0 to 0.15 with a brief decrease at value of 0.1. (2) General decrease between 0.15 and 0.4 with a brief increase at value of 0.35, reach to minimum at default activation value of 0.4. (3) Increases after 0.4.

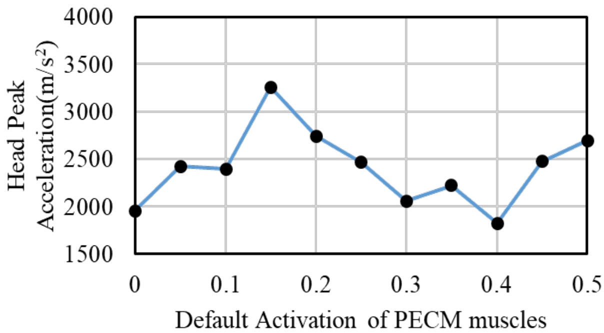

Fig. 10. Effect of default activation of PECM muscle on impact of older adult

The trends in the peak head acceleration are very close, despite the use of a model with different muscle strengths according to age changes. However, since the muscles of the older adult model were softer than those of the younger adult model, the trend of head peak acceleration with default muscle activation was always later in the older adult model than in the younger adult model.

The default muscle activation of minimum peak head acceleration can be served as the most effective activation value. The most effective activation value of younger adult is 0.35, and of older adult is 0.4. The simulation result is compared with the experimental results published by Calatayud J *et al.,* [20] which is 0.296 as a mean value of PECM muscle activation when push-up exercise, and the comparable but higher result because of the fall impact during falling down.

4. Conclusions

In this study, proposed human musculoskeletal model with biomechanical characteristics was used for falling simulation by OpenSim. Falling simulation in various situations with customized models have been manipulated. The effect of aging caused muscle strength decline to the effectiveness of self-protective measures on falls is concluded as following:

i. Under the falling down posture of same muscle controlling, the decline in muscle strength of older adult does not have a significant effect on the effectiveness of self-protective measures. But the softer muscle itself will also help cushion the impact partly.
ii. The trends of falling impact change with muscle pre-activation determined by the posture but little difference in stronger or weaker muscle. However, to reach a familiar effectiveness of self-protective measures, older adults need more muscle activation as preparation for the impact because of the muscle strength decline.

In the future, the more flexible muscle controlling strategies will be applied for obtaining the effect of muscle strength decline on the effective of more complicated self-protective measures on falls.

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