Effects of weight-bearing basic step of calisthenics on lower limb muscle morphology, strength and functional fitness in older women

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Abstract

Objective: To investigate the effects of 12-week weight-bearing basic step of calisthenics muscle morphology, strength and functional fitness in older women.

Methods: This controlled study recruited 37 elderly ale participants and was divided into intervention and control groups according to willingness. The intervention group received a 90-minute weight-bearing basic step exercise thrice a week for 12 weeks, while the control group ~~was kept without any intervention~~maintained normal activities. The groups were then compared by measuring muscle thickness, fiber and fiber length by ~~GE LOGIQ E~~ultasound, scle strength by ~~CON-TREX-M~~ isokinetic dynometer and functional fitness. The morphology, strength, and functional fitness outcome measures were compared using ANCOVA or Mann-Whitney U tests to study the effects of 12 weeks of weight-bearing basic step of calisthenics

Results: Among all recruited participants, 33 completed all tests. After 12 weeks, the thickness of the vastus intermedius (F=17.85, P<0.01) and quadriceps (F=15.62, P<0.01) were significantly increased in the intervention compared to the control group, along with a significant increase in the torque/weight of the knee flexor muscles (F=4.47, P=0.04). Similarly, the intervention group showed significant improvement in the single-legged closed-eyed standing test (z=-2.16, P=0.03) compared to the control group.

Conclusion: The study concluded that a 12-week weight-bearing basic step of calisthenics was show to possibly delay the decline in muscle mass and muscle strength in elderly women and improve physical function. In addition, this study provides a reference exercise program for older women.

Keywords: weight-bearing exercise; calisthenics; muscle loss; functional fitness

1. Introduction

A healthy physical function determines good life quality during later life[1], promotes an extended life expectancy among geriatrics[2], and helps reduce mortality[3]. Muscle mass and strength are pivotal in preserving physical function in geriatrics[4, 5]. It has been reported that muscle strength typically reduces by approximately 30% with aging[6], while muscle cross-sectional area experiences a reduction of around 40% within 50 years, spanning from 20 to 70 years of age[7]. Furthermore, the transition to menopause triggers hormonal changes in women, leading to a decline in muscle mass and grip strength[8]. Considering that women have longer life expectancy than men, the susceptibility to muscle loss may increase[9]. Therefore, recognizing the decline in muscle mass and strength, particularly among older women, holds vital practical implications for enhancing their physical function, and promoting healthy aging.

Physical activity is a potent protective strategy for delaying muscle loss and muscle strength decline in the elderly[10]. It is recommended that geriatrics should engage in different physical activities, including resistance exercise and balance training[11, 12]. A prospective study reported that weight-bearing, a resistance exercise using the body's weight as a load or introducing external weights through vests or pockets, enhanced muscle strength in premenopausal women[15]. Nevertheless, weight-bearing walking or running has shortcomings, such as lack of engagement and low adherence[16, 17]. In contrast, basic step of calisthenics enhance geriatrics' interest and enthusiasm, demanding engagement in muscular strength, endurance, balance coordination, cardiopulmonary endurance and cognitive involvement. However, it provides sufficient stimulation to the skeletal muscles required for substantial muscle strength enhancement[18, 19].

Since weight-bearing exercise amplifies training intensity and augments skeletal muscle stimulation, calisthenics can heighten interest and engagement among geriatrics. Therefore, amalgamating these dual exercise modes can address the limitations of singular training approaches and enhance outcomes regarding muscle mass, strength, and physical fitness. ~~Based on that,~~Therefore the present study ~~explores~~ explored the impact of basic step calisthenics, and weight-bearing exercises on the geriatric population's lower limb muscle morphology, strength, and functional fitness. It is hypothesized that geriatric women are envisaged to exhibit favorable adherence rates. Moreover, it is also envisaged that a 12-week ~~weight-bearing basic step of~~ weighted calisthenics program will yield augmented lower limb muscle dimensions, increase muscular strength, and enhance functional fitness among geriatric women.

2. Methods

2.1 Participants

Thirty-seven geriatric women were recruited by ~~pasting the~~advertising posters in the community and online platforms in the Yangpu and Hongkou districts of Shanghai. We enrolled all participants who met the following inclusion criteria: 1) women aged 60-75 years old; 2) had no regular exercise habit, specifically defined as exercise <3 times per week and duration <30 minutes each time; 3) signed informed consent and participated voluntarily. And all those were excluded for meeting the criteria: 1) individuals deemed at risk for exercise or advised against participating by medical professionals; 2) those affected by conditions that hinder physical activity, such as arthritis, joint replacements, or bone fractures; 3) participants who did not complete the entire experiment, resulting in incomplete experimental data.

The study was approved by the Ethics Committee of Shanghai Institute of Physical Education (Registration No.: 102772020RT096), and clinical registration also approved (Registration No.: ChiCTR2100047187).

2.2 Intervention

Thirty-seven participants were divided into two groups based ~~on~~ uponn their own preference, where 20 participants ~~were assigned to~~were in the intervention, and 17 were ~~assigned to~~in the control group based on their willingness. Participants in the intervention group carried out 12 weeks of weight-bearing aerobic training ee times a week, totaling 90 minutes, uding 10 minutes of warm-up, 60 minutes of exercise, 10-minute stretching, and two 5-minute rest periods. The music accompanied the exercise routine set at approximately 130 beats per minute. The subjects were engaged in basic steps calisthenics, luding but not limited to march, walk, easy walk, mambo, V-step, grapevine, step touch, leg curl, and knee lift up.

All the participants were made to wear a weight-bearing vest, in which the number of lead plates was gradually increased to increase the load. In the first week, participants acquainted themselves with the basic steps of calisthenics without load. Subsequently, the load was systematically increased, as shown in Table 1.

To adjust the intensity of exercise promptly and to prevent potential accidents, subjects wore a heart rate monitor (Polar OH1) to monitor real-time heart rate. Exercise intensity was formulated as 60%-75% of maximum heart rate[20], where age predicted maximum heart rate = 220 - age.

2.3 Measurements

2.3.1 Measurement of muscle morphology

Muscle thickness, fiber length, pennation angle of the rectus femoris (RF), vastus intermedius (VI), soleus, medial gastrocnemius (GM), and lateral gastrocnemius (GL) in the dominant leg were measured using a portable ultrasound device (LOGIQ e, US, L4-12t).

The RF and VI were measured at the midpoint between the femur's greater trochanter and lateral condyle, with the subject lying supine and relaxed. Soleus, GL, and GM muscles were measured at the proximal 1/3 between the medial femoral condyle and the medial ankle, with the body in the prone position. Each muscle was measured three times, and the results were averaged.

2.3.2 Measurement of muscle strength

The dominant leg's peak torque and endurance of the knee flexor and extensor muscle were measured using ~~the~~ an isokinetic dynometer (CON-TREX-MJ ~~(~~, PHYSIOMED, Germany). The isometric strength testing protocol was as follows: 1) peak torque: flexor/extensor, centripetal/centripetal, 60°/60° angular velocity, 5 repetitions; 2) endurance: centripetal/centripetal, 180°/180° angular velocity, 20 repetitions.

2.3.3 Measurement of functional fitness

2.3.3.1 2-minute step test

The two-minute step test reflected aerobic endurance. Participants were instructed to raise their knees to a height equivalent to the midpoint between their anterior superior iliac spine and patella. In the event of failure to raise knees to a specified height or do so on only one side, those were not counted. Participants were allowed to pause, rest, and then restart till completion of the 2-minute duration.

2.3.3.2 30-second chair stand (30s CST)

Lower body strength was evaluated by 30s CST. Participants were positioned in the center of a 43 cm high chair, with their feet resting flat on the ground and their arms crossed in front of their chests. Upon the command "start," participants were required to stand upright and return to a complete sitting position. The count of times participants completed the entire stand-sit cycle within a 30-second interval was recorded.

2.3.3.3 Chair sit-and-reach (CSR)

The lower limb flexibility was evaluated via CSR. The seated participants were made to extend their one leg and bend forward slowly, sliding the hands down the extended leg to touch (or past) the toes. The score was the distance between the tip of the middle finger and the toe. The score 0 was assigned if they succeeded in touching the toe, while if the middle fingers could not, the score was marked as a negative number (-). Similarly, if the middle finger extended beyond the tip of the foot, the distance score was recorded as a positive number (+). All measurements were taken twice, with the maximum distance recorded as the final score.

2.3.3.4 Time up and go (TUG)

TUG reflects dynamic balance and walking ability. Participants were required to sit in a 45 cm high chair, and walk a 3 m course as fast as possible, then walk back to the chair and sit again. The time taken, measured in seconds, was recorded. Each participant was tested twice, and the average was taken.

2.3.3.5 Single-legged closed-eyed standing test (SCST)

SCST reflected the subject's static balance. The subject was made to stand with eyes closed, and when hearing the command "start", following which, they had to lift one foot off the ground. The tester time was simultaneously started, while stop timing was defined as when the supporting foot moved or the raised foot touched the ground. The results were kept in two decimal places and were measured in seconds.

2.3.4 Compliance and attendance rates

Attendance records were maintained for each training session, and compliance was determined by comparing the number of people eventually included in the statistical analysis to the total number of people recruited. The attendance rate was calculated as follows[21]:

$$\text{Attendance rate} = \frac{\sum Number\ of\ sessions\ attended\ each\ person}{36¿¿}$$

2.4 Statistical analysis

The paired-sample t-test was used for intra-group differences comparison. Effect size, Cohen's d, was calculated, and categorized as small ($0.2 \leq$ Cohen's d < 0.5), medium ($0.5 \leq$ Cohen's d < 0.8), or large (Cohen's d ≥ 0.8) effect sizes[22]. With pre-test data as a covariate, ANCOVA was employed to compare inter-group differences. Effect size, partial η2, defines small, medium, and large effect sizes as 0.01, 0.06, and 0.14[23]. In cases where data did not conform to a normal distribution, and there was an interaction between the treatment factors and the pre-test data, Mann-Whitney U test was used to analyze the differences between the two groups pre and post-test change values, where effect size(r) was calculated by dividing the Z-score by the square root of N, indicating a large effect size using Cohen's d criteria of 0.10, 0.30, and 0.50 for defining small, medium, and large effect sizes, respectively[24]. All statistical analysis were conducted using SPSS (version 26.0), with significant differences at $P<0.05$ and borderline significance at $0.05 \leq \leq P < 0.1$.

3. Result

3.1 Basic Information

Among all participants, two participants from each intervention group and control group withdrew due to poor transportation and inability to ~~train~~ exercise consistently, which reduced the total number of participants to 33, with 18 in the intervention and 15 in the control group. The experimental process is shown in Figure 1. Apart from age, no significant differences were observed between the two groups in height, weight, BMI, duration of menopause, and age at menopause. An overall compliance rate of 89.19% was observed, with the intervention group displaying a 90% compliance rate. attendance rate in the intervention group reached 95.99%. The average heart rate in the intervention group was 112.5 beats per minute, ~~about~~ which represented approximately72% maximum heart rate (Table 2).

3.2 The effects on muscle morphological

The morphological results of the knee extensor and flexor muscles are shown in Table 3. Compared to baseline values, after 12 weeks of intervention, the thickness of the VI and quadriceps in the intervention group increased by 0.27 ± 0.44 cm (*P*=0.02) and 0.40 ± 0.61 cm (*P*=0.01), respectively. The RF had a trend of thickening (Cohen's d=0.41, *P*=0.095), with a reducing trend in RF pennation angle (Cohen's d=0.42, *P*=0.09). In contrast, the control group displayed a potential decline in the thickness of VI at the end of the 12-week duration (Cohen's d=0.48, *P*=0.09).

Moreover, compared to the control group, the VI and quadriceps thickness in the intervention group increased (F=17.85, P<0.01, partial η^2=0.37 and F=15.62, P<0.01, partial η^2=0.34), with a marginally significant increase in the thickness of soleus (F=3.59, P=0.07, partial η^2=0.11).

However, no significant difference was observed between groups regarding the thickness of RF, soleus, GL and GM, the length of all muscle fibers and the pennation angle.

3.3 The effects on muscle strength

The results of isokinetic muscle strength of the knee extensor and flexor muscles are shown in Table 4. The results indicated that after 12 weeks of intervention, the peak torque of knee flexors in the intervention group increased by 5.54 ± 4.81 Nm/kg compared with the pre-test, accompanied by a noteworthy rise in the peak torque/body weight ratio of 0.06 ± 0.10 Nm/kg. Furthermore, knee peak torque flexors/extensors significantly increased by 7.21 ± 10.43%. Conversely, no similar considerable change was detected in the control group.

Upon accounting for baseline differences (*P*=0.02) through covariance analysis, a significant increase was observed in the intervention group in terms of flexors peak torque/body weight ratio after the 12-week intervention, in comparison to the control group (*F*=4.47, *P*=0.04, partial η2=0.13).

3.4 The effects on functional fitness

The results of functional fitness are shown in Table 4. The results showed that the SCST in the intervention group increased by 3.91 ± 5.35s (*P*<0.01) after 12 weeks of intervention, which was significantly increased compared to the control group (*z*=-2.16, *P*=0.04).

Although the 30s CST in the intervention group tended to increase (Cohen's d=0.46, *P*=0.07), a similar significant increase was observed in the control group (*P*<0.01); thus, there was no significant difference between the two groups.

4. Discussion

The results of the 12-week exercise intervention ~~showed~~ indicated that ~~the basic step exercise of~~ weight-bearing calisthenics could increase the thickness of the lower limb muscles, the strength of knee flexion muscles, and improve the static balance ability.

4.1 Muscle Morphology

4.1.1 Muscle thickness

The study had various movements, such as kneeling steps and kicking, which engaged the quadriceps, particularly the VI muscle responsible for knee extension (39.6 to 51.8% contribution)[25], which has been reported to considerably benefit the VI muscle[26, 27]. After 12 weeks of intervention, the thickness of VI increased while reduced in the control group, cementing the claim that the weight-bearing basic step of calisthenics has specific effects on delaying muscle loss and increasing knee extender muscle mass[28]. Similarly, the RF displayed a trend of thickening while quadriceps were found to have increased thickness in the intervention group, paralleling earlier research which showed that eight weeks of aerobic exercise at 60 to 80% Max VO_2 intensity significantly improved the thickness of quadriceps in the subjects [29].

By introducing additional weight-loading, muscles involved in the ankle strategy, such as the tibialis anterior and soleus[30], are activated to maintain body balance. Previous studies indicated that wearing weight-bearing vests during exercise contributes to lower limb muscle mass increase[31, 32]. Our study observed a mere trend of thickening in the soleus in the intervention group, without significant differences compared to the control group, which could be attributed to methodological differences. Prior studies often quantified overall lower limb muscle mass through techniques like nuclear magnetic or dual-energy X-ray absorption[33], whereas this study primarily measured the thickness of specific muscles. Additionally, the applied weight in earlier studies was notably higher, reaching up to 10% of participants' body weight[32].

4.1.2 Muscle fiber length and pennation angle

Studies have demonstrated that in addition to inducing significant muscle hypertrophy, aerobic exercise training has the potential to influence muscle structure, especially muscle fiber length and pennation angle. These structural changes, in turn, can modify contraction properties and enhance overall muscle function[34]. However, aside from a marginal decrease in the RF pennation angle within the intervention group, other muscles' fiber lengths and pennation angles remained essentially unchanged compared to the baseline, which was in contrast to specific studies in which resistance or centrifugal exercises elicited varying degrees of muscle fiber length and pennation angle increments[28, 35]. Nevertheless, these results were similar to studies where exercise interventions did not yield significant modifications in pennation angle and fiber length[36, 37].

4.2 Muscle strength

Previous studies have shown that physical activity can enhance muscle strength and balance, significantly reducing the risk of falls and fractures[38]. Moreover, consistent participation in low-impact aerobic walking exercises can substantially improve knee extension torque among active individuals compared to their sedentary counterparts[39, 40]. Following the 12-week intervention, no significantly altered knee extension torque was observed in the intervention group; however, the peak torque/weight ratio of knee flexors in the intervention group was greatly improved compared to the control group, which was consistent with previous studies that aerobic and resistance exercises contribute to the enhancement of knee muscle strength[41, 42].

After 12 weeks of intervention, the intervention group's flexors peak torque /extensors peak torque (H: Q) increased from 0.57 to 0.64. The typical H: Q ratio is approximately 0.6 for individuals without any musculoskeletal issues, which tends to decline with age. A lower H: Q ratio may indicate the imbalance of lower limb muscle strength and the occurrence of leg injury[43]. The increased H: Q observed in this study might be related to an increase of knee flexion torque. Despite the prominent involvement of the quadriceps during the exercise regimen, the torque of the flexion muscle group increased, which could be attributed to the activation of antagonistic muscle groups, namely the flexion muscle group, during the exercise routine. This activation helps maintain dynamic balance, aids ligaments in preserving joint stability, and ensures even distribution of pressure across joint surfaces, particularly when executing rapid changes in the direction of basic aerobic steps[44].

4.3 Functional fitness

Functional fitness is the ability of the human body to carry out daily activities independently and safely without fatigue[45]. Enhanced functional fitness is associated with lower abdominal fat[46] and health-related quality of life in geriatrics[47].

One-leg standing is a standard balance indicator, with eyes open or closed in two states. Previous studies have shown that patients unable to sustain one-legged balance for 5 seconds with their eyes closed are 2.1 times more likely to fall than those who can maintain balance for more than 5 seconds[48]. Additionally, time spent on SCST was negatively correlated with somatic symptoms and anxiety/insomnia[49]. The SCST can enhance the arterial resilience of the supporting leg[50], thereby fostering cardiovascular well-being and preventing cardiovascular diseases in geriatric women. These dual benefits represent the significance of SCST as an indicator of balance ability and a predictive measure for fall susceptibility, thus reflecting overall health status. Evident improvements were observed in SCST following the 12-week intervention, consistent with previous findings[51, 52]. Notably, before the intervention, a majority (56%) of participants in the intervention group exhibited SCST durations of less than 5 seconds, which substantially decreased to 28% after the intervention. Conversely, the control group witnessed an increase in individuals with sub-5-second SCST from 47 to 53%. This highlights that 12-week weight-bearing exercise can improve static balance in geriatric adults and potentially further reduce the risk of falls and fractures.

At the same time, in intervention group, 30s CST reflecting muscle strength, also showed an increasing trend, indicating exercise can improve the physical function of sitting and standing tests in geriatrics[53]. This result was consistent with the above findings of improved muscle strength in the knee extensor and flexor muscles. In contrast to previous studies[54], this study did not yield evidence of weight-bearing exercise leading to improvement in the 2-minute step test and TUG, which could be attributed to the prior studies involving frail subjects[55] or older adults suffering from knee osteoarthritis. Notably, the geriatric subjects in this study with good physical condition had great physical function. Achieving more substantial enhancements in physical performance could necessitate an extended intervention period (>16 weeks) [54, 56] and more exercise to bring about significant improvement in physical performance.

4.4 Compliance and attendance rate

Compliance is closely related to the intervention effect[57]. In this experiment, weight-bearing exercise and calisthenics were combined, yielding an impressive overall compliance rate of 89.19%. Notably, the intervention group exhibited an even higher compliance rate of 90%, surpassing the compliance rates of prior weight-bearing exercise studies (80.4%[17] and 84%[16], respectively). Compared with the attendance rates of 79.7%[21] and 83%[58] in other combined exercise studies using weight-bearing vests, the attendance rate of 95.99% in this experiment was higher. These compliance and attendance outcomes underscore that the combination of weight-bearing exercise and calisthenics was more readily accepted by geriatric subjects, thereby amplifying the feasibility of the study. In future studies, it is crucial to prioritize a thorough of the real-life conditions faced by geriatrics and to explore the types of exercise ensuring higher acceptability for achieving the expected effect.

4.5 Limitations

This study has certain limitations that should be acknowledged. Due to COVID-19, intention grouping was adopted instead of a random group, potentially impacting the overall evidence level of the study. The participants were all geriatric women, which restricts the generalizability of the findings to other age groups or genders. For further studies, broadening the study population to include older men aged 60-75 years could provide insights into the impact of weight-bearing basic steps calisthenics on the lower limb muscles of older adults.

5. Conclusion

The study concluded that a 12-week weight-bearing basic step of calisthenics could delay the decline of muscle mass and muscle strength in elderly women, and improve physical function, thus improving the quality of life. In addition, this study provides a reference exercise program for older women and provides a reference for older women to participate in sports.

Author contributions

All authors contributed to the study conception and design. The first draft of the manuscript was written by Xiaoying Peng. The article was reviewing and editing by Tangzhou and Minghui Quan. Material preparation were performed by Tang Zhou, Yiyan Li. Data collection were performed by Xiaoying Peng, Tang Zhou, Yiyan Li, Jiajia Liu, Huan Huang, Changshuang He, Shaoyu Guo, Muyang Huan, Lei Shi. Funding was acquised by Minghui Quan. All authors read and approved the final manuscript.

Abbreviation

RF: rectus femoris

VI: vastus intermedius

GM: medial gastrocnemius

GL: lateral gastrocnemius

H: Q : flexors peak torque /extensors peak torque

30s CST: 30 second chair stand

CSR: chair sit-and-reach

TUG: timed up and go

STCT: single-legged closed-eyed standing test

BMI: Body Mass Index

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