Changes in Gait and Dynamic Balancing Ability in Elderly Persons after Ball Exercises

Katsuyuki Hoshino1, Haruhito Aoki1, Shoji Ishii1, Yutaka Hibino1, Takahiro Nishiyama1, Junko Taguchi2, Yumiko Taisou3, Chie Ishii3, and Moroe Beppu1

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Abstract

For the purpose of preventing falls in the elderly, we conducted fall-prevention classes using exercise balls. Here, we conducted a gait analysis, gravity-center flail test, and measurement of daily movement action time. The subjects were 24 females aged 59–86 years (mean, 71). Before starting the ball exercises and after one year, the step length, step width, weight distribution, and area under pressure during gait were measured using a gait measurement instrument. The total trace length and standard deviation area were also measured using an instrument for measuring the gravity-center flail. We also timed a daily movement—a sequence of movements from a supine position to a standing position at rest. Compared with values recorded before initiation of the exercise program, after a year step length had increased and the area under pressure and weight distribution decreased. The gravity-center flail test showed a tendency to improvement in the total trace length and standard deviation area. The daily movement action time had decreased significantly at the end of the 1-year exercise program.

Key Words

Gait analysis, Elderly, Ball Exercise

Introduction

The prevention of falls among the elderly is an important factor in maintaining the quality of life, as well as in improving it. However, an increasing number of fracture incidences have been reported among the elderly.1,2,4,10 Thus, we considered it important to improve muscular strength and balancing ability in the elderly and thereby to prevent falls, by providing a fall prevention class through exercise using a ball, starting in March 1999.

In this study, we investigated changes in gait ability and balancing ability among the elderly over a period of one year.11

All values were expressed as values ±SD. A p-value of less than 0.05 was considered to indicate a statistically significant difference.

Materials and Methods

The subjects included 24 females aged 59–86 years (mean, 71), who participated in fall-prevention classes using ball exercises for one year during 2000–2001. The participants had responded to a subject recruitment advertisement for the study on our web site. The participation rate in the fall-prevention classes was more than 70%. The participants kept a record of their activities of daily living (ADL), and did not have any serious disease that required orthopedic treatment. The nature of the study was explained to all the participants (including information about the protection of personal information, safety, and risk aspects, etc.) and an

1 Department of Orthopaedic Surgery, St. Marianna University School of Medicine
2 International University of Health and Welfare
3 Medical Fitness Institute
informed consent was obtained.

The fall-prevention classes comprised ball exercises, which were conducted once a week continuously for a year. The exercise ball was of 55–65 cm in diameter and was made from polyvinyl chloride. Each class comprised a 75-minute exercise, which included a 15-minute warm-up, a 45-minute aerobic exercise, and a 15-minute cooling-down exercise using a ball. The exercise ball was used in all sessions of the class. The basic posture for the ball exercise was such that the entire posterior surface of the thighs was in close contact with the ball and the plantar flexion angles of the ankle joints (a) and the flexion of the knee (b) were both 40°, and the soles of the feet remain firmly on the floor. The distance between the feet is wider than waist width to aid stability.

The warming-up sessions help the body adjust to the ball. Both arms are moved such that they are placed on the ball and the body is allowed to relax. Both legs and the body are also stretched during this part of the class (Fig. 2).

The aerobic exercises were conducted so that while the ball was bounced up and down, each subject performed combined actions with the feet stepping alternately, and stepping laterally to the right and left while the ball was rolled around (Fig. 3).

The cooling-down session involves setting-up exercises. The muscles used in the aerobic exercises are relaxed (Fig. 4).

The participants in the study were divided into a group aged 70 or younger (Group 1) and a group aged 71 or older (Group 2). Group 1 comprised 12 females aged 59–70 years (mean; 64.9), height 145.5cm–160.8 cm (mean; 152.6 cm) and weight 37.1 kg–60.6 kg (mean; 51.1 kg). Group 2 comprised 12 females aged 71–86 years (mean; 76.4) height 140.0 cm–164.5 cm (mean; 149.9 cm) and weight 41.5 kg–63.6 kg (mean; 53.5 kg).

Medical checks were conducted before initiation of the ball exercise program and after one year. The checks included gait analysis, a gravity-center flail test, and timing of a daily movement action (see below).

For the gait measurements, we used Gait Scan 8000 (Nitta Co., Tokyo, Japan), a gait analysis system using a large-area pressure sensor, which enabled us to demonstrate changes over time in the pressure distribution in the sole of the foot, in cooperation with the NTT Cyber Space Institute. Two types of measurement were made for each subject: a four-step gait trial and an open-eye 10-second static standing trial. The gait trial was attempted seven times and three stable trials were selected. The items measured were step length, step width, area under pressure, and weight distribution.
During gait.

Using gait basic parameter, which is superimposed images of foot pressure in temporal response, we made a few steps of footprint image and obtained step width and step length. Both step length and width were normalized to a person 155 cm tall, and a comparison was made between both groups.

A basic value for the area under pressure was established by measuring the mean ground contact area on 30 stable frames per second over 10 seconds in a static standing position. Ground contact area during gait was normalized by this basic value, and

Fig. 2. Method for warming-up sessions.

Help the body adjust to the ball. Both arms are moved such that they are placed on the ball and the body is allowed to relax. Both legs and the body are also stretched during this part of the class.

Fig. 3. Method for aerobic exercises.

Combined actions are performed, such as walking with the feet stepping alternately as the ball is bounced up and down, and stepping laterally to the right and left as the ball is rolled.
the mean value per step was taken as the area under pressure during gait.

A basic value for weight distribution over 10 seconds in the static standing position was established for each subject by taking the mean value of 30 stable frames per second. The sum of pressures at the area under pressure of both feet during gait at each measurement was normalized by this basic value and the value obtained was used to determine the weight distribution. The mean value per step from the landing of a foot until the foot had completely left the ground was used to determine the weight distribution during gait.

For the center of gravity fluctuation test we used a gravity-center vibroscope GS5500 (Anima Co., Tokyo, Japan), and the entire trace length and the standard deviation area were determined for 30 seconds each with the eyes open and the eyes closed (sampling rate 20 Hz). A series of actions performed when rising from a supine position to a static standing position were regarded as daily movement action, and the time taken to perform was recorded. The data were subjected to the t-test.

Results

Results of the gait trials showed that in Group 1 the mean step length increased significantly from 543.6 ± 11.3 mm before initiation of the exercise program to 596.5 ± 9.6 mm at the end of one year of exercise sessions (p < 0.01). In Group 2, the mean step length increased from 487.2 ± 11.3 to 518.6 ± 12.4 mm; however, this increase was not significant.

The mean step width in Group 1 changed from 70.6 ± 2.5 mm before initiation of the exercise program to 70.3 ± 3.7 mm after one year of the program, but the increase was not significant. In Group 2, step width increased from 88.1 ± 2.8 mm before initiation of the exercise program to 93.3 ± 4.5 mm after one year.

The mean area under pressure significantly changed from 88 ± 3.0 mm² before initiation of the exercise program to 62 ± 1.0 mm² after one year of the program in Group 1 (p < 0.01). In Group 2 it decreased from 89 ± 5.0 to 79 ± 2.0%. Group 2 was not significant.

Mean weight distribution decreased from 88 ± 3.0% before initiation of the exercise program to 62 ± 1.0% after one year of the program in Group 1 (p < 0.01). In Group 2 it decreased from 89 ± 5.0 to 79 ± 2.0%. Group 2 was not significant.

Mean weight distribution decreased from 149 ± 6.0% before the exercise program to 76 ± 4.5% after one year in Group 1, and from 148 ± 10.5% to 78 ± 3.0% in Group 2; both changes were significant (p < 0.01). When I compile the above. The mean step length in Group 1 changed significantly after one year of the program (p < 0.01). But Group 2 did not change significantly after one year of the program. The mean step width in Group 1 and Group 2 did not change significantly after one year of the program. The mean area under pressure in Group 1 changed significantly after one year of the program (p < 0.01). But Group 2 did not change significantly after one year of the program. The mean weight distribution in Group 1 and Group 2 changed significantly after one year of the program (p < 0.01).
The mean daily movement action time decreased from 7.95 ± 0.5 seconds before the exercise program to 6.95 ± 0.4 seconds after one year in Group 1; decreased from 13.0 ± 1.6 seconds to 10.9 ± 1.1 seconds in Group 2; both changes were significant. (Table 2)

In the gravity-center flail test, both groups showed a tendency toward an improvement between the start of the exercise program and after one year of the program in the total trace length and the standard deviation area with eyes open and closed, but the change was not significant. (Table 3)

**Discussion**

Falling is likely to occur as a result of stumbling when a person cannot adequately perform the following sequence of actions: recognizing an obstacle during gait; and then either stopping, avoiding the object, or lifting the foot\(^9\). One factor that has been reported as triggering falls among the elderly is insufficient control of the reflexes to maintain a standing posture, because of the decline in sensory and motor functions that accompanies aging\(^10\). Thus, once balance is disrupted, the body fluctuation becomes so great that the person falls immediately. This indicates that decreased gait ability, as well as reductions in muscular strength and balancing ability\(^11,12\), makes a considerable contribution to the likelihood of falling.

Ammussen\(^14\) reported that dynamic muscular strength in the elderly, decreases more markedly than static muscular strength and that muscular strength decreases more markedly in the lower extremities than in the upper extremities. Ferrandez et al\(^15\) reported that the decreased gait pace of the elderly is caused through a mechanism involved in the control of balance. Moreover, there have been many reports suggesting an increase in gravity-center flail with aging. Disorders of posture control in the elderly are divided into a static balance disorder, which appears only when maintaining a standing position, and a dynamic balance disorder, which appears with actions in a standing position, gait, and running. The gravity-center flail involved in balance control is conducted through the following mechanism: A sense of equilibrium from the inner ears; visual information from the eyes; and sensory and motor functions...
transmission of somatesthesia information from the skin, muscles, and joints to the brain. The brain integrates the information from these multiple sensory organs and can then control the muscular activities of the feet, legs, and body trunk.

Gait characteristics among the elderly are a small step length, reduced flexion and extension of the hip joints, reduced extension of the ankle joint, and reduced lifting of the heel in the posterior swing phase of the lower extremities, as well as reduced dorsiflexion of the ankle joint and reduced ability to elevate the tip toes in the anterior swing phase. Moreover, because swinging of the upper extremities is involved in anterior flexion of the shoulder joints and posterior extension of the elbow joints, the action is very likely to cause falling. Nishizawa et al. reported that decreased step length may be related to reductions in muscular strength and the range of motion of the hip joints, and a gait posture with an anterior inclination. In addition, Izumi reported that because the swing time during gait decreases, the step length decreases. Also during gait, Yoshizawa et al. reported that because there is a tendency to an inverse correlation between age-induced changes causing decreased gait pace and the floor contact time ratio or support time ratio for both legs, this is a restricting factor in maintaining the pace. That is, decreased step length and increased overlapped step time and ground contact time of both feet all occur in the elderly, and this is associated with a sliding walk with small steps becoming an important factor in making falls more likely.

These findings indicate that, generally, in the elderly the lift of the feet at the swing becomes insufficient and step length decreases. In addition, the base required to maintain a standing position becomes wider due to the decreased control ability of the gravity-center flail, and the shift length at each action becomes shorter, which compensates for the flail.

In this study, Group 1 showed a tendency toward greater improvement than Group 2 in all the items of the gait analysis, gravity-center flail test, and daily movement action time.

Also, from the gait analysis, it is acknowledged that the gait of Group 1 gets closer to that of younger people than that of Group 2. From this fact, it seemed that it is preferable to conduct ball exercise in relatively younger age of less than 70 years.

Moreover, when each item was investigated, the gait analysis showed how the step length, which is affected very strongly by decreased motor ability with aging, improved significantly, and how the area under pressure and the weight distribution also improved. These findings indicate that ball exercise might improve not only dynamic balancing ability but also muscular strength, leading to improvement in exercise ability of the elderly. We speculate that the shortened daily movement action time resulted from the improvement in dynamic balancing ability and muscular strength. Hibino et al. found an improvement in muscular strength in the abdomi-
nal muscles, muscles of the back, the quadriceps femoris, hamstring, gluteus medius, and gastrocnemius. In our study similar results were obtained. These were considered because ball exercises are also useful for improving muscular strength.

However, in the gravity-center flail test for the evaluation of static balance, Hibino et al. found a significant improvement in a study on the use of ball exercise for preventing falling conducted with a group of subjects who were, on average, 7 years younger than the participants in the present study. In the present study, although a tendency toward an improvement was seen, it was not significant. This was speculated to be because ball exercises enable dynamic balancing ability to improve rather than static balancing ability, and improvement in balancing ability takes more time than improvement in muscular strength. Moreover, the fact that the younger group tended to improve more indicated an influence of aging.

From the findings in this study, it was considered that exercises exploiting the characteristic instability of a ball, such as bouncing and rolling, enabled gait ability to improve dynamic balancing ability and muscular strength, which are closely associated with gait.

Conclusion

After participating in a 1-year program of fall-prevention classes using ball exercises, elderly females tended to show an improvement in gait, which is closely associated with the likelihood of falling, and decreased daily movement action time. The group aged up to 70 years showed a tendency toward more improvement than the group aged 71 or older.

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ボール体操による高齢者の歩行能力と動的バランス力の変化

星野 克之1 青木 治人1 石井 庄次1 日比野 豊1
西山 敬弘2 別府 諒秋2 田口 順子2
太澤ゆみこ3 石井 千恵3

抄録

われわれは転倒を予防する目的で、高齢者に対してエクササイズボールを用いた転倒予防教室を行っている。教室開始に際して、歩行解析、重心動揺検査、起居動作時間計測を行っている。対象は 59 歳から 86 歳（平均 71 歳）の女性 24 名で、ボール体操開始前、1 年経過時に歩容計を用いて歩幅、歩進、歩行時加速度、歩行時加圧面積を計測した。また重心動揺計にて総軌跡長と標準偏差面積を測定した。さらに、仰臥位から安静立位までの一連の動作を起居動作とし、て時間計測にて検討した。

その結果、1 年間のボール体操にて体操開始前と比較して、歩幅の増大、歩行時加圧面積の減少、歩行時加速度の減少を認めた。重心動揺検査においては総軌跡長、標準偏差面積は若干の改善傾向を認め、さらに起居動作時間は 1 年間の体操後に有意に動作時間の短縮が認められた。

索引用語
歩行解析、高齢者、ボール体操

1 聖マリアンナ医科大学 整形外科教室
2 国際医療福祉大学
3 メディカルフィットネス研究所