Original

The Impact of the Awareness during a Fall Has on Maintaining a Protective Posture to Prevent a Fall

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(Received: August 23, 2017)

Abstract

In Japan, a country that has become a rapidly aging society, dealing with problems associated with the increase of elderly citizens has become a social issue. An issue associated with the increase of elderly citizens includes physical injury caused by falling. We have been reporting on the risk level of external injury from falls, and the preventative effect of falling injury prevention wear. In this study, we examined through a falling experiment with participating people as the subjects on how awareness during a fall affects preventative postures. The results showed that by being aware of the fact that one is falling down during a fall, compared to an unanticipated fall, the time in which one makes contact with the surface of the floor decreased by 0.26 sec in a forward fall and 0.22 sec in a backward fall. It was found that such awareness during a fall alters the time till the impact and a significant difference was found with regards to preventative posture against a fall. In addition, the external injury risk level evaluation conducted in this study revealed that when using a protective posture during a fall, the external injury level differed greatly for each protective posture. As such, it was revealed that maintaining an appropriate protective posture is effective for preventing external injuries.

This implies that prevention training aimed toward promoting appropriate awareness during an actual fall is necessary for the purpose external injury prevention.

(JJOMT, 66: 172—180, 2018)

—Key words—

protective posture, falling injury

Introduction

In the 2016 White Paper on Aging Society, it was reported that the population ratio of those aged 65 or older within the total Japanese population was estimated to be 26.7% and was on an increasing trend. It had been reported that by 2060, 1 out of 2.5 people would be aged 65 or older, with 1 out of 4 people being 75 years old or older. An issue involving the increase in the elderly citizens is the decline in ADL (Activities of Daily Living) and the increase in medical expenses caused by being bedridden. A major factor that causes an elderly citizen to become bedridden is external injuries from falling. External injuries caused by falling do not only directly decline the ADL, due to the injuries, but can also become an event that serves as an impetus for declining one's activity level due to the psychological anxiety triggered from falling working as a ripple effect, which may lead to the elderly person becoming bedridden. Concerning such a risk level of injury from a fall, this paper will report on head injury risk and its preventative measures, using a falling experiment that employs a dummy model[1].

On the topic of external injury risk level from falls, there have been many studies on such injuries including the femoral neck fracture that utilized a simulation via the finite element analysis method[2][3]. However, there have not been reports from a study that looked at the impact of the awareness of falling has on the adoption of a preventative posture during a fall, or maintaining a preventative posture during a fall as an the injury preventative measure via a falling experiment with people as the subjects.

Table 1 Physical information of the subjects

Testee	Height	Body weight	BMI
1	172	74	25.1
2	170	62	21.4
3	162	63	24.1

Therefore, in this study, a falling experiment was conducted on three healthy male aged 30 to 38 years old. This study selection criterion was a mature age with low risk of falling experiment and less physical risk. The study examined the impact that awareness during a fall has on preventative posture movements and the injury preventative effect of maintaining a preventative posture.

Experiment method

Subjects

An experiment of falling into warm water was conducted using three healthy males who do not have any medical history related to musculoskeletal disorders or the nerves.

Equipment

A total of three high-speed cameras, 1 Phantom-miro-ex (manufactured by Nobby-tech) and 2 HAS-L1 (manufactured by Ditect), were used to film the change in posture during a fall, with the filming speed set at 1/500 sec. Concerning the change in posture of each body part during the fall, reflective markers were placed onto the six locations of the subject's acromial process, elbow joint, wrist, greater trochanter (waist area), knee joints, and lateral malleolus. The trajectory changes of these parts were processed using motion analysis software (Dipp-MotionV manufactured by Ditect) to obtain the variations such as obtained speed and acceleration. We examined the difference in falling time due to the difference in consciousness at falling using Mann-Whitney U test. A $p<0.05$ was deemed statistically significant. Data were analyzed using Stat Flax ver.6.

Methods

A total of 16 experiments of falling onto a warm water surface was conducted with each subject, involving the two conditions of two directions of: an intentional falling condition in which the subject was conscious of falling backward or forward and the sudden falling condition where the subject could not be conscious of the sudden falling. An intentional falling condition indicates a condition in which the subject falls onto the water of their own volition. A sudden fall condition indicates a condition in which the subject falls suddenly into the water in accordance with the researcher's signal.

The calculation of the impact force at the moment of the fall was done by using the motion analysis software to analyze the movement of the marker of each body part that was captured through the high-speed camera footage to calculate the speed and acceleration that is necessary for the calculation of the force. With the measured values obtained, the impact force was calculated using a conversion equation.

A falling injury evaluation was conducted by determining the risk of fracture in each body part that first came into contact with the surface of the floor when the preventative posture was maintained. The fracture risk level was estimated from the impact pressure of the points of contact, which was estimated from such values as the contact surface area and speed. Then, it was calculated by comparing the estimated value and the bones' yield stress.

In this study, excluding the 6 cases in which taking measurements failed and 4 cases in which the markers could not be read, 38 experimental results were used to evaluate the preventative effect and the external injury risk level arising from maintaining preventative postures.

Ethical considerations

The subjects were provided sufficient explanation verbally and in writing of the details of the study and the methods before measurement, and their consent was requested in writing. Furthermore, the experiment was conducted under the supervision of a collaborating doctor ensuring sufficient rest time was given to the subjects. The approval from the University of Occupational and Environmental Health Japan (No. H24-127) was obtained in advance to the running of this experiment.

Table 2 Falling time during a forward fall

Frontal Fall	Consciousness	Unconsciousness
1	0.82	0.906
2	0.764	1.008
3	0.882	1.014
4	0.664	1.336
5	0.866	0.986
6	0.574	1.06
7	0.696	1.024
8	0.624	0.892
9	0.75	
10	0.866	
average(sec)	0.7506	1.02825
SD	0.1	0.12
Z	3.55	$p < 0.001$

Table 3 Falling time during a backward fall

Backward Fall	Consciousness	Unconsciousness
1	0.98	0.642
2	0.698	0.738
3	0.662	1.136
4	0.61	0.64
5	0.65	0.682
6	0.548	0.952
7	0.558	1.078
8	0.594	0.89
9	0.754	0.9
10	0.61	
11	0.52	
average(sec)	0.653	0.851
SD	0.06	0.16
Z	2.39	$p < 0.05$

Results

1. Change in surface contact time due to the difference in the awareness of falling

In this study, a posture in which the falling was unavoidable was defined to be when the angle of the axis of acromial process- greater trochanter (waist area) - lateral malleolus which is 90° to the water surface shifts to exceeding the range of 15°. This was also used as the starting point of the fall. Table 2, 3 show the time it takes from the fall starting point to when the subject makes contact with the water in both the intentionally falling condition and the sudden falling condition.

Table 2 shows that in the case where the subject fell forward intentionally, the average time till making contact with the surface of the water was 0.75 sec, while it was 1.02 sec on average with the sudden falling condition. Regarding Mann-Whitney test to examine differences in falling time between awareness. We observed statistically differences in falling time ($p < 0.001$). Next, Table 3 shows that with an intentional backward fall, the average time till making contact with the water surface was 0.65 sec, with the sudden fall being 0.85 sec in average. Regarding Mann-Whitney test to examine differences in falling time between awareness. We observed statistically differences in falling time ($p < 0.005$). The above results show that the surface contact time becomes longer for both forward and backward directions with the sudden fall condition.

2. The change in collision acceleration and impact force due to the difference in the awareness of falling

Table 4, 5 show the mean value of collision acceleration and the estimated impact force of each body part during the contact with the water surface, depending on the subject's awareness during the fall aimed toward the front or the back. Here, the mean of collision acceleration and impact force of 18 forward fall cases and 20 backward fall cases, excluding the excluded experimental cases, are shown.

Table 4 displays the collision acceleration of the body parts of the shoulders-waist-knees when the subject fell forward while in a state of intentional awareness, with acceleration being shoulder area: 247.4 m/sec^2, waist area: 341 m/sec^2, and knee area: 312.2 m/sec^2, with the impact force being 49.5 G, 68.2 G, and 62.4 G, respectively. The collision acceleration of the body trunk during a sudden unaware fall was 374 m/sec^2, 421.5 m/sec^2, and 320.7 m/sec^2, with the impact force being 74.8 G, 84.3 G, and 64.1 G, respectively.

Table 5 displays the collision acceleration of the body parts of the shoulder-waist-knee when the subject fell backward while in an intentional awareness, with acceleration being shoulder area: 365.9 m/sec^2, waist area: 355.3 m/sec^2, and the knee area: 225.7 m/sec^2, with the impact force being 73.2 G, 71.1 G, and 45.1 G, respectively. The collision acceleration of the body parts during a sudden unaware fall was 438.8 m/sec^2, 492.4 m/sec^2, and 255.8 m/sec^2, with the impact force being 87.8 G, 98.5 G, and 51.2 G, respectively.

Results showed that regardless of the falling direction, collision acceleration and the impact force of the body parts showed a higher numerical value during a sudden fall. It was revealed that awareness during the

Table 4 The collision acceleration/impact force of each body part during a forward fall

	Shoulder	Elbow	Wrist	Greater Trochanter	Knee	Lateral Malleolus
Consciousness						
Acceleration m/sec^2	247.4	349.7	368.7	341.0	312.2	127.5
Inpact Force G	49.5	69.9	73.7	68.2	62.4	25.5
Unconsciousness						
Acceleration m/sec^2	374.0	335.8	358.0	421.5	320.7	475.9
Inpact Force G	74.8	67.2	71.6	84.3	64.1	95.2

Table 5 The collision acceleration/impact force of each body part during a backward fall

	Shoulder	Elbow	Wrist	Greater Trochanter	Knee	Lateral Malleolus
Consciousness						
Acceleration m/sec^2	365.9	441.1	485.5	355.3	225.7	140.5
Inpact Force G	73.2	88.2	97.1	71.1	45.1	28.1
Unconsciousness						
Acceleration m/sec^2	438.8	481.2	527.9	492.4	255.8	186.2
Inpact Force G	87.8	96.2	105.6	98.5	51.2	37.2

Table 6 The number of protective postures taken during a fall

	Consciousness	count	Unconsciousness	count
Frontal Fall	Knee-drop	7	Knee-drop	2
	Arm-planting	3	Arm-planting	6
BackWard Fall	Hip-landing	9	Hip-landing	6
	Arm-planting	2	Side-way fall	2
			Arm-planting	1

fall influenced the falling acceleration and impact force.

3. Changes in preventative posture due to awareness during the fall

Table 6 displays the number of times the characteristics of a protective posture were seen in this experiment during the forward and backward falls. Figure 1～5 show the representative preventative postures during forward and backward falls.

With regard to protective postures during a forward or backward fall, the two protective postures of an arm-planting protective posture (placing the arms onto the surface broadly; Figure 1) and a knee-drop protective posture (placing the knees onto the surface) were seen frequently. The change caused by the subject's awareness of the fall shows that out of 10 conscious forward fall experiments, subjects took the knee-drop protective posture (7 times) more than the arm-planting protective posture (3 times). With the sudden fall, subjects took an arm-planting protective posture 6 out of 8 times, with the knee-drop protective posture being used twice. This shows that differences in the maintenance of a protective posture are generated in the forward fall depending on the awareness of falling.

Next, in regard to protective postures during a backward fall, the following three protective postures were frequently seen: a hip-landing protective posture in which the gluteal region hits the floor first (Figure 3), an arm-planting protective posture in which the arms are placed widely across the floor (Figure 4), and a protective side-way fall posture in which the body is opened widely onto its side and the subject falls from their waist or gluteal region first (Figure 5). Changes caused by the subject's awareness during the fall includes, in the 11 backward falling experiment where the subject was aware, subjects who took the hip-landing protective posture 9 times and the arm-planting protective posture twice. With the sudden falling experiment, where the subject was unaware of falling, the subjects took the hip-landing protective posture 6 out of 9 times, arm-planting protective posture once, and side-falling protective posture twice. From the above results, no major changes to the maintenance of the protective posture was found depending on the awareness of the fall.

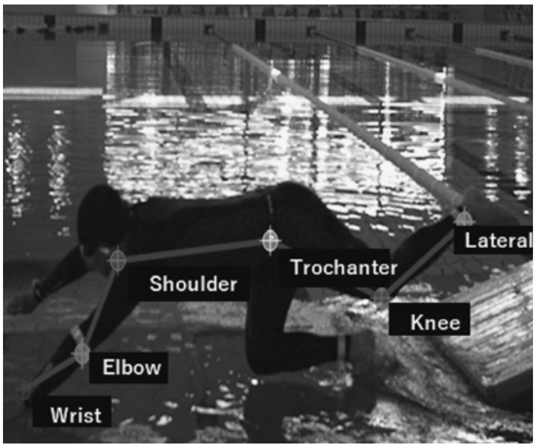

Figure 1 Arm-planting protective posture

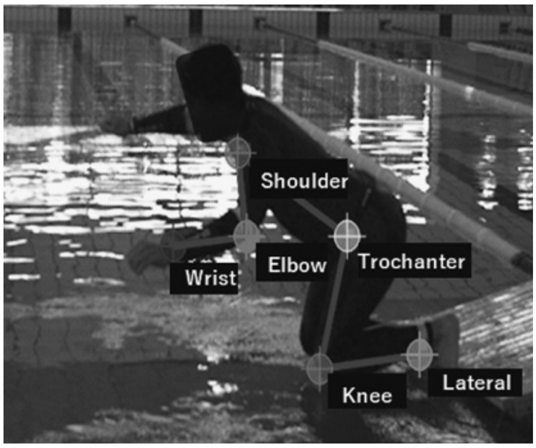

Figure 2 Knee-drop protective posture

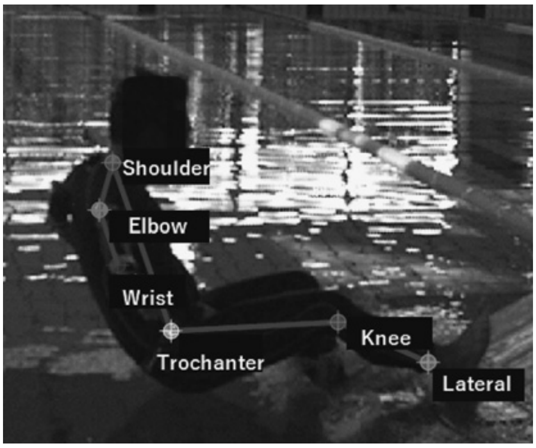

Figure 3 Hip-landing protective posture

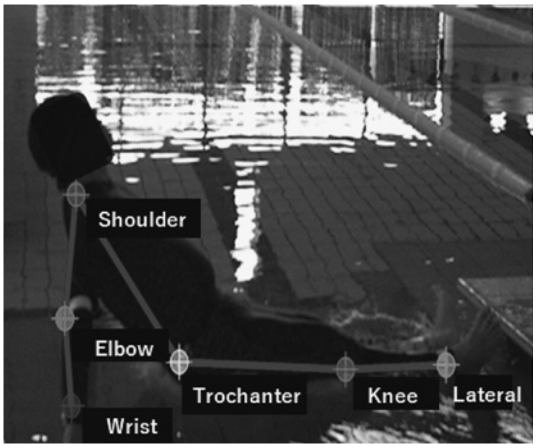

Figure 4 Arm-planting protective posture

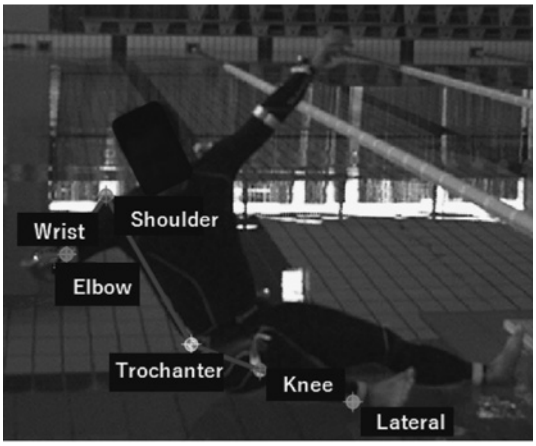

Figure 5 Side-way fall protective posture

4. The changes in impact pressure per protective posture during a fall

Table 7, 8 show the estimated value of the impact pressure that the subjects sustained while they maintained a representative protective posture during a forward or backward fall. There have been many research reports in the relationship between the bones' yield stress and impact pressure[2)~5)]. Evaluation of the external injury risk level in this study was conducted by also using impact pressure as the basis. The impact pressure was calculated by using Equation 1, with m representing the subject's weight (kg) and the v representing the

Table 7 Frontal fall protection

Weight	Arm-planting posture	Knee-drop posture
60	11.93	15.61
65	12.92	16.91
70	13.92	18.21

Table 8 Backward fall protection

Weight	Hip-landing posture	Side-way fall posture	Arm-planting posture
60	1.31	6.03	17.6
65	1.42	6.53	19.06
70	1.53	7.03	20.53

speed during the collision (m/sec) attained in this experiment. The area during the surface contact (*S*) was based on the subject B, with the contact surface area of the first contact part being substituted for each protective posture. The arm-planting protective posture had the contact surface area of the hand of 18 cm^2, the knee-drop protective posture had the contact surface area of the knee of 12 cm^2, hip-planting protective posture had a contact surface area of the hip of 225 cm^2, and the side-fall protective posture had the contact surface area of the greater trochanter area of 49 cm^2.

Equation 1

$$Mpa(N/m^2) = (\frac{F(m*v)*10{,}000}{S(cm^2)}) * \frac{1}{1{,}000{,}000}$$

A representative protective posture during a fall was defined to be the two postures of knee-drop and arm-plant for the frontal fall, and the three types of falling on the hip, side-fall, and arm-plant for the backward fall.

Table 7 shows that for the forward fall for Subject B, the estimated impact pressure during an arm-planting protective posture was 12.93 Mpa. Similarly, it was 16.91 Mpa for the knee-drop protective posture. Next, the estimated value of the impact pressure during a hip-planting protective posture was 1.42 Mpa, 6.53 Mpa for the sideway fall protective posture, and 19.06 Mpa for the arm-planting protective posture. The results revealed that the impact pressure differed greatly depending on the protective posture, with the external injury preventive effect and risk level being impacted by the protective postures.

Discussion

The impact of the awareness of falling has on a falling preventative posture

The result of conducting an experiment on the relationship between awareness during a fall and maintaining a protective posture revealed that the awareness of falling alters the time to collision and also alters the protective posture during a fall. It was found that the time it takes from starting to fall to making a contact with the surface will be reduced by being aware of the fall, by 0.26 sec for the forward fall and 0.22 sec for the backward fall. This is related to the protective posture motions during the fall; it is believed that when a certain level of equilibrium has been exceeded during a fall, whether one determines to act to try to regain the balance in order to avoid falling or to consciously move toward hitting the floor surface, perceiving the fall to be unavoidable, is the factor behind the difference.

An experiment that prompts an intentional fall showed that in the forward fall, the protective posture of dropping the knees, which is the body part that is at the closest distance to the floor surface, was seen the most. Even with the backward fall, protective postures such as dropping the gluteal region closest to the floor surface, while no body twisting motion took place, was seen the most. This is believed to be caused by a protective reaction in which by being aware that falling is unavoidable, one tried to get onto the floor surface using the safest position in the least distance possible. Due to this protective reaction, the acceleration time toward collision becomes shorter, as well as the centrifugal force generated at the colliding part that uses the supporting point that comes in contact with the floor, as the axis declining. This is believed to decrease the overall impact force compared to a sudden fall.

In contrast, in an experiment that promotes a sudden fall, which is similar to real-time conditions, the motions of trying to regain ones' balance, in which subject diverted their arms or the waist, or twisted the body to the side were seen even when the central axis of the body had collapsed by more than 15°. By doing these motions, the movement distance till hitting the surface of the floor becomes longer, elongating the time till the collision, and increasing the centrifugal force generated at the colliding parts, which are believed to have increased the impact force each body part sustained. Furthermore, the result showed that a shorter movement distance till hitting the surface floor during a fall shows a more stable center of gravity, while a longer distance saw the center of gravity greatly collapsing. In particular, in many of the examples where subjects fell suddenly forward, they demonstrated the protective posture of placing the arms right before their face. Although healthy adults can maintain such a protective posture with the strength of their arm, such a fall protective posture is believed to be high in risk of injury, such as hitting their face hard, for the elderly, who are the likely subjects of external injury during a fall and who cannot maintain such a posture due to their arm muscle strength. This implies that by perceiving early on that a fall is unavoidable when one is falling, this will lead to taking a safe protective posture for elderlies and other subjects whose muscle strength and balance have declined, which greatly impact their external injury prevention during a fall.

The external injury prevention effect and risk level of a protective posture during a fall

In this study, based on the experiment results, the representative protective posture during a forward fall were defined to be the arms-planting protective posture and knee-dropping protective posture. For the backward fall, the representative fall protective postures were the hip-landing protective posture, side-falling protective posture, and the arm-planting protective posture. The preventative effect and external injury risk level of maintaining each protective posture were verified. The result showed that the estimated impact pressure on the contact part from maintaining a protective posture during the frontal fall were 12.93 Mpa for the arm-planting protective posture and 16.91 Mpa for the knee-drop protective posture. This shows that when falling, the knee-dropping protective posture had a higher preventative effect against external injury. Using the equation estimate of impact pressure and bone yield stress found in the preceding study by Carter et al.[4], the estimated yield stress of bones of those in the 60s was found to be 29.0 Mpa per 0.75 g/cm^3 for the normal lower limit of bone density, 18.5 Mpa per 0.6 g/cm^3 for mid-level osteoporosis upper limit values, and 12.9 Mpa per 50.6 g/cm^3 for severe osteoporosis upper limits. These results show that maintaining a representative protective posture in a forward fall has a low bone fracture risk unless one suffers from a condition such as severe osteoporosis. Next, for the estimated impact pressure value of maintaining a representative protective posture during a backward fall, it was 1.42 Mpa for the hip-planting protective posture, 6.53 Mpa for the sideway-fall protective posture, and 19.06 Mpa and the arm-planting protective posture. The protective posture of landing on the hip during a backward fall had the highest external injury prevention effect while maintaining the arm-planting protective posture had the least preventative effect.

Concerning the risk level of bone fracture, maintaining a hip-planting protective posture is believed to have a low bone fracture risk even if one was suffering from a severe osteoporosis. These findings show that the eternal injury risk level is greatly influenced by the choice of protective posture during a fall, and that taking an appropriate protective posture during a fall can lead to the prevention of injuries.

Conclusion

As a result of conducting an experimental study on the relationship of awareness of falling and a protective posture during a fall, it was revealed that the time from the start of a fall to colliding with the ground becomes shorter when being aware of falling during a fall, reducing the impact force during the fall and maintaining a preventative posture. These findings show that immediately changing one's awareness of falling in a sudden fall is effective for preventing external injuries from falls. As such, training in breaking a fall that presumes an actual fall, as seen in judo, is believed to be effective. Instead of preventing falling, this type of perspective of prevention measures that aim to prevent external injury when falling is believed to be necessary in the future.

Limitations of this research

The estimation of impact pressure during collision was calculated from the contact surface area of a healthy adult. However, it has been reported that the muscle mass decreases as one grows older, with the skin thickness of the gluteal region decreasing due to bone protrusion advancing[7]. It is highly possible that for the late-stage elderly that this study is concerned with have a narrower contact surface area than the one used in the estimated equation. Therefore, the risk in which there is a greater level of force than the obtained estimated values of impact pressure is believed to be high. Other reports include studies using a simulation that showed that changes in the internal stress caused by the difference in the shape of the femur will greatly increase the risk in which a bone is fractured during an impact[2,3]. As such, an examination is needed concerning evaluating the risk of bone fracture only from impact pressure.

However, using the speed and acceleration obtained from a falling experiment that used people as subjects to validate with the usage of numerical values the preventative effect and the external injury risk level when maintaining a protective posture during a fall, revealed the impact that the awareness of falling had on maintaining a protective posture. This is a result that cannot be attained from simulations and does not negate the significance of this study.

Acknowledgement

This study has received aid from the Japan Society for the Promotion of Science 2015–2017 Grants-in-Aid for scientific research expenses (C) (No.15K11490).

References

1) Yamanaka M, Yukimasa T: On the preventative effect of wearable protective gear for preventing head injury from a fall. Japanese Society of Occupational Medicine and Traumatology 62 (2): 100―108, 2015.
2) Tanaka H, Yamamoto S, Ozeki S, et al: A biomechanical examination of preventing femoral neck fracture from a fall using a hip protector. The Japan Society of Mechanical Engineers 70 (697): 39―46, 2004.
3) Tanaka H: Fundamentals of motor disorders: The impact that proximal femur fracture caused by a fall have on soft issues and weight. Igaku no Ayumi 236 (5): 549―553, 2011.
4) Carter DR, Hayes WC: The compressive behavior of bone as a two-phase porous structure. J Bone Joint Surg Am 59 (7): 954―962, 1977.
5) Lotz JC, Cheal EJ, Hayes WC: Fracture prediction for the proximal femur using finite element models part 1 linear analysis. J Biomech Eng 113 (4): 353―360, 1991.
6) Lotz JC, Cheal EJ, Hayes WC: Fracture prediction for the proximal femur using finite element models part 2 Nonlinear analysis. J Biomech Eng 113 (4): 361―365, 1991.
7) Sugimoto Y, Oyama E: Change caused by the thickness of sacrum soft tissue and pressure among the elderlies and youths. Japan Society of Nursing Research 27 (2): 39―43, 2004.

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転倒時認識が転倒防御姿勢保持に与える影響

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―キーワード―
転倒時姿勢，転倒外傷

急速な高齢化社会となった我が国において高齢者の増加に伴った問題に対処することは大きな社会的課題の一つである．高齢者の増加に伴う問題の一つに転倒による身体外傷が挙げられる．これまでにも，転倒による外傷危険度や転倒外傷予防具の予防効果について報告を行ってきた．本研究では，人を対象とした転倒実験を通じて，転倒時における転倒認識が転倒防御姿勢にどのような影響を与えるかについて検証を行った．

その結果，転倒時において転倒を意識することにより不意に転倒した場合と比べて，床面へ接地するまでの時間が前方転倒において0.26sec，後方転倒において0.22sec減少するなど，転倒時の認識の違いによって衝突までの時間が変化することや，転倒防御姿勢に大きな変化が認められることが明らかとなった．加えて，実験により明らかとなった転倒時防御姿勢から外傷危険度の評価を行った結果，防御姿勢毎に外傷危険度は大きく異なり適切な防御姿勢を保持することが外傷予防に効果的であることを明らかとした．

これらのことから，転倒時に適切な転倒認識を促すことを目的とした予防訓練を行うことが転倒による外傷予防には必要であると考える．

利益相反：利益相反基準に該当無し

（日職災医誌，66：172―180，2018）
