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Could Vibration Training Be an Alternative to Resistance Training in Reversing Sarcopenia?

by

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Age dependent loss of strength and muscle mass, termed sarcopenia, worsens normal functioning of the elderly, increases the risk of fall and finally leads to the loss of their independence. Sarcopenia is also closely linked to age-related losses in bone mineral density, basal metabolic rate and increased body fat content.

Resistance training may reverse sarcopenia at any age. It may also reduce associated abnormalities. However, a safe and effective resistance exercise program requires complex exercises and close supervision, and quite a lot of time before any significant effect can be seen.

A novel form of exercise based upon the application of sinusoidal vibrations to the whole body (WBV), can enhance force generating capacity in humans. Recently it has been demonstrated that vibration training can induce skeletal muscle strength increase similarly to that seen after resistance training, both in young and elderly persons. Conflicting results concerning the effectiveness of VT in improving muscle strength, as well as bone mineral density could be related to insufficient intensity of VT applied in some studies. Knowledge on various aspects of physiological response to effective VT is at present very scarce, therefor well-founded decision as to whether VT could be an alternative to RT in reversing sarcopenia seems currently premature.

Key words: *vibration training, sarcopenia*

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Sarcopenia

Lengthening of average span of human life unveils a host of age related ailment, among them age dependent loss of strength and muscle mass, termed sarcopenia. Maximal muscle strength declines gradually, about 15% during 6th decade and further 15% in 7th decade, later the rate of loss doubles. Doherty [2003] summarizing the number of studies on age dependent loss of maximal strength, states that on average, healthy men and women in the 7th and 8th decades retain 60-80% maximal strength compared with their younger counterparts. Very old persons retain half or less than half of their peak strength. This age dependent loss of maximal strength, reduces the strength reserve and brings elderly persons towards their "threshold for independence" [Young and Skelton 1994, Rantanen and Avela 1997, Kozakai et al. 2000], and increases the risk of fall [Morley et al. 2001]. Sarcopenia is also closely linked to age-related losses in bone mineral density, basal metabolic rate and increased body fat content [Evans 1997].

Resistance training (RT) reverses age dependent strength loss.

Resistance training (termed also strength training) requires the body's musculature to move against an opposing force, hence its name. The basic unit of strength training is arepetition. The repetition is sequence of movements ending back in starting position. It normally consists of the concentric muscle action, when the muscles involved are shortening, and the eccentric muscle action, when they are lengthening. Set is usually a predefined number of repetitions of chosen exercise performed continuously without stopping. The number of repetitions per set typically range from 1 to 15.

The maximum number of repetitions per set (RM) is the maximal number of repetitions, which can be performed without stopping at given resistance. Thus, 1-RM is the resistance at which only one repetition can be performed. The intensity of an exercise can be expressed as a percentage of the 1-RM. The smaller intensity, the smaller percentage of 1-RM, and the more repetitions can be performed. The 85% 1-RM intensity usually allows performing 3 repetitions. Alternatively, this intensity may be expressed as 3-RM. Using 80% 1-RM may allow performing 10 repetitions, thus this intensity equals 10-RM. The intensities allowing 1 to 6 repetitions are the most effective in increasing strength muscle. Increase of strength muscle obtained with small number of repetitions performed against heavy resistance can not be gained with large number of repetitions performed against light resistance. Intensity of 50% 1-RM suffices to increase strength muscle,. The intensities which allow more than 25 repetitions have small or no influence on increasing strength muscle [Atha 1981].

Effective resistance training increases the 1-RM, therefore maintaining the same individual percentage of 1-RM will typically require increasing resistance along with training induced increase of muscle strength.

Resistance training, .but not endurance training, may reverse sarcopenia. It was demonstrated that increase of muscle strength and endurance could be achieved at any age, given resistance exercise program of sufficient frequency, intensity and duration. Number of authors has demonstrated substantial increase of maximal knee extensors strength after 10 or more weeks of resistance training expressed as 1 RM gain. Frontera et al. [1988] reported over 100% of 1 RM gain (and almost 230% gain of knee flexors 1 RM) after 12 weeks of resistance training in 60-72 years old men. Also, over 100% increase of knee extensors 1 RM was reported by Fiatarone et al. [1990] in the group of 72-98 years old men and women after 10 weeks of resistance training. Lexell at al. [1995] noted even grater increase, over 150%, after 11 weeks of resistance training in 70-77 years old men and women. Harridge et al. [1999] found over 130% increase in a group of very elderly subjects (85-97 years) after 12 weeks of strength training. Other researchers reported more modest increases: from 26 to 50% of knee extensors 1 RM in men and women in their 7th and 8th decades [Charette et al. 1991, McCartney et al. 1996, Hakinnen et al. 1998, Hunter et al. 1999, Tracy et al. 1999, Yarasheski et al. 1999, Hagerman et al. 2000, Lemmer et al. 2000, Brose et al. 2003 Ferri et al. 2003]. Even lesser improvements, below 20% have been documented by Roelants et al. [2004], and Reeves et al. [2004]. Reeves et al. give following explanation for these disparate results: 1/ different average age of study participants, 2/ difference in pretraining sedentary status, 3/ effect of familiarization period (if applied) which may induce neural adaptation resulting in increased weight-lifting capacity. Also, beside these causes of disparity, details of training protocols should be taken into consideration.

Resistance training may also reduce associated abnormalities: in comparison to endurance training the beneficial effects of resistance training on bone density are superior, on CHO metabolism similar, and on maximal oxygen consumption, blood pressure, lipid profile, hypertension, obesity smaller [Pollock and Evans 1999].

Resistance training in elderly

A training session includes all exercises performed in a given time period. A recommended training session for older adults consists of 8 kinds of exercises, which increases strength of large muscle groups that are important in everyday activities (arms, shoulders, spine, hips, and legs). At the beginning of training 80% 1-RM (i.e. 10-15 repetitions per set) intensity is recommended. Progressive increase in 1-RM percentage is possible. At the start of training it is suggested to perform only one set of repetitions for every kind of exercise with 2-3 min of rest between sets. Progression can go from 1 to 3 sets over training time for each type of exercise. The training consisting of 2-3 session per week is recognized as sufficient for gaining health benefits, each session consisting of single sets of 8-10 exercises [Evans 1999, Fleck and Kraemer 1997]. Similar recommendations can be found also in [ACSM 1998, ACSM 2002, Feigenbaum and Pollock 1999, Mazzeo and Tanaka 2001].

Safe and effective resistance exercise program requires the use of complex exercises and close supervision, and quite a lot of time before any significant effect can be seen. Therefore, given the generality of sarcopenia, which will accompany everybody's aging, though to variable degree [Kallman et al. 1990], enabling safe and resistance training to all, who could benefit from it and are willing to train, seems practically impossible. In search for solution, a partially supervised training program has been proposed, in which training consists of supervised training sessions and sessions at home [Capodaglio et al. 2005].

Vibration training (VT)

Another solution could be akind of training, which eliminates aneed of employing highly qualified supervisors. Anovel form training, consisting of exercises performed on the vibrating platform, which applies the application of sinusoidal vibrations to the whole body (WBV). Such vibration has been shown to produce adaptive responses similar to the ones obtained with conventional RT [Bosco et al. 1999, Cardinale and Bosco 2003, Cardinale and Pope 2003]. Recently, group of Belgian researchers has shown, that VT and RT could bring similar increase in maximal strength in elderly women [Roelants, Delecluse, and Verschueren . 2004; Verschueren et al. 2004]. The VT consisted of unloaded static and dynamic knee-extensor exercises (high and deep squat, wide-stance squat, and lunge) performed on vibrating platform. Training progressed slowly toward higher intensity according to the overload principle. The training volume was increased by increasing duration of single session, the number of series of one exercise, and the number of exercises. The training intensity was increased by increasing the amplitude of platform vibration (from 2.5 to 5 mm), frequency of vibration (from 35 Hz to 40 Hz), and by shortening the rest periods. Additionally, training intensity was increased by changing the form of exercise from predominantly two-legged to one-legged. The total duration of vibration in one session increased from 5 min at the start of training to 30 min at its end.

Resistance training was programmed in accordance with recommendation of ACSM Position Stand [1998]. Resistance training was design as slowly progressing, similarly to VT. It started from two sets at intensity of 20-RM and progressed through 15-RM, 10 -RM up to 8-RM. The trainees performed a total body resistance training program including leg extension and leg-press. Both VT and RT lasted 24 weeks, with 3 training sessions per week.

Vibration training was well accepted: most subjects enjoyed vibration loading, and they did not consider it to be difficult workout. The participants reported a moderate muscle fatigue at the end of each session. There were no reports of adverse side effects. During the first sessions only there were some erythrema, edema and itching of the legs after vibration exercise, which resolved rapidly after training. Of initial 30 persons in each group, four from each group left the training because of non-training related problems. Of the remaining: one subject from VT group and 3 subjects from RT group left the training because of mild knee-joint discomfort. Further 3 subjects left RT group because of anterior knee pain (patellofemoral dysfunction, patellar tendinopathy), finally one subject left RT group because of back problems, and 2 subjects from both groups left the programs because of some knee-pain related to a history of knee-injuries. The VT training was completed by 24 persons, and RT by 20 persons. It might be said than, that among elderly women dropout from VT training was lesser than from RT. However, such conclusion is limited to this particular study, and in face of lack of other studies comparing VT and RT in elderly subjects, such conclusion need support from further studies of this kind.

Maximal isometric knee-extensor strength increased significantly already after 12 weeks of training in both groups: on average 12.4% in VT group, 16.8% in RT group. Next 12 weeks of training brought no significant increase, final gain being 15% and 16.1% in VT and RT groups respectively. Maximal dynamic strength, measured as peak torque during the knee extension performed at 100°/s velocity also increased significantly after 12 weeks of training: 12.1% in VT group, and 12.4% in RT group, achieving 16.1% and 13.9% increases respectively. Speed of movement of knee extension significantly increased (about 6-7%) only at low resistance only in VT group. Counter-movement jump height rose significantly by 19.4% in VT group, and by 12.9% in RT group. These results justified the authors' conclusion, that VT is as efficient as conventional RT in improving knee-extension maximal strength, speed of movement and counter-movement jump performance in older women. However, this study does not support notation, that VT training requires less supervision, than RT, thus being the solution to logistic problem of providing safe and efficient countermeasures against sarcopenia. Both groups, VT and RT, were supervised through all 24 weeks of training by certified American College of Sports Medicine health and fitness instructors, with one-to-three trainer-to-subject ratio. It follows that solving accessibility problem requires specially designed study, of the kind being performed for RT [Capodaglio et al. 2005]. The positive effect of VT on nursing home residents has been found by Bruyere et al. [2005]; these researchers found that 6-week VT combined with physical therapy significantly decreased the risk of all and improved health-related quality of life, whereas physical therapy alone caused no improvement.

The results obtained in the group of elderly women [Roelants, Delecluse and Verschueren 2004] are similar to those obtained in young untrained women (mean age 21.4 years) [Delecluse et al. 2003]. In this study 12 weeks of either VT or RT training caused significant increse of maximal isometric (dynamic) knee-extensor strength: on average 16.6% (9%) in VT group, and 14.4% (7%) in RT group. Counter-movement jump height rose significantly by 19.4% only in VT group, maximal speed of movement remained unchanged. Of particular interest in this study is the proof, that static and dynamic knee-extensor exercises performed without sufficiently high amplitude of platform vibration did not influence maximal knee-extensor strength.

The effectiveness of VT has not been confirmed in all studies. Recently Delecluse et al. [2005] found "despite the expanding use of Whole Body Vibration training among athletes", no surplus value of adding RT to conventional training program in sprint-trained athletes. De Ruiter et al. [2003] found no improvement in functional knee-extensor muscle strength after 11 weeks of standard two-legged VT in healthy young subjects. However the training program implemented by these researchers did not obey overload principle, volume and intensity remaining constant throughout the whole training program and resembling that used in the start period by Roelants, Delecluse and Verschueren [2004]. In a study on young and adult (19-38 years) men and women Torvinen et al. [2003] found benefit in the vertical jump height and no improvement in maximal isometric strength of lower extremities after 8-month VT, training load being merely 4 min/day vibration, 3-5 times aweek. Luo, McNamara, and Moran [2005] reviewing the use of VT stated that using insufficient amplitude and duration of vibration renders VT ineffective.

Need to know physiological response to VT

In a recent review on VT Jordan et al. [2005] conclude essential, in face of substantial evidence regarding the negative effects of vibration on the human body [Seidel 1993], that athorough understanding of the VT implications be acquired prior to application of this type of training in athletic situations. This postulate is of particular importance if VT would be applied permanently to aged individuals. Only with sufficent body of knowledge on physiological consequences of VT in elderly will be acquired, the sound decision which kind of training: RT or VT fits better needs of aged persons could be met. At present relative abundance of knowledge about various aspects of physiological response to RT are in contrast with the scarcity of such knowledge regarding VT.

Cardiovascular response to RT and VT

Resistance training is often recommended with reservation due to belief it will be accompanied by large rise of arterial blood pressure. Indeed, during different forms of resistance training high increase in blood pressure and heart rate has been observed [Fleck and Dean 1985, MacDougall et al. 1985, Fleck and Dean 1987, Stone et al. 1991, Sale et al. 1993, Sale et al. 1994, Scharf et al. 1994]. However, relative safety of resistance training has been demonstrated [Sheldahl et al. 1983, Sheldahl et al. 1985, Vander et al. 1986, Keleman et al. 1986, Crozier et al. 1988, Sparling iCantwell 1989]. Evans [Evans 1999] states clearly: "with proper breathing technique, the cardiovascular stress of resistance exercise is minimal"). Fleck and Kraemer [1997] draw attention to significance of Valsalva maneuver; they showed that blood pressure increase could be greater during Valsalva maneuver performed without isometric exercise than during isometric exercise performed without Valsalva maneuver.

The mechanism of circulatory response to resistance exercises is complex. Rise of blood pressure results from rise in cardiac output (CO) and/or total peripheral resistance (TPR), with variable share of these parameters.

The heart rate and arterial pressure increase over repetitions, with the highest values recorded during the last two repetitions of aset and greater responses at the higher relative load [Stone et al. 1991, McCartney et al. 1993]. In dynamic resistance training, higher blood pressure but not heart rate occurs during the concentric than during the eccentric portion of repetition [Falkel et al. 1992]. Stroke volume is not elevated significantly above resting values during the concentric phase. However, during the eccentric phase stroke volume is significantly increased above resting values and is significantly greater than during the concentric phase of repetition. During the resistance training CO can increase several times when the mass of muscles engaged in exercise is large. However, during an exercise involving a smaller muscle mass rise in CO could be insignificant [Miles et al. 1987]. The blood pressure response increases with the active muscle mass, but the response is not linear. The peak blood pressure and heart rate are higher during sets at submaximal loads to voluntary failure than using 1-RM resistance [MacDougall et al. 1985, Fleck and Dean 1987, Sale et al.1994].

Is the claimed cardiovascular safety of RT justified? If seems more appropriate to speak about relative safety of RT, as compared to endurance training [Vinson et al. 1990, Faigenbaum et al. 1990, Green et al. 2001]. For instance Faigenbaum et al. observed much more adverse cardiac events in cardiac patients during the graded exercise stress test than during maximal contraction effort or during repetitions with submaximal force. Vinson et al. observed considerable inter-individual variability in cardiovascular response to resistance exercises as compared to response to endurance exercise: in some persons the maximal response to resistance exercise was less than to endurance exercise, however in the others reverse was true. RT did not change maximal response of arterial blood pressure in elderly men [Hagerman et al. 2000].

It is likely that age-dependent diminished adrenergic responsiveness of the heart would result in qualitatively different mechanism of cardiovascular response. It has been found that in elderly the cardiovascular adaptation to exercise relies to lesser degree on adrenergic stimulation and instead the mechanism of Frank – Starling law of heart is utilized [Gerstenblith et al.1987].

At present, we are unaware of any study on cardiovascular response to WBV.

Hormonal response to RT and WBV – disparate results

Whether WBV can acutely alter the hormonal profile is at present uncertain. In earlier study Bosco, Iacovelli et al. [2000] reported, that in response to WBV treatment of young males, plasma concentration of testosterone and growth hormone increased, whereas cortisol level decreased. Recent study by DiLoreto et al. [2004] reports no change after 25 min of WBV of middle-aged men in variety of hormones: insulin, glucagon, cortisol, epinephrine, growth hormone, IGF-1, free and total testosterone. Also disparate results has been obtained concerning resistance exercises: in the study of Bosco, Colli et al. [2000] single heavy resistance training session performed by male sprinters resulted in postexercise lowering of testosterone and cortisol. Borst et al. [2002] found in young healthy adults, after acute resistance exercise, no change in testosterone but increase in cortisol level. This authors also did not find any changes in resting serum concentration of IGF-1, IGF binding proteins –1 and –3 (IGFBP-1 and IGFBP-3), testosterone, and cortisol induced by 6 month RT. No data concerning hormonal changes induced by long-term VT are yet available.

Osteogenic effects of RT and VT

The effect of different exercise interventions on bone mineral density (BMD) has been extensively studied [Todd and Robinson 2003]. In general, these studies shown that high impact exercises like vigorous aerobic exercises, weight training, running and squash increases BMD at hip and lumbar spine, whereas low impact exercises like swimming, walking or gentle aerobic exercise offer no protection or protect against farther loss of BMD at best. Regarding RT, it has been shown that in persons, aged 60-83 years, low- and high-intensity RT increased bone turnover, as evidenced by increased serum levels of osteocalcin and bone-specific alkaline phosphatase, but high-intensity RT only increased bone mineral density of the femoral neck [Vincent and Braith 2002]. Authors concluded that exercises intensity of 80% 1-RM may be indispensable to increase bone mineral density. Experiments on animals showed that vibration treatment could also represent an effective non-pharmacological intervention for increasing osteogenic stimulus in animals [Rubin et al. 2001]. Equivocal results have been presented regarding osteogenic effects of VT. Torvinen et al. [2003] found no BMD improvement in any skeletal site, whereas Verschueren et al. [2004], applied much greater training load and noted significant increase of hip BMD. Thus, achieving BMD increase most probably requires high enough intensity of VT similarly to intensity of strength exercises required to achieve strength improvement, also.

Exercise-induced oxidative stress

Beside beneficial health effects of physical activity, many studies have reported increased generation of reactive oxygen species (ROS) [Witt et al. 1992, Sanchez-Quesada et al. 1995]. Prolonged submaximal exercise elevated whole body [Gee and Tappel 1981] and skeletal muscle [Davies et al. 1982] concentration of lipid peroxidation byproducts. However, the activities of antioxidant enzymes such as superoxide dismutase, catalase, and gluthatione peroxidase, and the concentration of glutathione can increase following aerobic exercise training [Evelo et al. 1992, Hellsten et al. 1996, Powers et al. 1998, Vincent et al. 2002]. Higher training intensities induce greater changes in the antioxidant defense [Powers et al. 1994]]. These observation led to what have been termed " the exercise-induced oxidative stress paradox" [Leaf et al. 1999]: it was found, that exercise training increased work capacity without a concomitant increase in expired markers of lipid peroxidation, and decreased lipid oxidation product plasma malondialdehyde (MDA) level. It has been even suggested, [Radak et al. 2001] that regular exercise results in overcompensation against increased level of reactive oxygen and nitrogen species, what may lead to a decreased base level of oxidative damage and increased resistance to oxidative stress. This paradox seems of particular interest in elderly. A senescent organism is more susceptible to oxidative stress during exercise, and muscle repair capacity is reduced, however the elderly who are physically active seem to benefit from exercise-induced adaptation in cellular antioxidant defense system [Ji 2001].

Plasma antioxidants, lipids oxidation products, and muscle damage in response to RT.

There are few studies on changes in plasma antioxidants and lipids oxidation products after resistance exercises. McBride et al. [1998] found increased MDA level at 6 and 24 h after high intensity resistance exercise. Alessio et al. [2000] compared effect of exhaustive aerobic and anaerobic isometric exercise on biomarkers of oxidative stress. They found 14-fold increase of oxygen consumption with aerobic and 2-fold after anaerobic exercise, and accordingly lesser and shorter lasting increase in protein carbonyls – product of protein oxidation, however lipid hydroperoxides (LH) increased more after anaerobic exercise. Both types of exercises increased total antioxidants. Vincent et al. [2002] found that 6 months of RT in elderly can prevent the elevation of serum lipid peroxidation levels following acute aerobic exercise and can enhance thiol group mediated detoxification system. Ramel, Wagner and Elmadfa [2004] examined resistance-trained and non-resistance trained subjects, and found after submaximal resistance exercise increase of fat soluble antioxidants, MDA, but not ascorbic acid. Another product of lipid oxidation – conjugated dienes – increased only in non-resistance trained group. Authors suggest that regular RT partly prevents lipid peroxidation during exercise. Recently, protective effect of RT against oxidative stress in elderly subjects has been confirmed by Parise, Brose and Tarnopolsky [2005].

It is believed, that beside muscle cells damage caused by physical forces, these cells could be also damaged by increased rates of lipid peroxidation resulting from oxygen radical production, especially in untrained persons, older men and women, and those with an inadequate antioxidant system [Evans 2000]. Acute resistance exercise with the eccentric overload elevated muscle damage marker plasma creatine kinase (CK) concentration 24 h and 48 h, more in untrained than in resistance trained subjects [Dolezal et al. 2000].

Young healthy subjects increased their oxygen uptake up to 50% of their VO_2max while performing static and dynamic squats on a vibrating platform [Rittweger et al. 2000]. Oxygen uptake in young healthy subjects has been shown to increase with increase of vibration frequency and amplitude, and external load [Rittweger 2002]. Increased oxygen consumption may lead to enhanced production of free radicals, however, there is currently a lack of knowledge on the acute effects of whole body vibration and chronic effects of VT on the markers of exercise-induced oxidative stress and antioxidant defense.

Conclusions

Vibration training, if applied in accordance to the overload principle, seems, as could be judged from first studies, as effective as resistance training, in reversing sarcopenia and increasing bone mineral density. However, because VT (like RT) has to be performed permanently by elderly trainees in order to sustain increased muscle strength, potential adverse side effects have to be carefully determined and , if found, minimized by proper design of VT training. At present VT should be regarded promising alternative to RT as a sarcopenia countermeasure, however scarcity of data on physiological responses to VT precludes recommending VT as standard sarcopenia treatment.

References

Alessio HM, Hagerman AE, Fulkerson BK, Ambrose J, Rice RE, Wiley RL 2000. Generation of reactive oxygen species after exhaustive aerobic and isometric exercise. Med. Sci. Sports Exerc. 32, 1576-81.

American College of Sports Medicine. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. 1998. Med. Sci. Sports Exerc. 30, 975.

American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. 1998. Med. Sci. Sports Exerc. 30, 992-1008.

American College of Sports Medicine Position Stand. Progression Models in Resistance Training for Healthy Adults. 2002. Med. Sci. Sports Exerc. 34, 364-380.

Atha J 1981. Strengthening muscles. Exerc. Sport Sci. Rev. 9, 1-73.

Borst SE, Vincent KR, Lowenthal DT, Braith RW 2002. Effects of resistance training on insulin-like growth factor and its binding proteins in men and women aged 60 to 85. J. Am. Geriatr. Soc. 50, 884-8.

Bosco C, Colli R, Introini E et al 1999. Adaptive responses of human skeletal muscle to vibration exposure. Clin. Physiol. 19, 183-7.

Bosco C, Iacovelli M, Tsarpela O et al 2000. Hormonal responses to whole -body vibration in men. Eur. J. Appl. Physiol. 81, 449-54.

Brose A, Parise G, Tarnopolsky MA 2003. Creatine supplementation enhances isometric strength and body composition improvements following strength exercise tra ining in older adults. J. Gerontol. A Biol. Sci. Med. Sci. 58, 11-9.

Bruyere O, Wuidart MA, Di Palma E, Gourlay M, Ethgen O, Richy F, Reginster JY 2005. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. Arch. Phys. Med. Rehabil. 86, 303-7.

Capodaglio P, Ferri A, Scaglloni G 2005. Effects of a partially supervised training program in subjects over 75 years of age. Aging Clin. Exp. Res. 17, 174-80.

Cardinale M, Bosco C 2003. The use of vibration as an exercise intervention. Exerc. Sport Sci. Rev. 31, 3-7.

Cardinale M, Pope MH 2003. The effects of whole body vibration on humans: dangerous or advantageous? Acta Physiol. Hung. 90, 195-206.

Charette SL, McEvoy L, Pyka G, Snow-Harter C, Guido D, Wiswell RA, Marcus R 1991. Muscle hypertrophy response to resistance training in older women. J. Appl. Physiol. 70, 1912-6.

Crozier L, Holly R, Amsterdam E 1988. Effect of high resistance training on cardiac patients (abstract). Med. Sports Exerc. 20(2 Suppl), S94-6.

Davies KJA, Quintanilha AT, Brooks GA, Packer L 1982. Free radicals and tissue damage produced by exercise. Biochem. Biophys. Res. Commun. 107, 1198-205.

Delecluse C, Roelants M, Verschueren S 2003. Strength increase after whole -body vibration compared with resistance training. Med. Sci. Sports Exerc. 35, 1033-41.

Delecluse C, Roelants M, Diels R, Koninckx E, Verschueren S 2005. Effects of whole body vibration training on muscle strength and sprint performance in sprint-trained athletes. Int. J. Sports Med. 26, 662-8.

de Ruiter CJ, Van Raak SM, Schilperoort JV, Hollander AP, de Haan A 2003. The effects of 11 weeks whole body vibration training on jump height,contractile properties and activation of human knee extensors. Eur. J. Appl. Physiol. 90, 595-600.

Di Loreto C, Ranchelli A, Lucidi P, Murdolo G, Parlanti N, De Cicco A, Tsarpela O, Annino G, Bosco C, Santeusanio F, Bolli GB, De Feo P 2004. Effects of whole -body vibration exercise on the endocrine system of healthy men. J. Endocrinol. Invest. 27, 323-7.

Dolezal BA, Potteiger JA, Jacobsen DJ, Benedict SH 2000. Muscle damage and resting metabolic rate after acute resistance exercise with an eccentric overload. Med. Sci. Sports Exerc. 32, 1202-7.

Doherty TJ 2003. Invited review: aging and sarcopenia. J. Appl. Physiol. 95, 1717-1727.

Evans WJ 1997. Functional and metabolic consequences of sarcopenia. J. Nutr. 127(5 Suppl), 998S-1003S.

Evans WJ 1999. Exercise training guidelines for the elderly. Med. Sci. Sports Exerc. 31, 12-17.

Evans WJ 2000. Vitamin E, vitamin C, end exercise. Am. J. Clin. Nutr. 72, 647S-52S.

Evelo CTA, Palmen NG, Artur Y, Janssen GME 1992. Changes in blood glutathione concentrations, and in erythrocyte gluthatione reductase and glutathione-S-transferase activity after running training and after participation in contests. Eur. J. Appl. Physiol. 64, 354-8.

Falkel JE, Fleck SJ, Murray TF 1992. Comparision of central hemodynamics between powerlifters and body builders during resistance training. Journal of Applied Sport Science Research. 6, 24-35.

Faigenbaum AD, Skrinar GS, Cesare WF, Kraemer WJ, Thomas HE 1990. Physiological and symptomatic responses of cardiac patients to resistance exercise. Arch. Phys. Med. Rehabil. 71, 395-398.

Feigenbaum MS, Pollock ML 1999. Prescription of resistance training for health and disease. Med. Sci. Sports Exerc. 31, 38.

Ferri A, Scaglioni G, Pousson M, Capodaglio P, Van Hoecke J, Narici MV 2003. Strength and power changes of the human plantar flexors and knee extensors in response to resistance training in old age. Acta Physiol. Scand. 177, 69-78.

Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ 1990. High-intensity strength training in nonagenarians. Effects on skeletal muscle. JAMA. 263, 3029-34.

Fleck SJ, Dean LS 1985. Influence of weight training experience on blood pressure response to exercise. Med. Sci. Sports Exerc. 17, 185.

Fleck SJ, Dean LS 1987. Previous resistance-training experience and the pressor response during resistance training. J. Appl. Physiol. 63, 116-20.

Fleck SJ, Kraemer WJ 1997. Designing resistance training programs. Human Kinetics, Champaign, IL.

Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, Evans WJ 1988. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J. Appl. Physiol. 64, 1038-44.

Gee DL, Tappel AL 1981. The effect o exhaustive exercise on expired pentane as a measure of in vivo lipid peroxidation in the rat. Life Sci. 28, 2425-9.

Gerstenblith G, Renlund DG, Lakatta EG 1987. Cardiovascular response to exercise in younger and older men. Fed. Proc. 46, 1834-9.

Green DJ, Watts K, Maiorana AJ, O'Driscoll JG 2001. A comparison of ambulatory oxygen consumption during circuit training and aerobic exercise in patients with chronic heart failure. J. Cardiopulm. Rehabil. 21, 167-74.

Hagerman FC, Walsh SJ, Staron RS, Hikida RS, Gilders RM, Murray TF, Toma K, Ragg KE 2000. Effects of high-intensity resistance training on untrained older men. I. Strength, cardiovascular, and metabolic responses. J. Gerontol. A Biol. Sci. Med. Sci. 55, B336-46.

Hakkinen K, Kallinen M, Izquierdo M, Jokelainen K, Lassila H, Malkia E, Kraemer WJ, Newton RU, Alen M 1998. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. J. Appl. Physiol. 84, 1341-9.

Harridge SD, Kryger A, Stensgaard A 1999. Knee extensor strength, activation, and size in very elderly people following strength training. Muscle Nerve. 22, 831-9.

Hellsten Y, Apple FS, Sjodin B 1996. Effect of sprint cycle training on activities of antioxidant enzymes in human skeletal muscle. J. Appl. Physiol. 81, 1484-7.

Hunter SK, Thompson MW, Ruell PA, Harmer AR, Thom JM, Gwinn TH, Adams RD 1999. Human skeletal sarcoplasmic reticulum Ca2+ uptake and muscle function with aging and strength training. J. Appl. Physiol. 86, 1858-65.

Ji LL 2001. Exercise at old age: does it increase or alleviate oxidative stress? Ann. N. Y. Acad. Sci. 928, 236-47.

Jordan MJ, Norris SR, Smith DJ, Herzog W 2005. Vibration training: an overview of the area, training consequences, and future considerations. J. Strength Cond. Res. 19, 459-66.

Kallman DA, Plato CC, Tobin JD 1990. The role of muscle loss in the age-related decline of grip strength: cross-sectional and longitudinal perspectives. J. Gerontol. 45, M82-8.

Kelemen MH, Stewart KJ, Gillilan RE, et al 1986. Circuit weight training in cardiac patients. J. Am. Coll. Cardiol. 7, 38-42.

Kozakai R, Tsuzuku S, Yabe K, Ando F, Niino N, Shimokata H 2000. Age-related changes in gait velocity and leg extension power in middle-aged and elderly people. J. Epidemiol. 10(1 Suppl), S77-81.

Leaf DA, Kleinman MT, Hamilton M, Deitrick RW 1999. The exercise-induced oxidative stress paradox: the effects of physical exercise training. Am. J. Med. Sci. 317, 295-300.

Lemmer JT, Hurlbut DE, Martel GF, Tracy BL, Ivey FM, Metter EJ, Fozard JL, Fleg JL, Hurley BF 2000. Age and gender responses to strength training and detraining. Med. Sci. Sports Exerc. 32, 1505-12.

Lexell J, Downham DY, Larsson Y, Bruhn E, Morsing B 1995. Heavy-resistance training in older Scandinavian men and women: short- and long-term effects on arm and leg muscles. Scand. J. Med. Sci. Sports. 5, 329-41.

Luo J, McNamara B, Moran K 2005. The use of vibration training to enhance muscle strength and power. Sports Med. 35, 23-41.

MacDougall JD, Tuxen D, Sale DG, Moroz JR, Sutton JR 1985. Arterial blood pressure response to heavy resistance exercise. J. Appl. Physiol. 58, 785-90.

Mazzeo RS, Tanaka H 2001. Exercise prescription for the elderly. Current recommendations. Sports Med. 31, 809-818.

McBride JM, Kraemer WJ, Triplett-McBride T, Sebastianelli W 1998. Effect of resistance exercise on free radical production. Med. Sci. Sports Exerc. 30, 67-72.

McCartney N, McKelvie RS, Martin J, Sale DG, MacDougall JD 1993. Weight-training-induced attenuation of the circulatory ressponse of the older males to weight lifting. J. Appl. Physiol. 74, 1056-1060.

McCartney N, Hicks AL, Martin J, Webber CE 1996. A longitudinal trial of weight training in the elderly: continued improvements in year 2. J. Gerontol. A Biol. Sci. Med. Sci. 51, B425-33.

Miles DS, Owens JJ, Golden JC, Gothsall RW 1987. Central and peripheral hemodynamics during maximal leg extension exercise. Eur. J. Appl. Physiol. 56, 12-17.

Morley JE, Baumgartner RN, Roubenoff R, Mayer J, Nair KS 2001. Sarcopenia. J. Lab. Clin. Med. 137, 231-43.

Parise G, Brose AN, Tarnopolsky MA 2005. Resistance exercise training decreases oxidative damage to DNA and increases cytochrome oxidase activity in older adults. Exp. Gerontol. 40, 173-80.

Pollock ML, Evans WJ 1999. Resistance training for health and disease: introduction. Med. Sci. Sports Exerc. 31, 10 -11.

Powers SK, Criswell D, Lawler J, Ji LL, Martin D, Herb RA, Dudley G 1994. Influence of exercise and fiber type on antioxidant enzyme activity in rat skeletal muscle. Am. J. Physiol. 266(2 Pt 2), R375-80.

Powers SK, Demirel HA, Vincent HK, Coombes JS, Naito H, Hamilton KL, Shanely RA, Jessup J 1998. Exercise training improves myocardial tolerance to in vivo ischemia-reperfusion in the rat. Am. J. Physiol. 275, R1468-77.

Radak Z, Taylor AW, Ohno H, Goto S 2001. Adaptation to exercise-induced oxidative stress: from muscle to brain. Exerc. Immunol. Rev. 7, 90-107.

Ramel A, Wagner KH, Elmadfa I 2004. Plasma antioxidants and lipid oxidation after submaximal resistance exercise in men. Eur. J. Nutr. 43, 2-6.

Rantanen T, Avela J 1997. Leg extension power and walking speed in very old people living independently. J. Gerontol. A Biol. Sci. Med. Sci. 52, M225-31.

Reeves ND, Narici MV, Maganaris CN 2004. In vivo human muscle structure and function: adaptations to resistance training in old age. Exp. Physiol. 89, 675-89.

Rittweger J, Beller G, Felsenberg D 2000. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin. Physiol. 20, 134-42.

Rittweger J, Ehrig J, Just K, Mutschelknauss M, Kirsch KA, Felsenberg D 2002. Oxygen uptake in whole-body vibration exercise: influence of vibration frequency, amplitude, and external load. Int. J. Sports Med. 23, 428-32.

Roelants M, Delecluse C, Verschueren SM 2004. Whole -body-vibration training increases knee-extension strength and speed of movement in older women. J. Am. Geriatr. Soc. 52, 901-8.

Rubin C, Turner AS, Bain S, Mallinckrodt C, McLeod K 2001. Anabolism. Low mechanical signals strengthen long bones. Nature. 412, 603-4.

Sale DG, Moroz DE, McKelvie RS, MacDougall JD, McCartney N 1993. Comparision of blood pressure response to isokinetic and weight-lifting exercise. Eur. J. Appl. Physiol. 67, 115-20.

Sale DG, Moroz DE, McKelvie RS, MacDougall JD, McCartney N 1994. Effect of training on the blood pressure response to weight lifting. Can. J. Appl. Physiol. 19, 60-74.

Sanchez-Quesada JL, Holmes-Serradesanferm R, Serrat-Serrat J, Serra -Grima JR, Ordonez-Llanos J 1995. Increased of LDL susceptibility to oxidation occuring after intense, long duartion aerobic exercise. Atherosclerosis. 118, 297-305.

Scharf HP, Eckhardt R, Maurus M, Puhl W 1994. Metabolic and hemodynamic changes during isokinetic muscle training. Int. J. Sports Med. 15, S56-S59.

Seidel H. Selected health risks caused by long-term, whole-body vibration. 1993. Am J Ind Med. 23:589-604.

Sheldahl LM, Wilke NA, Tristani FE, Kalbfleish JH 1983. Response of patients after myocardial infarction to carrying a graded series of weight loads. Am. J. Cardiol. 52, 698-703.

Sheldahl LM, Wilke NA, Tristani FE, Kalbfleish JH 1985. Response to repetitive static-dynamic exercise in patients with coronary artery disease. J. Cardiac Rehabil. 5, 139-45.

Sparling PB, Cantwell JD 1989. Strength training guidelines for cardiac patients. Phys. Sports Med. 17, 190-6.

Stone MH, Fleck SJ, Triplett NR, Kraemer WJ 1991. Physiological adaptations to resistance training exercise. Sports Med. 11, 210-31.

Todd JA, Robinson RJ 2003. Osteoporosis and exercise. Postgrad. Med. J. 79, 320-3.

Torvinen S, Kannus P, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Nenonen A, Jarvinen TL, Paakkala T, Jarvinen M, Vuori I 2003. Effect of 8-month vertical whole body vibration on bone, muscle performance, a nd body balance: a randomized controlled study. J. Bone Miner. Res. 18, 876-84.

Tracy BL, Ivey FM, Hurlbut D, Martel GF, Lemmer JT, Siegel EL, Metter EJ, Fozard JL, Fleg JL, Hurley BF 1999. Muscle quality. II. Effects Of strength training in 65- to 75-yr-old men and women. J. Appl. Physiol. 86, 195-201.

Vander LB, Franklin BA, Wrisley D, Rubenfire M 1986. Acute cardiovascular responses to Nautilus exercise in cardiac patients: implications for exercise training. Ann. Sports Med. 2, 165-9.

Vincent KR, Braith RW, Feldman RA, Kallas HE, Lowenthal DT 2002. Improved cardiorespiratory endurance following 6 months of resistance exercise in elderly men and women. Arch. Intern. Med. 162, 673-8.

Vincent KR, Braith RW 2002. Resistance exercise and bone turnover in elderly men and women. Med. Sci. Sports Exerc. 34, 17-23.

Vincent KR, Vincent HK, Braith RW, Lennon SL, Lowenthal DT 2002. Resistance exercise training attenuates exercise-induced lipid peroxidation in the elderly. Eur. J. Appl. Physiol. 87, 416-23.

Vinson S, Lindsay B, Mettler P, Murray T 1990. Cardiovascular response to isokinetic endurance exercise testing. J. Sports Med. Phys. Fitness. 30, 93-6.

Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S 2004. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. J. Bone Miner. Res. 19, 352-9.

Witt EH, Reznick AZ, Viguie CA, Starke Reed P, Packer L 1992. Exercise, oxidative damage and effects of antioxidant manipulation. J. Nutr. 122, 766-73.

Yarasheski KE, Pak-Loduca J, Hasten DL, Obert KA, Brown MB, Sinacore DR 1999. Resistance exercise training increases mixed muscle protein synthesis rate in frail women and men >/=76 yr old. Am. J. Physiol. Endocrinol. Metab. 277, E118-25.

Young A, Skelton DA 1994. Applied physiology of strength and power in old age. Int. J. Sports Med. 15, 149-51.