Effects of Exercise and Anti-Aging

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Abstract

As demographic aging continues in Japan, the number of very elderly individuals aged 75 years or older is increasing rapidly, as is the number of bedridden, elderly individuals, with ramifications extending to economic problems such as health care costs and insurance for long-term care. Consequently, there is a great importance to questions of how to prevent age-related loss of muscle (sarcopenia) to prevent bedridden states, and further to improve quality of life (QOL) and maintain active lifestyles. Exercise is the most effective means for preventing and addressing sarcopenia. Regular exercise is also reported to prevent progression of arteriosclerosis, prevent lifestyle diseases, and delay onset of dementia. However, the effects of exercise are known to differ substantially for different types of exercise. Regular walking and other aerobic exercise improves cardiovascular endurance, but among the elderly, loss of muscular strength, muscular atrophy, and other diminished physical functions have implications for falling and fractures, and it is not uncommon to see a consequent aggravation of disuse syndrome due to inactivity, leading to a bedridden state. In this light, strength training is also important for elderly individuals, to increase muscular strength and muscle mass. It is also highly important for elderly individuals to eat a diet, particularly amino acids, that enhances the effects of exercise. Here we present an overview of aerobic exercise, resistance training, and “kaatsu training” (i.e., training under pressure-restricted blood flow to the extremities) representing anti-aging exercise methods. We likewise discuss the importance of diet for exercise.

KEY WORDS: Kaatsu training, anti-aging, resistance exercise, amino acids, sarcopenia

Introduction

Muscular strength and muscle mass are well known to decline with age. This phenomenon is called sarcopenia. When an individual passes age 30, muscle mass decreases approximately 0.3-0.5% every year, and after age 60, the rate of decrease is very substantial. At age 80, muscle mass is thought to decrease to 50% or lower than during the prime years. In bed, muscles also decrease by 0.6% per day. Consequently, hospital admission for cerebrovascular accident, fracture, or other such reasons can lead, in 3 weeks of bed rest, to even a 12% reduction in muscle mass, and particularly for elderly individuals or sarcopenia patients, such an instance often leads to a bedridden state or disuse syndrome. Additionally, age-related sarcopenia not only increases the risk of falling; it can also be a factor in decreased independence or frailty of the elderly due to insulin resistance or glucose metabolism disorder associated with decreased muscle mass. Routine measures to maintain muscular strength and muscle mass and prevent sarcopenia are therefore highly important.

In gross distinction, exercise can be divided into strength training versus aerobic exercise such as walking (treadmill) and bicycling (ergometer) 11. Fig. 1 presents differences in the effects of aerobic exercise versus strength training. The effects of aerobic exercise are more apparent than those from strength training in terms of peak oxygen uptake, extension of exercise endurance time, and other improvements in cardiovascular endurance. However, aerobic exercise does not increase muscle mass, and its effect of increasing bone density is reputedly lower than that of strength training. In contrast, resistance (muscular strength) training has a stronger effect than aerobic exercise on enhancing muscular strength and muscle size and likewise acts strongly to increase bone density. Resistance training also elevates basal metabolism. Each type of exercise has an apparently similar effect of improving glucose metabolism and fat metabolism, and both are reputedly useful for improving insulin resistance, in particular, decreasing insulin response to glucose loading.

American College of Sports Medicine (ACSM) guidelines report that elderly individuals show sarcopenia and diminished muscle strength in nearly all cases and state that resistance training is needed to enhance muscle strength and maintain muscle mass. Strength training is also seen to improve insulin resistance, increase bone density, and improve QOL and is recommended for progressive, age-related osteoporosis, a cause of fractures. However, the guidelines also state that elderly individuals should not engage in high-intensity strength training with weights. While muscle strength and muscle mass clearly diminish with age, peak oxygen uptake is also known to decrease. Myers et al. studied the association between peak oxygen uptake and prognosis by comparing individuals with peak oxygen uptake at or lower than 5 METS with those at higher levels; they reported a distinct difference in long-term prognosis both among healthy individuals free from obvious disease and among patients with cardiovascular disease 21. Recently, the incidence of dementia has also increased rapidly, and after 10 years, 10% of those age 65 years or older are said
Effects of Exercise and Anti-Aging to develop dementia. In contrast, routine exercise is reported to improve QOL in dementia\(^3\), and results from a prospective cohort study state that routine exercise may also delay onset of dementia\(^4\). In this light, anti-aging is the joint pursuit of both types of exercise to manifest their independent effects: aerobic exercise to improve peak oxygen uptake and impart endurance, and strength training to improve muscle strength, and this regimen is also recommended for its anticipated complementary effects.

Here we provide an overview of aerobic exercise, resistance training, and kaatsu training, together representing anti-aging exercise. Kaatsu training is a new training method reported to increase muscle size and muscular strength even with low-intensity loading, in a manner not achieved by conventional resistance training. We also discuss diet, and particularly amino acid intake, highly important elements for enhancing the effect of exercise in elderly individuals.

### I. Aerobic exercise and strength training

#### Ia. Aerobic exercise

Aerobic exercise (e.g., walking, treadmill, bicycle ergometer) known to improve cardiopulmonary endurance is fundamental to exercise therapy. Evidence as to its multifaceted effects proves the usefulness of exercise therapy\(^5,6\). In particular, 1) improved exercise endurance is shown by improved anaerobic threshold (AT) and peak oxygen uptake, which increases patient QOL. 2) Symptomatic improvement in identical ADL tasks and 3) improved life expectancy are shown by numerous meta-analyses indicating that cardiovascular death and total deaths decrease by 20-30%. 4) Improved lipid metabolism and glucose metabolism and improvement in obesity are demonstrated by further improvement with concomitant dietary guidance and weight loss. 5) Decreased smoking rates and 6) improved psychosocial satisfaction and decreased stress are psychological improvements. Other reported effects include decreased blood pressure at rest and during exercise, decreased heart rate, decreased myocardial oxygen consumption during exercise, increased mass of active muscles, and increased muscular mitochondrial activity. In this light, routine aerobic exercise is also useful for preventing progression of arteriosclerosis, preventing lifestyle disease, and at the same time improving QOL of the elderly.

Actual aerobic exercise is often prescribed by determining load intensity using a treadmill or bicycle (ergometer)\(^7,8\). The effects of exercise are closely related to exercise intensity, and the effect of an increase in peak oxygen uptake (an index of exercise endurance) increases with increasing exercise intensity. In general, improvement in aerobic capacity requires exercise at an intensity of 50-80% of peak oxygen uptake (VO\(_{2}\)max) for 20 min. or longer, 3-5 times per week. However, for considerations of safety among elderly and other such individuals, the load intensity used is, for example, 40-60% of peak oxygen uptake and 50-70% of maximum heart rate as measured by an exercise load tester, and AT as prescribed (intensity of 70-80% AT or 1 minute prior to AT). Exercise with a somewhat challenging target value (Borg scale 13) as a subjective symptom is often pursued for 20-60 min. per day, 2-5 days per week. The effects of exercise are also manifest more readily at low levels of physical capability and activity. In a study of the effect of cardiac rehabilitation (aerobic exercise) on peak oxygen uptake among patients participating in cardiac rehabilitation at our facility\(^9\), a mean 15% increase in peak oxygen uptake was observed after 3 months of 40 minutes of aerobic exercise (ergometer) performed 2-3 times per week. The patients involved were age 34-85 years and thus included very elderly individuals. In this respect, ongoing, appropriate aerobic exercise is regarded as a safe means of exercise pursued actively even among elderly individuals. Recent reports state that repetitive training alternating between high and low loads, i.e., interval training and hypoxic training involving exercise in a low-oxygen environment\(^10\), increases cardiopulmonary endurance more than ordinary aerobic exercise, and future applications are also anticipated.

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**Fig. 1.** Comparative effects of aerobic exercise and strength training (cf. Reference 1)
**Ib. Strength training**

As described, appropriate aerobic exercise is useful for improving cardiopulmonary endurance even in the elderly. However, sarcopenia and diminished muscular strength are seen in virtually all elderly individuals, and resistance training is also needed to enhance muscular strength and increase muscle mass. Strength training is also known to have effects of improving insulin resistance, increasing bone density, and improving QOL. Strength training is therefore recommended as an anti-aging measure to increase muscular strength and muscle mass [7]. Resistance training is strength-enhancing exercise of the extremities or trunk using free weights, rubber bands, or machines and is performed with careful setting of loads for each exercise. The recommended resistance exercise regimen is 2-3 times per week, and for the most part, 2 times per week is used. The procedures used come from a strength training menu of several categories (8 categories) for the major muscle groups and include chest press, shoulder press, triceps extension, biceps curl, pull-down (upper back), lower back extension, abdominal crunch/curl-up, leg extension or leg press, leg curls (hamstrings), and calf raises, with load intensity at 40-60% of 1RM. In strength training using training machines, the load intensity is preferably 30-40% for upper extremity exercise and 40-50% for lower extremity exercise. In most cases, 1 set comprises 8-15 repetitions, and 1-2 sets are performed. However, effective improvement of the structure and function of skeletal muscle, for example, to increase muscle size and muscular strength, generally requires a high intensity exceeding 70% of maximum weight lift potential (1RM), to the point of muscular fatigue, i.e., 3 sets, 2-3 times per week. In a systematic review of the literature published to date concerning the sarcopenia-improving effect of strength training, Michiya et al. [10] reported that even moderate intensity could have the effect of increasing muscular strength, but high-intensity training is required to increase muscle mass. Accordingly, conventional strength training pursued at an intensity of 40-60% 1RM often simply does not produce increases in muscle size. However, high-intensity loading entails a risk of injury to the moving organs or circulatory system in elderly individuals. High-intensity strength training studied in healthy, young subjects is also reported to increase arterial stiffness, an index of arteriosclerosis [12-14], and among elderly individuals too, high-intensity strength training is often not recommended due to increased stress on the joints.

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**IIa. About kaatsu training**

Kaatsu training is strength training in which specialized pressure-applying belts are used to apply pressure at the base of the extremities, and training is performed in a state of restricted blood flow [15,16,19,23]. The training is distinctive for producing increases in muscle size and strength through short-duration, low load-intensity training. While there is considerable research on the load intensity used in ordinary strength training and its principal effects, load intensity, essentially, mechanical stress, is thought to be the most crucial element for effecting increases in muscle size. In ordinary exercise procedures, a load intensity of 65-70% 1RM or greater is needed to increase muscle strength and size; however, an intensity of 65% 1RM or greater is often difficult for elderly individuals and patients presenting muscular atrophy. In addition, resistance training at high-intensity raises blood pressure, and due care is required. In contrast, because one characteristic of kaatsu training is production of increased muscle size and strength at low load-intensity that cannot be realized through conventional resistance training, larger muscle size and greater strength are produced even at the low intensity of 20%-40% 1RM, i.e., nearly a routine level of activity. Takarada, Ishii, et al. [20] studied the effects of kaatsu training (30%-50% 1RM, 3 sets, 2×/week, 4 months) of upper arm flexors among subjects comprising healthy females of mean aged 60 years old, and reported in their results that both cross-sectional area and muscle strength of the biceps brachii increased by a mean of approximately 20.3%, an effect equivalent to training at an intensity of 80% 1RM. Conversely, there was virtually no observed effect in the same training at an intensity of 30%-50% 1RM when kaatsu pressure was not applied, suggesting that the effect of increased muscle size was attributable to kaatsu pressure. Ishii et al. [21] also stated that leg extension kaatsu training (20-30 RM [sic], 5 sets, 2×/week, for 2 months) among top athletes also produced an approximate mean of 10% increase in muscle size and 15% increase in strength, but muscle size and strength did not increase in training at the same intensity without kaatsu pressure. These results suggest that kaatsu training has a substantial effect without regard to the age or training history of the subject, and that the primary factor in such effects is kaatsu pressure itself. Wernorm [24] recently studied the domestic and foreign literature concerning high-intensity strength training and low-intensity training under restricted blood flow and reported that the relative increase in quadriceps size from leg extension exercise was similar in each case. In high-intensity strength training (80% 1RM, 3-4 sets, 6-10 repetitions, 60-120 second pause), the increase was 0.03-0.26%/day and 1-7%/month; in the low-intensity training under restricted blood flow (20-50% 1RM, 3-4 sets, 15-30 repetitions, 30-60 second pause), the increase was 0.04-0.22%/day and 1.2-6%/month.

In high-intensity strength training, muscle fatigue also precludes consecutive-day training for healthy individuals who are non-athletes, and patients as well, but the use of low-intensity loading in kaatsu training allows consecutive-day training. Yasuda et al. reported that muscle cross-sectional area increased approximately 8% in the short duration of 2 weeks when kaatsu training (intensity approximately 20% 1RM) was performed twice per day (morning and evening) every day by healthy individuals using the lower extremities [25]. Kaatsu training is also not limited to resistance training using strength machines and can also be applied in aerobic exercise such as walking or ergometer use [26,27]. Abe et al. [28] reported observing increased lower limb strength and muscle size in young, healthy individuals after 3 weeks of walking at a normal pace (walking at approximately 20% of peak oxygen uptake). In this fashion,
kaatsu training can also be applied in aerobic training methods and can be performed ordinarily by anyone, and the training can also be adjusted according to individual abilities. By inducing effects of increased muscle strength and size at a low intensity of 20% 1RM, kaatsu resistance training allows development of individual muscle groups without use of special machines, and if machines are used, even more effective strength training can be accomplished.

There are several recent reports concerning the effects of kaatsu training among elderly individuals. One concerning research using strength training machines reports that increased muscle strength akin to that in high-intensity strength training was observed 28. We likewise studied the effects of kaatsu strength training on muscle strength and size among 7 patients with stable ischemic heart disease (52±4 years, 5 pPCI, 2 pCABG) 29. The low-load strength training was performed with lower leg extremity only (leg extension, leg press, leg curl) at 20-30% 1RM, 4 sets. The interval between sets was 30 seconds, and the training duration was 2×/week for 3 months. Fig. 2 presents the effects of kaatsu training with regard to increased muscle size and strength. After kaatsu training, effects of a significant increase in muscle size (A) and muscle strength (B) were observed. Additionally, during the training, no particular problematic adverse effects were observed.

Abe et al. reported that increased muscle size was observed in a research study concerning kaatsu-walk training conducted with elderly individuals 30,31. High-intensity strength training has been reported to increase arterial stiffness, an index of arteriosclerosis 12,13, but in kaatsu-walk training, arterial stiffness was instead seen to improve 32,33. Venous stiffness as well as arterial stiffness has been reported to increase with aging, and we studied the effects of kaatsu-walk training by elderly individuals on venous stiffness. In the results, we reported that kaatsu-walk training by elderly individuals also improved venous stiffness 34. This series of results suggests that in kaatsu-walk training, an effect of increased muscle size is observed even among elderly individuals only with low intensity loads at which conventional training does not produce such an effect, and likewise, that vascular compliance may be improved, and that progression of arteriosclerosis may be prevented.

IIB. Muscle growth mechanism of kaatsu training

Through various mechanisms, kaatsu training can increase muscle size and strength effectively 16,19. Kaatsu training involves exercising while pressure is applied to the base of the extremities with specialized pressure-application

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**Fig. 2** Effect of kaatsu training on ischemic heart disease patients (cf. Reference 29)
A: Change in muscle cross-section after kaatsu training. Relative increase in size of separate muscle groups, thigh region, according to MRI. Relative increase in cross-section versus pre-training value for separate muscle groups 30% down from top of thigh region, at central 50%, and 70% down from top of thigh region. Quadriceps femoris (QF), hamstring (HAM), adductor (ADD).
B: Relative increase in 1 RM for various strength training exercises (leg extension, leg press, leg curl). p < 0.05 vs. control.
belts to restrict primarily venous blood flow in the muscles (intramuscular blood pooling)\(^{21,22}\). Oxygen supply to the muscles is then reduced and clearance of lactic acid and other metabolic products is obstructed. As a result, it is thought that a large number of motor units are mobilized during exercise in order to maintain strength\(^{36}\). This mobilization of a large number of motor units during exercise is regarded as one cause of the increase in muscle size, and in reality, kaatsu training under low-intensity load has been shown to accelerate protein synthesis\(^{35}\). Fujita et al. also carried out leg extension exercise at 20% 1RM and reported that muscle protein synthesis was stimulated by a change in the mRNA translation initiation system\(^{35}\). A report\(^{39}\) based on electromyogram analysis also states that activity in a large number of muscle fibers has also been observed under kaatsu pressure, as in high-intensity training, in spite of the light load applied.

Ohta et al. studied the effect of kaatsu training on muscle fibers and reported that both Type I (slow-twitch fibers) and Type II fibers (fast-twitch fibers) each demonstrated a trend of increased size in muscle biopsy performed after 8 weeks of kaatsu rehabilitation following reconstruction of the anterior cruciate ligaments\(^{37,38}\). Type II fibers are also reported to increase in size in kaatsu training by healthy individuals\(^{23}\). In general, it is Type II fibers that show conspicuous enlargement due to muscle training. Consequently, the muscle-enlarging effect of kaatsu training is thought to result mainly from enlargement of fast-twitch fibers, but further studies to include the effect on slow-twitch fibers are needed. As fast-twitch fibers also decrease markedly with aging, and this phenomenon is closely related to decreased muscular strength in the elderly, kaatsu training may be effective for increasing muscle size and strength in elderly individuals.

Growth hormone (GH) and other such humoral factors are said to contribute to muscle growth through resistance training. One mechanism of the muscle size-increasing effect of kaatsu training is thought to be the role of increased growth hormone secretion. GH is secreted by the pituitary gland, is an import growth factor affecting the muscles, bones, and other effectors, and is known to have various functions. Secretion of GH pursuant to exercise depends on the intensity, type, and duration of exercise and other related factors and requires at least 10 minutes of high-intensity exercise or exercise exceeding the anaerobic threshold (AT); at lower loading, distinct secretion does not occur. In low-intensity kaatsu training (20% 1RM) studied in the thigh muscles, the level of GH in blood was reported to increase markedly immediately after exercise\(^{39}\). Our investigation also found distinct secretion under kaatsu pressure at low-intensity resistance loading of 20% 1RM\(^{40}\). This effect was observed not only with resistance loading of the extremities, but also in ordinary walking\(^{39}\). In kaatsu training, accumulation of lactic acid and other such substances stimulates multifunctional afferent nerves distributed in skeletal muscle, and triggers a metabolic reflex mediated by the hypothalamic-pituitary system, which is considered to play a crucial role in secretion of G.H.

Localized mechanisms may also contribute to the overall mechanism of muscle growth. These include growth factor secreted by muscle fibers or their surrounding cells. In an experiment using a kaatsu animal model (rat with surgically-induced selective blocking of veins from muscles of the posterior extremities), Kawada et al.\(^{41}\) reported that fast-twitch muscle fibers were selectively enlarged approximately 10 days after restriction of blood flow. These enlarged muscles demonstrated characteristics including 1) decreased myostatin expression, 2) increased active hepatocyte growth factor (HGF), 3) increased nitric oxide synthase (NOS-I), and 4) increased muscular glycogen. Myostatin in particular is a factor which strongly restricts muscular growth, and the fact that this change is regarded as a factor accelerating muscular growth means that the changes in such local factors due to kaatsu pressure may cause muscle growth.

\section*{IIc. Effect of kaatsu training on trunk muscles}

Like the lower extremities, the trunk muscles are known as skeletal muscles readily susceptible to sarcopenia\(^{42,43}\). Sarcopenia in these muscles, which play a crucial role in daily activities and walking, can lead to diminishment of bodily functions required for activities of daily living. We therefore summarize the effects of kaatsu training on the trunk muscles.

Investigation of the effect of kaatsu training at 30% 1RM on the trunk muscles using primarily the bench press, a multiarticular exercise, showed that the amount of muscular activity in the pectoral muscles and triceps brachii during kaatsu exercise increased in both muscle groups as the number of lifting repetitions increased, and at the last stage of the final set, activity reached a high value of 110-120\% versus the start of exercise in both muscle groups. Kaatsu exercise also produced a significantly higher level of muscular activity than exercise without kaatsu pressure\(^{44}\). This finding represented results similar to those in single-articular exercise moving only the limbs, and in low-intensity kaatsu bench press exercise, large mechanical stress in excess of the loading weight lifted was found to be on the muscles of the trunk, not merely on those of the arms\(^{45,46}\). The stimulation from kaatsu training is thus regarded to substantially affect even the trunk muscles, where blood flow is not restricted.

Changes in muscle thickness have also been observed in the triceps and pectoral muscles during 2-week kaatsu training performed 2×/day (morning and afternoon, Fig. 3)\(^{47}\). Typically, muscle thickness at these locations demonstrates an extremely high correlation with muscle cross-sectional area and muscle volume, therefore, any changes in muscle thickness can be a primary indication of changes in muscle mass. Muscle thickness of the pectorals measured prior to the morning training increased approximately 11\% in the first 1-week period, did not decrease even with the interruption of a break on Sunday, and was observed to increase approximately 6\% further in Week 2. These changes in muscle thickness did not decline even 3 weeks after the completion of training. However, virtually no changes in muscle thickness were observed throughout the 2-week period in training without kaatsu pressure. Such changes in muscle thickness were also observed in the triceps, and the limbs and trunk demonstrated similar changes. Next, to determine whether any changes in cross-sectional area of the pectorals would be observed under ordinary training conditions, the effects of kaatsu training were observed during 6 weeks (3×/week) of bench press exercise. As a result, muscle cross-sectional area measured by MRI showed an approximate 5\% increase in the triceps muscle and an approximate 8\% enlargement of the pectoral muscles\(^{48,49}\). These results therefore show that kaatsu training may also enlarge the muscles of the trunk. As stated previously, a marked increase in muscular activity was observed in the pectorals, and not only the triceps, during low-intensity bench press exercise with kaatsu pressure. It is possible that when kaatsu pressure fatigues the muscle groups of the arms, the thoracic muscle groups, as cooperative muscles, compensate and work more actively than usual, and that this stimulation is one important factor causing an increase in the size of the trunk muscles. Dramatic activation of the endocrine system has also been observed in kaatsu exercise, and in conjunction, effects
outside the local area where blood flow is restricted have also been reported (i.e., effect migration), which may be another substantial factor.

Because pressure is applied at the base of the extremities in kaatsu training, it is readily but incorrectly thought that perhaps only the extremities grow. But in reality, as such purely local enlargement occurs, a similar response has also been found to occur in muscles of the trunk which contribute to motion of the shoulder joints and hip joints. Consequently, kaatsu training performed at low intensity can also enlarge the muscles of the trunk, and not only those of the extremities, indicating that this training is extremely effective for frail and elderly individuals and may hold substantial promise as a supportive method to correct sarcopenia in particular.

IId. Potential effect of kaatsu training on muscular atrophy

Cachexia and sarcopenia are known as particularly conspicuous states of muscular atrophy. Sarcopenia refers to a decrease in muscle size leading to a distinct reduction in muscle strength. The diseases engendering this state are most often chronic obstructive pulmonary disease (COPD) and heart failure but also include senility, rheumatoid arthritis, and cancer. Various factors contribute to cause sarcopenia, including degeneration of muscle fibers, inflammation due to increased levels of tumor necrosis factor (TNF)-α and other cytokines, nutrition, and disuse. Resistance training, as well as aerobic exercise, are useful in preventing muscular atrophy, but improvement is often slow. Here we present an actual case where kaatsu training proved useful for such a patient. A 39-year-old female experienced decreased muscle strength in the lower limbs due to allergic
granulomatous angiitis, making plantar flexion and dorsal flexion impossible in this case. Before training started, lower limb circumference at the distal portion was 26.9 cm in the right leg and 31.7 cm in the left leg, showing clear atrophy on the right side. Kaatsu training was performed 2 times per week with an attachment pressure of 40 mmHg applied to the lower limbs, and setting pressures of 200 mmHg and 150 mmHg applied to the right and left legs respectively at the beginning of the training. Training comprised light, low-load exercise including plantar flexion and dorsal flexion of the hands and feet (3-point set), non-loaded leg extensions (alternating), non-loaded squats, and kaatsu-walk training. The fact that even pressures of 200-300 mmHg do not cause hemostasis is a particular feature of the specialized kaatsu belts used, though individual differences and setting pressures produce different results. Training was then changed to lower limb-only exercise, and the exercise level was raised with increased loads. The 22nd training comprised kaatsu exercise of the lower limbs only. The attachment pressure used was 45 mmHg, and setting pressures were 300 mmHg and 180 mmHg for the right and left legs respectively. Three-point sets of leg extensions with a 5 kg load and leg curls with a 14 kg load applied deliberately to the right leg were performed, followed by calf raises under kaatsu pressure and kaatsu-walk training. Fig. 4 presents MRI findings for the lower limbs before inception of kaatsu training and 3 months later. The individual also perceived an increase in muscle strength and muscle size, and plantar flexion and dorsal flexion also became possible. Kaatsu training was thus determined to have a clearly effective improvement, even in a patient presenting muscular atrophy.

As stated above, recent investigations of the effect of kaatsu training on muscle strength and mass among elderly individuals have reported a distinct effect.

III. Exercise and nutritional intervention for correction of sarcopenia

Measures have been studied to maintain muscle mass and prevent atrophy in occurrences of sarcopenia, a phenomenon among the elderly in which muscular atrophy leads to decreased muscle mass, resulting in impaired mobility. In particular, nutritional intake and consumption of essential amino acids including branched chain amino acids (BCAA) are crucial for rapidly increasing synthesis of skeletal muscle proteins. The amount of muscle proteins present is determined by the balance of muscle protein synthesis and decomposition. Fig. 5 presents the effects of exercise (resistance exercise) and diet (amino acid intake) on muscle protein synthesis and decomposition. Muscle proteins are continually and repeatedly synthesized and decomposed, and at rest, decomposition of muscle proteins outweighs synthesis, and the net balance of muscle protein addition and subtraction produces no increase. At the same time, muscle protein synthesis is regulated by amino acid concentrations in the blood, and when such concentrations decline, muscle protein synthesis decreases rapidly; conversely, when such concentrations increase, muscle protein synthesis also increases. Consequently, when amino acids are administered at rest, muscle protein synthesis increases (Fig. 5). In addition, when amino acids are consumed after exercise, muscle protein synthesis is accelerated, while muscle protein decomposition caused by exercise is inhibited, moving the net balance of muscle proteins distinctly toward increase and improvement. However, when amino acids are not administered, decomposition of muscle proteins is not inhibited, and the balance does not become positive. Thus, consumption of BCAA is thought to decrease the amount of amino acids liberated from muscle proteins, inhibit decomposition of muscle proteins, and in this way incline the balance toward an

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**Fig. 4.** Effect of kaatsu training in a case of decreased strength and muscular atrophy, lower extremities, due to allergic angiitis (cf. Reference 53). MRI findings before/after kaatsu training shown. Clearly atrophied right lower thigh muscle is perceptibly larger after kaatsu training.
Effects of Exercise and Anti-Aging

Fig. 5. Effect of amino acid (AA) administration at rest and during exercise on muscle protein synthesis and decomposition (from Reference 54)

FOM (intracellular amino acid utilization (protein synthesis)), FMO (intracellular amino acid appearance (proteolysis)), N.B. (net amino acid balance across the leg (negative numbers indicate net release)). Muscle protein synthesis at rest is increased by administration of amino acids. In exercise, amino acid administration makes that balance positive, and synthesis of muscle proteins overcomes decomposition. See reference for details.

An adequate supply of amino acids in the blood is also crucial for stimulation of muscle protein synthesis by insulin. In sum, nutritional intervention is regarded as an extremely important factor for increasing muscle size.

Many factors are regarded as causes of sarcopenia among the elderly, including age-related changes in endocrine secretion function, inactivity, and inadequate nutrition, particularly inadequate amino acid intake. Irregular meals or amino acid intake and inactivity is theorized to lead to a negative balance of muscle protein addition and subtraction and cause muscle atrophy. However, resistance training has been proven to accelerate synthesis of skeletal muscle proteins even among the elderly, just as in young individuals. Volpi et al. investigated muscle protein metabolism as a function of amino acid intake among elderly individuals. Their results showed that the accelerating effect on muscle protein synthesis was equivalent when complete amino acids were provided and when essential amino acids were provided, and essential amino acids produced a muscle protein synthesis-accelerating effect even among elderly individuals. Thus, exercise and nutritional intervention are regarded as useful for correction of sarcopenia even among elderly individuals, just as among younger individuals.
Conversely, Volpi et al. investigated the effects of amino acids and sugars on muscle protein assimilation among elderly individuals, and reported that protein assimilation produced by amino acids alone was clearly lowered when sugar was consumed. This effect is deemed related to factors such as insulin resistance, but it can also be assumed that the capability for dietary-based protein synthesis is reduced among the elderly. Fujita et al. also reported that increase in intramuscular blood flow is highly important for acceleration of muscle protein synthesis by insulin. Consequently, when insulin resistance or other such factors preclude increase in muscular blood flow, muscle protein synthesis is also thought to decline. In the elderly, such nutritional deficiency may contribute to sarcopenia, and further study of effective nutritional intervention for the elderly is needed.

**Conclusion**

As societal aging continues, questions of how to prevent age-related muscle loss (sarcopenia) to prevent bedridden states, and further to improve QOL and maintain active lifestyles are crucial issues. Exercise therapy is highly useful in these respects. Our paper discusses aerobic exercise, strength training, and kaatsu training in particular as anti-aging exercise. Diet that enhances the effects of exercise, and amino acid intake in particular, are regarded as extremely important measures to correct sarcopenia among the elderly. Further study is needed on prevention and improvement of sarcopenia through multifaceted programs combining exercise and dietary intervention.
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ANTl-AGING MEDICINE
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