bioDensity Isometric Technology and Whole Body Vibration Research Review

Gregory Ellis, PhD, CNS
68 Skyline Drive
Glen Mills, PA, 19342
610-459-0200
gregoryellis@comcast.net

bioDensity Isometric Technology Conceptual Framework

General Concept

biodensity Technology is a preventative care solution, conditioning system, and method for accurately assessing strength that enables individual age 12 and older to:

- Build strength
- Increase bone mass
- Improve organ functionality
- Improve joint support
- Improve the quality of life
- Accurately assess initial and on-going strength levels

It is well established that strength declines in a linear fashion as people age due to losses in muscle mass (sarcopenia) and other factors. It is also well established that a certain threshold of strength, particularly in the lower body, is necessary to perform typical activities of daily living such as standing up from a chair or toilet, walking, climbing stairs, and carrying groceries or young children, etc. The predictable loss of strength that occurs with aging can and does bear directly on day-to-day functional capacity in a very direct way and is directly related to the risk of falling.

bioDensity Technology represents the most efficient and universally usable system to improve functional strength. bioDensity Technology is a proven technology based on hard data that is incontrovertible. By allowing maximal "self-loading" along with real-time feedback on force production, bioDensity Technology allows safe, maximal loading of all major muscular skeletal structures. In addition, the system records all force production data and compares exercise sessions to provide a highly reliable and valid system for assessing strength that can be used to provide targeted exercise prescription and on-going program modification. This feedback motivates users and provides specific targets during each session based on the user's previous exercise performance.

Executive Summary

In 2011, seventy-eight million baby boomers will turn 65 years of age. This population balloon will tax many existing systems including the government, Medicare, health-care, and housing needs. The general population is characterized by diminished functional ability despite the national dialogue about fitness. The fitness revolution is not nearly as widespread as most people believe. Beyond the issue of diagnosing frank states of disease, functional decline and losses of physical "reserve capacity" is at epidemic proportions. The health care system is not equipped to evaluate these decays in aging people. There is little hope that this current condition will change soon. The majority of older people suffer from "disuse syndrome" and many no longer possess enough lower body strength to rise from a chair without assistance. These functional losses are often modifiable by the use of appropriate methodologies. Both physiological and environmental factors contribute to the risk of falling.

There are several important developments in the conditioning of "de-conditioned" individuals. These include the use of vibration exercise, a recently discovered method of improving strength, functional ability, balance, and gait. There are now studies of improvements in function for community-dwelling seniors and those in nursing homes. Isometric exercise rapidly increases muscular strength and recent developments in equipment design and training methodologies are outlined in the following paper. Most adults over 65 years of age have lost up to 40% of the muscle mass they possessed in their twenties. This decline has components in both the muscular system and nervous system. Rehabilitation in muscle strength and function is possible in even the oldest old. Strength increases of more than 10% per week are possible.

Vibration Exercise

Total Body Vibration has recently been shown to be a very effective stimulus for creating significant improvements in overall health. It has multiple effects on all parts of the body including both neuromuscular and neuroendocrine systems. Studies have shown that vibration exercise is an effective therapeutic approach for sarcopenia (muscle loss) and osteoporosis (1).

Vibration at high levels is well known to cause damage to the human structure. Recently, it has become apparent that low doses of vibration have a powerful stimulatory effect on human tissue. The benefits are wide-ranging. The concept of hormesis states that substances or treatments have the paradoxical ability to be beneficial or harmful depending upon the dose: low doses can produce net gain, while high doses can produce net harm (2, 3). This appears to be the case with vibration exercise whose stimulus intensity is 1/1,000th of the intensity that would be harmful.

Vibration exercise machines provide oscillatory motion at various levels of intensity and frequency. Vibration exercise is quite a new topic in sport science. Yet it is even newer in respect to the prevention and recovery from various diseases, particularly diseases of aging. Both athletes and those in rehabilitation centers, (including nursing homes and homes for the aged) use vibration in their exercise programs.

Vibration exercise provides a very powerful stimulus that causes strong adaptations in the body's structural tissues. Importantly, there are changes in body systems such as the cardiovascular and nervous. Our bodies rely on a range of structures and mechanisms to control the transmission of impact shocks through the body including bone, cartilage, joint fluids, soft tissues, joint function and movement, as well as muscular activity.

Because vibration is such a common part of everyday life, the body seems to have developed very sophisticated methods for adapting to vibration. In fact, some have proposed that the body has a strategy of "tuning" its muscle activity to avoid the harmful effects of higher levels of vibration. Vibration exercise appears to act as a "tuning fork for the body."

Therefore, the body is highly stimulated by vibration activities. This implies that the application of vibration exercise has the ability to be highly specific and targeted in causing significant adaptations. Our modern style of living may have led to a significant reduction in our exposure to vibrations. If true, the resultant lack of vibration may have contributed to a de-conditioning effect. This effect is likely similar to that experienced by astronauts traveling in space under zero gravity conditions.

Below, we will review some of the improvements in diseases and physiological changes that occur after training with vibration exercise. It is my thought that vibrations are essential to human health. A reduction in one's exposure to a threshold level of daily vibration may be a cause for the development of degenerative disease.

Around 1900, the typical male walked 10 miles each day and females covered about 7 miles. In walking, vibration impact is encountered by the foot and sequentially transferred upward through the legs, hips, and torso. This site of impact and direction of transmission of vibration forces may be fundamental to the "tuning" system developed by the body to handle vibration exposure.

Osteoporosis

Several recent studies have demonstrated increases in bone mineral density after doing vibration training. Bone mineral density in the hip of postmenopausal women increased about 1% with six months of vibration exercise (4). Interestingly, women who followed a weight-training program had a decrease in bone mineral density of one-half percent. Weights are thought to increase density. A control group (no weights and no vibration) experienced a decrease in bone density of 0.6%. In another fascinating study, eight months of vibration exercise led to a bone mineral density increase at the top of the thigh bone of 4.3% (5).

In another study of post-menopausal osteoporotic women (6), once weekly vibration training led to a reduction in chronic lower back pain, increased bone density, and increased muscle size. One of the suggested reasons for increases in bone mass is that vibration alters fluid flow, both in blood vessels and in lymphatic vessels (7).

Osteoporosis is one of the most common complications of aging. In animal studies, one year of vibration exercise increased bone volume, the thickness of internal bone scaffolding, and bone stiffness and strength. The authors concluded that vibration training offers a unique, non-pharmacological preventative for osteoporosis (8).

In young women, increases in spine bone density of 3.9% and thigh bone density of 2.9% occurred after twelve months of vibration training. Benefits happened from as little as 2 minutes per day of training. The conclusion was that: "Short bouts of extremely low-level mechanical signals, *several orders of magnitude below that associated with vigorous exercise*, increased bone and muscle mass in the weight bearing skeleton of young adult females. The authors suggested that this type of treatment may prove to slow the development of osteoporosis in the elderly (9).

In a study by Rubin (10), 70 postmenopausal women performed vibration exercise for one year and bone mineral density increased by 3.35%.

It is clear from the reports listed above that vibration training is good for bone health in both younger and older women. It also worked well for those in nursing homes (11). Non-pharmacologic approaches to prevent bone loss are well suited for elderly patients to help them avoid using multiple drugs and the side effects of their use.

The lack of regular exercise in the elderly is a major concern. In the Hannan study (11), they assessed compliance in 24 elderly women (mean age 86, range 79-92 years). The result was that 83% of the trainees were regular during 6 months. Excluding three study dropouts, the 21 women were regular 93% of the time with no differences between active and control treatment. Main reasons for missing treatment days during the 6 months were vacation (54% of missed days) and illness (29%). Among participants, 95% reported overall satisfaction with the vibrating platform, and 57% preferred the platform versus daily oral medications for prevention of bone loss. Elderly women showed high regularity, high satisfaction, and few bad experiences with a daily non-pharmacological treatment to prevent bone loss.

It is also suggested that low back pain can be "cured" by use of vibration if the use of it is at a low threshold and controlled (12).

Strength

Mechanical vibrations applied to muscles and tendons create a reflex contraction named "tonic vibration reflex." This is a reflex action caused by excitation of muscle spindles. The body senses vibration, not only by nerve-muscle spindles but also by skin, joints, and secondary nerve endings. Changes in the neuromuscular system also involve all of the body's sensory systems.

Vibration applied to different parts of the body, acting through nerves, directly influences brain activity. Vibration training can 'prepare muscles' for forceful activation. This is another important contribution that this method of training provides.

Muscle contractions caused by vibration increase muscle metabolic rates. Vibration exercise increases oxygen use. Vibration training is as efficient as conventional resistance training in increasing the strength of thigh muscles (13).

Forty-eight untrained females were split into two groups. One group performed unloaded and loaded exercise on a vibration plate three times per week. The other group followed a conventional cardiovascular and resistance training program three times per week. Fat free mass and body fat were measured. After 24 weeks, lean body mass (fat free mass) increased by 2.2% in the vibration group. Strength increased by 24.4% with vibration training versus 16.5% with conventional exercise (14).

One of the most exciting studies supporting the stimulatory power of vibration was conducted on male athletes (15). Strength training of the arms while on a vibration platform led to increases in arm strength of 49.8% versus a gain of only 16% when arm exercises were performed without the added vibration stimulus.

Hormonal System

Vibration training alters hormonal profiles and will enhance performance in athletes. Vibration training will improve athlete's responses during training. Vibrations will also help during event pre-competition by providing a warm-up (16).

In another study (17), tests of performance showed increases in nerve-muscle efficiency. Jumping ability increased after one 10-minute session. Measurements of blood testosterone and growth hormone resulted in increased levels of each while cortisol levels decreased. The biological changes produced by vibration are similar to the effect produced by explosive power training. Cortisol is a hormone released by the adrenal gland due to high levels of stress; reductions in cortisol, therefore, are a good thing.

Often, training time to reap improvements from the use of vibration is very little. In one study (18), 29 postmenopausal women stood on a ground-based vibration plate for three 2-minute sessions, twice weekly for six months. Test subject's muscle power improved by 5%.

Balance and Gait

Vibration exercise also improves balance (19-22). Improvements in balance would help the elderly by decreasing the chance of falling. In a study of nursing home residents (23), six weeks of vibration training improved gait (ability to walk) compared to no change in the control group. Body balance also improved by 3.5 points on a body balance scale test compared with a decrease of 0.3 points in the control group. A test that measures the ability to stand and walk was improved by vibration. It took the trained group 11 seconds less time to reach a point on the walk path whereas the control group moved more slowly by 2.6 seconds. The vibration group also improved on eight out of nine items when tested by the World Health Organization's questionnaire that measures the quality of life.

The Elderly

Studies confirm the benefits of vibration exercise for osteoporosis, sarcopenia (muscle loss), and improvements in body balance. Clearly, vibration exercise should be a key strategy for both the elderly and for younger persons to avoid the ravages of aging. Vibration exercise is an effective way to change risk factors for fractures in older women. Not only is muscle loss avoided, slight increases in muscle mass and increases in strength are an outcome of vibration training.

The most important part of these findings is that they occur without the use of drugs (24). Muscle strength in this study improved by about 16.0% and bone mineral density in the hip improved by about 1%. Yet the group of women who performed resistance (weight-training) exercise had no improvement!

This is one of the unique outcomes of vibration exercise: it can often outperform resistance training. Also, vibration exercise improved bone mineral density equivalent to what the most effective drugs can accomplish. Of course, although medication may prevent the loss of bone, it is unable to provide any of the other benefits of vibration exercise including improvements in strength, balance, neuromuscular function, and quality of life. Vibration exercise has enormous potential to improve people's health.

Vibration exercise, therefore, is an effective intervention for reducing the effects of aging on musculo-skeletal structures. Also, the positive effect upon the hormonal system means that this form of passive exercise can benefit those in training and assist in rehabilitation from different diseases (25).

Circulation

Vibration exercise increases the circulation in both skin and in muscle tissue (26-29). These changes in blood flow will benefit the elderly for wound healing and tissue regeneration. Already, reports have shown that vibration therapy assists in healing venous leg ulcers (30). There is now some evidence that vibration training will assist those with diabetes with their concurrent poor leg circulation (31). More capillaries open resulting in more efficient gas and material metabolism between the muscles and blood (32).

Increased arterial stiffness is a risk factor for cardiovascular disease. Ten healthy men participated in a study using vibration exercise at 26 Hz, 10 sets of 60 seconds vibration interspersed with 60 seconds rest. To estimate arterial stiffness, the researchers measured the brachial-ankle pulse wave velocity, an index of arterial stiffness, which showed that vibration acutely decreased arterial stiffness (33).

An interesting observation and realization by trainers and users of vibration exercise is that they will observe that users start itching in various locations on their body. This often occurs in the nose. Rittweger (34) made this same observation in one of his studies that demonstrated increased blood flow and pointed out that he saw this response in about half of the 37 young subjects who participated in the study.

Vibration exercise will improve the cardiovascular system. One of the most important benefits of active exercise in health and disease is the release of nitric oxide from the endothelial cells lining the vascular system. A stimulus for the release of nitric oxide is a shear stress on the endothelial cell. Nitric oxide acts as a dilator of the vascular system. Nitric oxide has direct vasodilator and anti-atherosclerosis properties as well as anti-inflammatory and anti-tumor actions. Passive vibration exercise has great possibilities as a therapeutic treatment.

A single bout of vibration exercise led to an increase in shear stress in the endothelial cell. A measuring system to detect nitric oxide release was used to measure the changes caused by vibration. Passive exercise using a vibration plate allows important benefits that normally occur only with active exercise (35).

Chronic Fatigue and Fibromyalgia

For a while, we have known that moderate exercise lessens the symptoms of fibromyalgia and chronic fatigue syndrome. Recently, vibration exercise has been shown to be effective for reducing the symptoms of fibromyalgia and chronic fatigue syndrome (36). Because vibration exercise stimulates the release of nitric oxide from the endothelial cell, it is effective in providing a potent anti-inflammatory reaction in the body. Both fibromyalgia and chronic fatigue syndrome are diseases that have chronic inflammation as their basis.

In summary, passive vibration exercise provides strong stimuli that lead to adaptations in the human body that improve health and function. The body must have a well-developed internal adaptation system because the changes caused by vibration activities are so powerful. Vibration changes the structure and function of the body more effectively than both resistance and aerobic exercise. This does not suggest that one should give up those forms of exercise, but suggests that using vibration training along with the other two is a more effective approach.

Fat Loss

Several recent animal studies have shown a loss of body fat via vibration exercise. Vibrating rats had 20.8% body fat versus 26.8% in non-vibrating rats. Whole body vibration led to no differences in food intake (37). In a study by Rubin, there was a 27% loss of torso fat in the vibrating animal group and he theorized that vibration provides a mechanical stimulation on non-differentiated stem cells to turn into both bone and muscle cells instead of adipocytes (fat cells) in response to the mechanical stimulus. This effect is independent of the normal metabolic factors (calorie expenditure) involved in body composition changes (38).

Vibration Training and Falling

Researchers are beginning to look at the effects of vibration in seniors and the elderly. Older people suffer from disuse syndrome and are extremely de-conditioned so vibration may be a viable alternative to conventional exercise programs. Nursing home residents with limited functional dependency increased balance and mobility from following a 6-week vibration program (39). Bogaerts et al. (40) demonstrated increases in muscle strength, explosive muscle strength, and muscle mass (9.8%, 10.9%, and 3.4% versus a fitness trained group, 13.1%, 9.8%, and 3.8%). There were no changes in the control group. Their results suggested that vibration training has the potential to prevent and reverse the normally occurring age-related loss in muscle mass (sarcopenia).

Fall risk was assessed by a battery of tests in forty-two elderly volunteers and twenty-two were enrolled in a vibration plus physical therapy program and twenty in PT alone (41). The intervention group improved by 3.5 points on the body balance score compared with a decrease of 0.3 points in the control group. Controlled whole body vibration can improve elements of fall risk. Balance was improved through the use of vibration training in sixty-nine community-living elderly persons. Training consisted of 3 minutes per day for 3 days per week for 3 months at 20 Hz. The protocol improved balance and reduced the risk of falls (42).

De-conditioned people improve to a greater degree and faster than those who are already in some type of shape. This was proven also in the use of vibration training. In this study (43), sedentary and elderly subjects demonstrated significant gains in most measures of muscle performance, similar to the results provided by traditional resistance exercise programs. Another study used 12-20 Hz vibration to test muscle strengthening, balance, and walking ability. Of interest is that subjects only exercised 1-day per week for 4-minutes. After two months of training, walking speed, step length, and the maximum standing time on one leg improved from vibration exercise (44).

Vibration exercise improved static one-legged balance (a good predictor of fall risk). Confirming earlier research, those subjects with the lowest baseline scores improved the most and vibration exercise appears to provide a greater benefit to those with the most diminished postural control (45). In further research by this group (46), vibration increased plantar flexion strength, another important parameter for fall risk. A recent review article looked at multiple studies and showed there is good evidence of enhanced leg muscle performance after a period of vibration training (47). Vibration training improved isometric and dynamic muscle strength (+15% and +16%, respectively) in seventy volunteers ranging in age from 58-74 years (44). The authors concluded that "whole body vibration training may be a feasible and effective way to modify well-recognized risk factors for fall and fractures in older women."

Muscle strength is a strong predictor of postural sway, as is tactile sensitivity. Some of the work in Parkinson's and multiple sclerosis shows increased sensitivity from vibration exercise. Clearly, many studies now show the value of vibration training to improve muscle strength, mass, and leg performance. The increase in functional capacity is significant and the perception of little effort makes vibration training feasible for even frail elderly. Improvements can arise from as little as one 4-minute session per week and the gains will be higher in those who are the most de-conditioned and are at the greatest risk of falling.

Isometric Training

There are multiple strength training modalities:

1) **Isotonics**: Resistance training with weights, machines, bands, and bodyweight as the resistance type; included in this category are the subdivisions of heavy, progressive, and variable resistance exercise, speed loading, eccentric (training by allowing the muscle to lengthen against a load versus shortening or contracting against a load), plyometric training, and other hybrids

2) **Isokinetic**: in this style of exercise a machine is used that controls the speed of movement against which a muscle contracts and offers only concentric, or positive, movements (muscle shortening)

3) **Isometrics**: muscle contraction against a force that is greater than a muscle's maximal force generating capacity thereby allowing no movement of the applied load.

It is this third type of muscle contraction, isometric training, that will be described in detail in this section of the white paper. Isometric training was created in a laboratory, in contrast to isotonics which evolved in the field over many years. The main principles of strength training have been known since the days of the Greek city-states.

First identified in the late 1920's (48), isometric training was studied extensively by scientists since the mid-1940's (50) when Hellebrandt discovered that controlled, high muscle tension generation increased muscle strength to high levels quickly. This discovery was commercialized by Charles Atlas in his *Dynamic Tension Method* of exercise.

Isometrics was little known other than Atlas's salesmanship and remained ignored until 1953 when Hettinger and Muller's classic paper was first published (50). The author's research conclusion: a maximum muscle strengthening effect was produced by one daily isometric contraction, lasting six seconds, using an effort level of two-thirds of the muscle's maximum contractile power.

This claim raised some skepticism (51), but led to much general interest. Further research by Muller (52) reaffirmed the earlier work confirming that these maximum training effects occurred even if contractions were very brief and exceeded little more than one-third of the maximum possible effort.

The idea that so little time and effort would lead to such a profound response in so short a time led some to argue that years of dedicated resistance work, lifting weights totaling tons each year, had been a needless effort. This opinion shook the foundations of the strength establishment and it has not abated today.

But, in fact, today, there is little interest in isometric training by exercise enthusiasts and it is little talked about in public. There are few research publications: in science, isometric training is used as a *method* to study the effects of exercise on cellular and physiological functions, not to define *training methods* to optimize its usefulness.

With isometric's explosion on the muscle strengthening platform in the 1940's and early 1950's, previous training practices dating back to the times of the Greeks and Romans were now open to question and previous beliefs about muscle strengthening suddenly appeared dated. The lack of a sound scientific basis to training had previously concerned few people, but now it was clear there were no sound theoretical insights or adequate experimental grounds to support old ideas. In the past, studies of strength had been made; and strength had been measured for centuries. *However, evaluations of techniques, methods, principles, training outcomes, relative needs, explanations, and theoretical considerations were lacking.*

A review article, written about the time the research on isometrics appeared, discussed 89 studies of *strength* completed since the turn of the century, but only mentioned four studies of *strength training* (53). The years that followed produced few research papers dealing with *strength training*. Most of the work in this area was then, and now, conducted by lay people outside the laboratory setting.

Commercial concerns have always spearheaded research into these areas, not to suggest there is anything untoward about that since these efforts were directed by people who had a passion for this field. It is rather unusual to find many scientists who have an interest in the strength training field, studying optimal methods of training, although that is now changing. Spawned by the aerobics movement in 1970 and the introduction of the Nautilus machines, also in 1970, a fitness revolution developed and more passionate young people developed a scientific curiosity and pursued PhD degrees in exercise physiology and then went on to pursue academic careers.

This, however, has not led to studies specifically directed to the ***optimization*** of strength training via studies testing one method versus another, i.e., choosing the winner, say A beats B, and then introducing test C to run against A. There are, no doubt, many programs, but they evolved no differently than did the field programs during the last centuries.

Between the years of 1950-1960, 57 papers were published on isometrics and 45% of those appeared after 1953 (48). Many of the authors of these papers carefully analyzed the work of Hettinger and Muller, as did they themselves (54), but support for the positive results they presented overshadowed any negative disagreements against their claims of rapid and powerful increases in strength from brief, intense isometric muscle contractions.

The questions that did arise related to issues such as repetition frequency, percent of effort needed to maximize strength increases, and comparisons from one muscle group to another (55). Questions also arose about the comparison to isotonic training methods, effects on muscle hypertrophy (growth), and responses to training among a wide variety of people. In 1970, Muller gave little ground to any of the differing opinions and stated: "that repeating the isometric stimulus a second time within 24 hours produces very little additional benefit to that resulting from the single contraction" (56).

By the 1970's, isometrics had been so thoroughly studied that it seemed there was no need for further investigations (57).

During those early decades, investigations about isometrics included studies about it and its effects on: the cardiovascular system, use with steroids, use in industry, use with electrical stimulation, use in hospitals to help fight disease, and laboratory studies to determine its effect on stimulating muscle growth (48, 58).

Isometric Strengthening Effect

The result of isometric training on strength development was first reported to provide a 5% per week increase (59), but later it was reported as 1.8% per week in their subsequent publications. There was some outcry as to the accuracy of the work by Hettinger and Muller (60,61).

1n 1962, against mounting criticism, Muller argued that strength increases depended upon an individual's current state of conditioning, with those who were less fit, gaining more rapidly, and those who were more fit, less rapidly.

The following table indicates the resultant strength increases based on a subject's initial level of conditioning.

Table 1
Weekly Gains in Strength Expected from Isometric Training for Muscles in Different States of Training*

State of Training (percent of limiting strength)	Rate of Gain (percent per week)	Training Time to Reach Limiting Strength (weeks)
98	2.0	2
95	3.6	-
80	5.6	3-5
85	7.5	-
80	8.6	-

75	10.0	5
<75	12.0	-
*(76)		

The weekly gains vary from 12% (2.4% per session) assuming five training sessions per week for those in a poorer state of health to less than 2% (0.4% per session) for those close to their limiting strength. Therefore, according to Muller, even for the untrained, very few weeks are needed to reach limiting strength. Muller believed the results depicted in the **Table** explained why the results of other studies may have been at variance with his own: "Contrary findings are distorted by comparing unequal states of training."

They (Hettinger and Muller) later defined the training state operationally: the state of training of a muscle is its initial strength (P_i) expressed as a percentage of its end strength (P_e). Limiting strength is defined as the final value to which strength can reach at its maximum potential regardless of how long training goes on, i.e., training can go on forever, but it is believed that strength increases have a limit. So the final value depends on two things: 1) the strength *capacity* of the muscle and 2) the *efficiency* of the training method adopted. Therefore, if the training program chosen is of little value, then end strength would occur rather quickly since the method cannot serve to increase strength because of its ineffectiveness.

There is an inherent weakness to assessing strength in this manner and certainly one way around this is to establish a database of age and sex-related norms to qualify an individual's initial fitness status.

Establishing the Components of the Exercise Prescription

I have already described briefly the exercise prescription in an earlier section. Here, I want to review it again as it serves as the basis for understanding strength-increasing protocols.

An exercise prescription has three main components:

1) **Intensity**: how hard one exerts himself
2) **Frequency**: how often one exerts himself
3) **Duration**: how long one exerts himself

The application of the exercise prescription to isometrics has received particular attention. The purpose of the studies was to define if any of the three conditions was more important in providing the fastest and most significant improvements for muscle strengthening.

Tension (Intensity)

The isometric tension (intensity of muscle contraction effort) required to elicit maximum strengthening effects has been carefully examined, but limits to these examinations exist due to the paucity of formal studies. This is even true for the hectic period during the 1950's with the rise in interest about isometrics and, even more recently, during present times. One of the exceptions was the original study by Hettinger and Muller (50) from which the authors decided that once a threshold tension of about 30% of maximum tension had been reached few extra strength gains could accrue by inducing further increases in tension. Others agreed, but Cotten found that strength increases with 50%, 75%, and 100% of maximum tension produced marked yet similar increases in strength (62) beyond those induced by tension levels of 30% maximum.

In some studies, workers varied tension, frequency, and duration by doing more repetitions in the same session, experimenting with changes in tension, and varying training sessions per week. Obviously, the total number of potential variables to test made it difficult to test all possible conditions. Muller (56) re-evaluated his own work and found that the rate of strength improvement did appear to correspond "roughly to the strength of the training contractions." Coleman also decided that "increases in strength are related to the intensity of the training stimulus" (63). Coleman, however, compared strength increases for two separate groups: one using isometrics and the other using isotonic training. He used similar loads in the two groups and drew his conclusion from that and never tested them (or other groups) across a wide range of loads. Coleman did believe that strength increases were related to the percent of maximum tension applied to the muscle.

An earlier study also concluded that tension was the predominate factor in attaining the best increases in muscle strength because increases of 4.5% per session resulted from maximum tension whereas two-thirds maximum tension output provided only 2.8% increases per session (64).

From these results, it appears that the increase in strength from isometric training is probably not a simple one-step function that turns-on when one reaches a threshold of tension, but is an increasing function based upon an ever-increasing tension during contraction.

Frequency

Both session frequency and repetition frequency have been studied (66). Hettinger calculated that training on alternate days is 80% as effective as daily training, and training once per week is 40% as effective as daily training (65). He also found that training once every two weeks produced no gains at all, but did maintain strength. More research is needed to clarify training session frequency.

Disagreements exist about the needed number of contractions per session and there have been many trials of different combinations (48). In 1972, Berger compared the effects of 1, 2, or 3 repetitions of 6 to 8 seconds for each contraction, during 8 weeks of training. He found no evidence that more contractions were better than fewer (66).

In summary, it seems that increasing the number of repetitions helps to increase strength, but the advantage is not significant. In isometric training, the duration of contractions likely has an effect, but no studies exist that manipulated this factor.

Duration

The length of the duration of a contraction is less well studied than that of repetition frequency. Hettinger and Muller (50) used 6-second contractions. Others have tested contraction times ranging from 1 second to as many as 100 seconds. No study, according to Muller (56), provided any evidence to favor longer contractions over shorter ones. Hettinger claimed that 1 second contractions had a negligible value, and that to be effective, a contraction must last about 10-20% as long as a maximum contraction can be held. He further observed that a comparison between 1 second and 6 second duration contractions not only accelerated the increases in strength, but carried them to a greater height. The shortest duration of contraction for a threshold stimulus and the optimum duration for maximum strength increases are unknown within the database of scientific publications.

Time to Reach Maximum Tension Development

The production of a maximum tension output in muscle takes time; it is not instantaneous and requires between 200-300 milliseconds (ms) to reach almost maximal tension. Once contraction is initiated, motor units must be recruited, muscle shortening must begin, slack must be removed from the muscle fibers, activation of the structural proteins must occur (myosin and actin cross-links must fire: these are proteins that cause muscle shortening and contraction), and fuel requirements must be met. Different muscles have different times to peak tension output, for example, elbow flexor muscles can carry out the process of full tension development more quickly (1.6 seconds) than lower limb extensors (4.4 seconds).

The above cited studies were nearly unanimous in the conclusion that the most important factor inducing maximum increases in muscle strength was a maximal contraction. Muscle contraction times to peak output would negate the idea that 1-2 second contractions would be effective since muscles are unable to reach maximal tension output that quickly.

A question arises: Is the increase in muscle strength related to both the initiating excitation-contraction coupling process and the process of sustaining maximum tension for a period of time? In a study to address this question, researchers trained the elbow flexors of human subjects for three weeks. The observed strength increases were associated with no change in muscle activation rates (67).

When selecting the duration of contraction, consideration to the differing rates of a muscle's ability to develop maximal tension output must be part of the planning process.

Joint Angle

It has been argued that isometric exercise to increase strength, which is most often conducted at one fixed joint angle, has little transferability to other muscle/joint angulations. The training position for isometric contractions is defined by the joint angle across which the muscle contracts. The angle of the joint sets muscle architecture and length. Depending on the joint angle, there will be changes in mechanical advantages, modifications of neural input, and alterations in opposing muscles by way of synergistic actions. The force that the elbow flexor muscle can generate varies throughout its range of motion (as it does for any individual muscle) so, as such, joint angle is associated with varying levels of force production.

The forces produced at joint angles between 50 degrees and 140 degrees for elbow flexors have been *predicted* from the force recorded at *one* angle with high accuracy (68). Predictions for the elbow extensors were less accurate.

Garg and Chaffin demonstrated this same predictability on a broader scale (69). By using multiple mathematical equations in a computer model, they predicted the force output of the hand in 18 widely differing positions. Comparing the *predicted* forces with the *actual measured* forces, they recorded validity coefficients ranging from a very high r=0.93 to r= 0.97, a consistency which suggests that training effects should be consistently transferred from one to other joint positions.

There were opponents. Some studies (56) indicated joint angle specificity effects. Lindh saw the same specificity when training knee extensors. He concluded that the joint-angle dependent effects were of neuromuscular origin and as a result argued that effective isometric training should be conducted at multiple joint angles (70).

This training methodology had already been adopted, but it produced no significant general increase in strength (71). Others found the same result. Hetherington employed a measuring procedure designed to remove the effects of differing lever positions as a result of varying joint angulations so he could measure pure tension (72). Further research to address the issue of joint-angle-specific-training-adaptation continued until the question was resolved with the use of sophisticated methods. Rosentswieg measured muscle action potentials from elbow flexors and found the potentials to be constant and concluded that: "differences in strength at divergent angles are a function of the lever and not of muscle activity" (73).

In 1967, Whitley found that increases in muscle strength occurring at one fixed angle of training did transfer to all joint angles (74). He convincingly showed that strength gained at one joint angle is usually available for the provision of muscle power at other un-trained joint angles and finally put the issue to rest.

Modern Research into Isometrics

The early research concerned itself with issues related to defining the elements of the exercise prescription and how each contributed to the training stimulus. Striking to this research was the failure of researchers to set up split testing models to evaluate the outcomes of strength increases from varying protocols. Certainly some tests were made, but the number pales in comparison to the enormous number of programs that could be studied.

What did become clear was that tension development to maximum levels was the primary factor in strength increases. The future research path that followed after this early period was to test protocols characterizing the differences between isometrics, isokinetics, and isotonics. Invariably, a single protocol was used within each modality. There was no split testing of specific programs. For the most part, the evolution of testing programs, A versus B for example to see which is better, was relegated to the pages of muscle magazines as "gym experts" extolled the virtues of a particular style of training. There were none more vociferous than Arthur Jones, the developer of the Nautilus equipment.

Included with the Nautilus equipment was a specific style of training deemed "one-set-to-failure." Jones was also a proponent of negative and isometric training and developed specific pieces of equipment so one could train in such a manner. Some researchers published papers on the effects of Jones's training methods and arguments and discussions were a common occurrence in the muscle-head periodicals of the day.

In the modern era, the sophistication of explorative technology has given way to an investigation of the physiological responses to isometric training rather than more research into the superiority of one method of training versus another, a split test if you will.

For example, a recent 2007 article characterizes changes in the activation of muscle and determined if there were "linked" neural adaptations in the motor pathway following isometric training. The training protocol was 12 sessions of isometric training of the foot plantar flexor muscle over a four-week period (75).

To estimate spinal changes, the researchers used the Hoffman reflex to detect evoked spinal reflex responses. They tested the subjects at 50%, 75%, and 100% of their maximal voluntary contraction strength (MVC). MVC increased by 20.0% in these young healthy subjects during 4 weeks. The rate of increase was, therefore, 5% per week, a figure comparable to the results found in early research, although more than expected for those in a healthy state. An explanation for this is that few people train their plantar flexors so that particular muscle may have been relatively deconditioned. Interestingly, in contrast to work already cited, this study showed an increase in efferent neural drive (nervous system) of 57.3%. The results suggest that increases in MVC observed in the first few days of isometric training can be accounted for by an increase in the rate of activation of muscle at the onset of contraction. These increases in muscle activation may arise from increased volitional drive from supraspinal centers.

In a recent study, researchers looked more extensively into the components of the contractile muscle-tendon complex for insights into the contribution of each component to contractile force: tendon versus muscle (76).The purpose of the study was to investigate the relationship between the mechanical properties of the connective tissue and muscle performance in maximal isometric actions. Sixteen trained men consented to participate. Maximal isometric strength was determined. The mechanical properties of the muscle, vastus lateralis (outside of the thigh), were determined by ultrasonography. The rate of torque development was positively related to the mechanical properties of the tendon structures and showed that tendon mechanical properties might account for up to 30% of the variation in the development of torque. Power, force, and velocity measurements were correlated to tendon stiffness. The results of this study demonstrate that the stiffness of the tendon structures affects the development of force transmission from the contractile machinery to the movement of bone.

It is obvious from the above that the sophistication of the analytical methodologies and the advances in technological assessments allow a significantly more refined understanding of the effects of training programs.

That statement, however, shows only the evolution in the understanding of the physiological, biochemical, and molecular basis of the effects of isometric training regimens. We realize no further advances in the ***identification of optimal procedures for increasing muscle strength***. The intention of physiologists is not to identify optimal training procedures, but to identify changes in tissue structure and function. Optimization of procedures is of little interest to the academic scientist.

In another recent study of isometric training, researchers from York University, Toronto, Canada, studied the changes in maximal voluntary (MVC) force. They evaluated the percentage maximal activation, and maximal surface EMG (electromyography, a measure of muscle fiber activation), and M-wave characteristics of the EMG. They also acknowledged that few studies have measured motor unit firing patterns during training. The purpose of this study was to measure average single motor unit firing rates during almost maximal and submaximal (50 and 75%) of MVC.

The training protocol was three sessions per week for three weeks, providing a total of nine training sessions. Subjects were males, average age 25, and were untrained. Each participant warmed up and then the training was 3-5 attempts to reach MVC, each with superimposed twitches (reach MVC, back off, and go for it again) with 90 seconds rest in between. Then the training protocol followed which consisted of 10 MVCs with 3 minutes rest between sets. Each MVC was held for 3 seconds with 3 second rest intervals in between.

For the training group, the absolute MVC in the knee extensor muscles increased significantly after only four of the nine sessions and the end value increase was 35%, equal to an increase in strength of 3.88% per session after just nine training days. Single motor unit firing rates were higher at 75% versus 50% and at 100% versus 75%. They concluded that the adaptive response in the neuromuscular system to resistance overload is rapid since increased muscular strength was significantly increased after just four sessions. They highlighted the fact that this rate of increase is not uncommon, citing work showing a 15-18% increase in MVC during the first four weeks of training (77,78) and up to 36% by 8 weeks (79).

One of the purposes of this study was to define both the neural contribution and the hypertrophic contribution to increased muscular strength. The desired outcome, to attribute percentage contributions for each, was not realized. They did conclude, however, that a combination of mechanisms including increased protein synthesis, changes in muscle activation characteristics, changes in muscle agonist versus antagonist activity (extensor muscle increased activity as a result of neural inhibition of its opposing flexor muscle, example leg extension versus leg curl), may all contribute to the increase in maximal muscle force output during the first few weeks of resistance training.

In an earlier study by Cafarelli, the purpose was to define more clearly whether increases in strength arose because of contributions from neural adaptations and/or muscle hypertrophy (80). An experimental group of fifteen female university students trained knee extensor muscles in one leg using isometric exercise. Training consisted of 30 MVC per day, 3 times per week, for 8 weeks. After 8 weeks of training, MVC increased by 28% and muscle cross sectional area increased by 14.6%, but the amplitude of the electromyogram was unchanged. The conclusion drawn by the researchers was that there was no evidence of a strength increase that *was unrelated to an increase in muscle size*. In other words, all of the increase in strength came as a result of increases in the growth of contractile proteins: because of muscle hypertrophy.

Both the historical and modern-day literature is clear: isometric resistance exercise leads to rapid and dramatic increases in muscle strength. These increases slow with time and they are relatively high and rapid the more deconditioned a subject is at the beginning of training. According to early research, most of the muscle strength gains occur within five weeks of beginning training, ***but the hallmark of strength increase studies is that they are constrained by time limits and there are no studies available that extend beyond 8-12 weeks.***

The most effective isometric program had not been defined by scientific investigation. It is clear that a maximal contraction, held for brief seconds, is the most effective stimulus for inducing strength increases, and, most likely, hypertrophy. Optimal duration and frequencies had not been clarified.

Another important area of incomplete research is recovery. Of course, this issue relates to the exercise prescription. The overarching issue, however, remains the fact that there has never been a systematic test of the many possible isometric combinations of exercise protocols that are possible over the wide range of the components of the exercise prescription and, in and for, many varied human population types. As I have shown, research has focused on the physiological, biochemical, and molecular changes that occur as a result of training.

Aging and Muscle

The muscle wasting and weakness that occurs with aging have been of interest since early Greek and Roman history. Muscle loss and decay, at the opposite pole of our interest in muscle strength, both have a long history of human interest. The Greeks despised aging as it represented a deterioration of youthful vigor. If the problem of physical frailty in aging is to be effectively slowed, we must have a full understanding of the causes and mechanisms underlying muscle weakness (81).

Sarcopenia, the loss of muscle mass with aging, is the main cause of muscle weakness in old age. This process begins around the 6th decade and by the 8th decade muscle mass attains a value that is 40% less than the whole body muscle level that one possessed in his 2nd decade (82). The causes of sarcopenia are multi-faceted, but are mainly driven by neuropathic changes leading to motor neuron death (83) along with cell death (apoptosis). During the aging process, the number of muscle fibers decreases, as well as fiber size arising from changes in hormonal growth factors (84), and a decrease in the level of physical activity (85). Malnutrition in aging is quite common due to a progressive loss of appetite and the consequent reduction in food intake.

The loss of muscle size occurs along with the inability to generate force based on a muscle's cross-sectional area and this is referred to as a decrease in muscle quality (86). These factors affect both the neuromuscular system and the tendon connective tissue system. Among the muscular changes is the inability to generate as much force output as one could perform when younger. There is a decrease in the myosin:actin cross-bridge connections which are responsible for creating contractile force. Further, there is less neural drive (87). There are also changes in the shape of the muscular architecture that contribute to the loss of force that account for about 50% of the loss in muscle function in the elderly.

Neuromuscular Alterations with Training in the Aged

Since the early 1990's resistance training has been shown to slow and even reverse the detrimental effects of aging (88-92). What is most significant about this body of work is that it shows the adaptability of human physiology and implies that the losses attributed to the aging process are not fixed and unalterable.

Skeletal muscle has the capacity to regenerate when exposed to an appropriate stimulus. With the use of specialized technology such as computerized tomography, ultrasound, and magnetic resonance imaging, muscle cross sectional area under the influence of resistance training has been shown to increase significantly from resistance training. Increases in muscle cross-sectional area after 3-month's training, range from 5-17%, a figure comparable to the changes seen in young adults during similar periods of training (93). In order to assess the true maximum force-producing capability in response to training programs, isometric strength testing may be the most appropriate choice (81).

Changes in tendon stiffness also accompany changes in muscle size and the force-generating capability of trained elderly muscle (94). The implications of these findings is that functional activities requiring a rapid generation of joint torque force may benefit, such as an attempt to recover from a slip or fall.

In contrast to work demonstrating that neural factors are little involved in strength increases in the young, studies with the elderly indicate that maximal muscle activation (neural factors) played a dominant role in the strength increases they experienced (95). Their data suggest that the effect of muscle training in the old may rest entirely on neural factors, presumably acting on various levels of the nervous system, which act to increase muscle activation (neural) in the absence of significant hypertrophy (muscle growth). Of course, as we have seen, above, hypertrophy does occur. And, as we have also seen, increases in neural input will be a factor since sarcopenia is characterized by diminished neuronal stimulation of the contractile proteins.

This is an interesting observation in comparing muscle adaptations in old versus young and brings into play the long-standing question of the percent participation of neural versus hypertrophic changes in muscle in response to training. The preceding discussion of sarcopenia outlined the predominate characteristic of sarcopenia that is motor neuron loss, a neural aspect of muscle function decline. Of course, there is also a loss of muscle fiber size and muscle fiber contractility function. Since fiber function is quite dependent on neural input, it is clear that neural activation is an important component of the maintenance of muscle size and its contractile properties.

Several studies, that used conventional resistance training in the elderly, have shown significant increases in muscle strength in 8-12 weeks: 107.4% (96), 113.0% (89), and 174.0% (92).

The only conclusion that can be drawn from the above studies is that increased muscle strength in the elderly occurs as a result of the combined improvements in both activation (neural) and hypertrophy. These two mechanisms, acting in tandem, demonstrate the extraordinary potential for rehabilitation of the loss of muscle strength and function in the elderly and the associated potential to prevent falls, improve the quality of life, and maintain independent activities of daily living (ADL).

bioDensity Isometric Technology by Performance Health Systems

A very interesting recent development in the science of exercise training was the creation of the bioDensity System of training. Founders of Performance Health Systems (PHS), Paul Jaquish and John Jaquish, have gone back in time to the early days of isometric training and tied the understanding of its extraordinary effectiveness to the technology of our current times. They have produced a device and system of training that will revolutionize exercise science as we know it. Their passion for strength training and its impact on human health led to the development of the machine and system of training.

In doing so, they rewrote the science of muscle strength as pioneers in cutting-edge technology. Not since the days of the introduction of the Nautilus machines and system of training by Arthur Jones in 1970 have we seen such a dramatic improvement in exercise training science.

What is uniquely different between bioDensity Technology and Nautilus is that PHS fully realized the power of isometric training and produced a unique device to tap its potential. Nautilus relied upon conventional training ideas using isotonic resistance training as its recommended format. Nautilus sniffed around the edges of isometrics with some of its machines, but never really embraced isometrics as the king of training methods.

There are many limitations to the science underlying isometrics. The only solid piece to what has been uncovered about isometrics is that intensity (tension development) is the most important factor for realizing maximal increases in muscle strength. Much of the other areas of interest in identifying the combinations of the exercise prescription (intensity, duration, and frequency) are largely unknown. There are several reasons for this: scientific investigation has focused on identifying the physiological, biochemical, and molecular changes that occur from following an exercise training program. In general, the identification of optimal training programs is left to the laity and those involved in training that may, or may not, possess a PhD and have employment in a university.

It is well known that the decay in physical fitness is an epidemic, and that people are unwilling to devote time to maintaining their fitness. The “disuse syndrome” is now well-known as one of key features of the aging process that leads to falls and loss of independence. Loss of muscle strength is one of the main predictors of falling.

How can we help the frail and weak maintain their quality of life? The only way is to improve their strength and all other aspects of physical function. The bioDensity system can dramatically and quickly change muscle strength.

So, what did PHS do? By using modern-day load cells that precisely and accurately measure tension output, PHS was able to collect and develop a database from more than 100,000 workouts since 2005. With this enormous amount of analyzable information, PHS filled in the blanks leftover from the scientific investigation into isometric exercise. PHS could now define all the elements of the exercise prescription and from that develop, finally, an optimized training program for the development of human strength.

Results of pilot testing over 4 years with hundreds of participants are as follows:

Client results after 48 months of operation, 100,000 data sets:

- Gains over 4 years: 296%
- Gains over 3 years: 201%

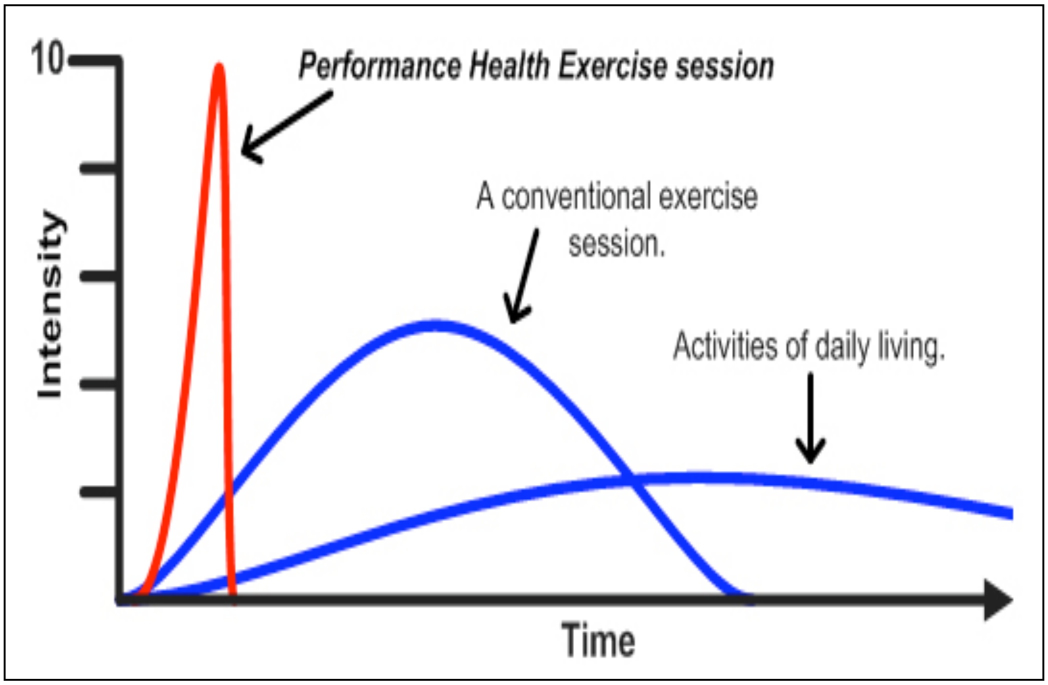
- Gains over 2 years: 138%
- Gains over 1 year: 73%
- Average client age 52

This data is an extension of the research during the early days and clearly resolves many unanswered questions.

PHS based their beginning work on the initial studies of Hettinger and Muller (50) and that he tried many variations in the training regimen. Because the system accurately measured every training session's tension output and collected and analyzed the data, PHS was able to begin to answer questions related to frequency and duration. They could easily see the tension output in real time while the trainee exercised. From this they were able to deduce optimal contraction times relative to the fatigue properties of the muscle.They could also test recovery time and determine the amount of rest required between training sessions. The bioDensity system made all this possible.

The chart above shows how one subject's strength improved during five months of continuous training during which time his whole body strength increased by 35% equaling 7% per month and 1.75% per week. (After a client finishes an exercise session, he or she gets a printout representing all sessions, and including an analysis and recommendation section to the software can prescribe the proper recovery timing. This is a feature called adaptive response management and will be discussed in detail later.)

In the following graph PHS demonstrates the use of maximal contraction development during isometric training in comparison to conventional training and individuals living freely and doing no exercise.



Intensity is clearly the most important factor in the development of maximal strength and endurance (97-101). What is less well understood is the time course of metabolic adaptations (9,102,103). The interest of scientific investigation is often about changes in cellular enzymes or other changes at the cellular level and, most often, changes at the whole body level are of little interest (100).

What is unique about PHS testing is that it was able to arrive at whole body reactions to exercise to define, for the first time ever, optimal muscle strengthening protocols and the most viable form of training for muscle strength increases. In doing so, PHS arrived at answers for the exercise prescription. For example, by varying the work:rest ratios, PHS could define the length of time required for full muscle recovery. If subjects trained again before full muscle adaptation occurred, PHS could easily see that the subject was unable to generate maximum tension because full recovery had not actually taken place.

Summary of Benefits of bioDensity Isometric Technology

The key features of bioDensity Technology are:

Utilizes compound, Isometric Exercises

Each isometric exercise is performed at the position of maximum biomechanical leverage and maximal contraction of targeted muscles.

Allows for maximal safe "self-loading" of all major muscular-skeletal structures

Provides immediate real-time force production/loading feedback to exerciser and trainer

Stores all force production data from each exercise and each session and provides comparison from one session to the next and from initial session to latest session.

Calculates optimal recovery time between sessions

Although there are circumstances where a single joint, isolation, rotary exercise like a leg extension is preferred – in general compound, multi-joint exercises such as a squat or leg press will tend to produce more functional strength gains – all things being equal. Compound exercisers tend to recruit more muscle mass, provide loading of multiple joint structures, and are more compatible with actual daily movement patterns.

By performing each exercise at the point in the range of motion where maximum force production and loading is possible and at the point where targeted muscles are fully contracted (such as near full extension in the bench press and leg press exercises) bioDensity Technology allows for maximal "self-loading". In addition, since the exerciser is creating the force/load being imposed on the body risk of injury is minimized because the exerciser has immediate and complete control over load unlike other forms of resistance training.

By providing real-time force production/load feedback motor learning and motivation is enhanced. The exerciser has a goal for each exercise each session that is based on their previous exerciser performance. The psychological benefit of this feedback is extraordinary and is one of the primary reasons bioDensity Technology has delivered accelerated increases in strength.

Because bioDensity Technology stores and compares all force production/load data over time the system provides a highly accurate and repeatable way to assess strength, and this information can be used to create and update exercise prescriptions for any population.

Based on the analysis of over 100,000 sets of exercise data recovery algorithms have been created that analyze individual client performance and provide specific recovery recommendations that have been proven to allow on-going strength increases that exceed any other known system of strength training.

Perhaps most significantly the bioDensity System protocol involves only four exercises: Chest Press, Leg Press, Core-Pull, and Vertical lift. Because of the maximal loading and high intensity a single repetition maximal effort of 5 – 10 seconds for each exercise done one time per week has been proven to provide significant increases in strength.   The entire bioDensity Exercise Session requires 20 – 40 seconds of maximal effort and even with changes of seat position and exercise station the entire session can easily be performed in 5 minutes one time per week.   In addition, exercisers do not need special shoes or clothing and will not have time to break a sweat so no shower is needed.

Because of the extremely low time commitment, immediate feedback, rapid results (within 1st week for most users), and overall convenience bioDensity System users have a very low dropout rate and stick with the program. At the initial test facility in Napa California attrition was 4% per year compared with a fitness industry average of 35%!

Dr. Greg Ellis

This paper is based on an extensive research review conducted by Greg Ellis, PhD, CNS, and many hours of conversation with Dr. Ellis on strength training, conditioning in the aging population and fall prevention. Dr. Ellis also regularly uses bioDensity Technology for himself, his family, and clients. Among many other business ventures including a large nutrition practice and multiple books published, Dr. Ellis is an expert on fall prevention and conditioning programs and orthotic devices to reduce falls. He can be reached via the contact information below.

Gregory Ellis, PhD, CNS
68 Skyline Drive
Glen Mills, PA, 19342
610-459-0200
gregoryellis@comcast.net

Reference List

1. Cardinale M, Wakeling J. Whole body vibration exercise: are vibrations good for you? Br J Sports Med 2005;39:585-9.

2. Calabrese EJ. Hormesis and medicine. Br J Clin Pharmacol 2008 [Epub ahead of print].

3. Calabrese EJ, Bachmann KA, Bailer AJ et al. Biological stress response terminology: Integrating the concepts of adaptive response and preconditioning stress within a hormetic dose-response framework. Toxicol Appl Pharmacol 2007;222:122-8.

4. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. 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 2004;19:352-9.

5. Gusi N, Raimundo A, Leal A. Low-frequency vibratory exercise reduces the risk of bone fracture more than walking: a randomized controlled trial. BMC Musculoskelet Disord 2006;7:92.

6. Iwamoto J, Takeda T, Sato Y, Uzawa M. Effect of whole-body vibration exercise on lumbar bone mineral density, bone turnover, and chronic back pain in post-menopausal osteoporotic women treated with alendronate. Aging Clin Exp Res 2005;17:157-63.

7. Stewart JM, Karman C, Montgomery LD, McLeod KJ. Plantar vibration improves leg fluid flow in perimenopausal women. Am J Physiol Regul Integr Comp Physiol 2005;288:R623-R629.

8. Rubin C, Judex S, Qin YX. Low-level mechanical signals and their potential as a non-pharmacological intervention for osteoporosis. Age Ageing 2006;35 Suppl 2:ii32-ii36.

9. Gilsanz V, Wren TA, Sanchez M, Dorey F, Judex S, Rubin C. Low-level, high-frequency mechanical signals enhance musculoskeletal development of young women with low BMD. J Bone Miner Res 2006;21:1464-74.

10. Rubin C, Recker R, Cullen D, Ryaby J, McCabe J, McLeod K. Prevention of postmenopausal bone loss by a low-magnitude, high-frequency mechanical stimuli: a clinical trial assessing compliance, efficacy, and safety. J Bone Miner Res 2004;19:343-51.

11. Hannan MT, Cheng DM, Green E, Swift C, Rubin CT, Kiel DP. Establishing the compliance in elderly women for use of a low level mechanical stress device in a clinical osteoporosis study. Osteoporos Int 2004;15:918-26.

12. Rittweger J, Just K, Kautzsch K, Reeg P, Felsenberg D. Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise: a randomized controlled trial. Spine 2002;27:1829-34.

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

14. Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. Int J Sports Med 2004;25:1-5.

15. Issurin VB, Liebermann DG, Tenenbaum G. Effect of vibratory stimulation training on maximal force and flexibility. J Sports Sci 1994;12:561-6.

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

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

18. Russo CR, Lauretani F, Bandinelli S et al. High-frequency vibration training increases muscle power in postmenopausal women. Arch Phys Med Rehabil 2003;84:1854-7.

19. Torvinen S, Kannu P, Sievanen H et al. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. Clin Physiol Funct Imaging 2002;22:145-52.

20. Torvinen S, Kannus P, Sievanen H et al. Effect of four-month vertical whole body vibration on performance and balance. Med Sci Sports Exerc 2002;34:1523-8.

21. Torvinen S, Kannus P, Sievanen H et al. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. J Bone Miner Res 2003;18:876-84.

22. Torvinen S, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Kannus P. Effect of 4-min vertical whole body vibration on muscle performance and body balance: a randomized cross-over study. Int J Sports Med 2002;23:374-9.

23. Bruyere O, Wuidart MA, Di PE et al. Controlled whole body vibration to decrease fall risk and improve health-related quality of life of nursing home residents. Arch Phys Med Rehabil 2005;86:303-7.

24. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. 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 2004;19:352-9.

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

26. Lohman EB, Petrofsky JS, Maloney-Hinds C, Betts-Schwab H, Thorpe D. The effect of whole body vibration on lower extremity skin blood flow in normal subjects. Med Sci Monit 2007;13:CR71-CR76.

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

28. Zhang Q, Ericson K, Styf J. Blood flow in the tibialis anterior muscle by photoplethysmography during foot-transmitted vibration. Eur J Appl Physiol 2003;90:464-9.

29. Kerschan-Schindl K, Grampp S, Henk C et al. Whole-body vibration exercise leads to alterations in muscle blood volume. Clin Physiol 2001;21:377-82.

30. Wilson JM, Arseculeratne YM, Yang Y, Cherry GW. Healing venous ulcers with cycloidal multidirectional vibration therapy. J Wound Care 2002;11:395-8.

31. Maloney-Hinds C, Petrofsky JS, Zimmerman G. The effect of 30 Hz versus 50 Hz passive vibration and duration of vibration on skin blood flow in the arm. Med Sci Monit 2008;14:CR112-CR116.

32. Mester J, Kleinoder H, Yue Z. Vibration training: benefits and risks. J Biomech 2006;39:1056-65.

33. Otsuki T, Takanami Y, Aoi W, Kawai Y, Ichikawa H, Yoshikawa T. Arterial stiffness acutely decreases after whole-body vibration in humans. Acta Physiol (Oxf) 2008 [Epub ahead of print].

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

35. Sackner MA, Gummels E, Adams JA. Nitric oxide is released into circulation with whole-body, periodic acceleration. Chest 2005;127:30-9.

36. Sackner MA, Gummels EM, Adams JA. Say NO to fibromyalgia and chronic fatigue syndrome: an alternative and complementary therapy to aerobic exercise. Med Hypotheses 2004;63:118-23.

37. Maddalozzo GF, Iwaniec UT, Turner RT, Rosen CJ, Widrick JJ. Whole-body vibration slows the acquisition of fat in mature female rats. Int J Obes (Lond) 2008 [Epub ahead of print].

38. Rubin CT, Capilla E, Luu YK et al. Adipogenesis is inhibited by brief, daily exposure to high-frequency, extremely low-magnitude mechanical signals. Proc Natl Acad Sci U S A 2007;104:17879-84.

39. Bautmans I, Van HE, Lemper JC, Mets T. The feasibility of Whole Body Vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility: a randomised controlled trial. BMC Geriatr 2005;5:17.

40. Bogaerts A, Delecluse C, Claessens AL, Coudyzer W, Boonen S, Verschueren SM. Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men: a 1-year randomized controlled trial. J Gerontol A Biol Sci Med Sci 2007;62:630-5.

41. Cheung WH, Mok HW, Qin L, Sze PC, Lee KM, Leung KS. High-frequency whole-body vibration improves balancing ability in elderly women. Arch Phys Med Rehabil 2007;88:852-7.

42. Dolny DG, Reyes GF. Whole body vibration exercise: training and benefits. Curr Sports Med Rep 2008;7:152-7.

43. Kawanabe K, Kawashima A, Sashimoto I, Takeda T, Sato Y, Iwamoto J. Effect of whole-body vibration exercise and muscle strengthening, balance, and walking exercises on walking ability in the elderly. Keio J Med 2007;56:28-33.

44. Rees SS, Murphy AJ, Watsford ML. Effects of whole body vibration on postural steadiness in an older population. J Sci Med Sport 2008 [Epub ahead of print].

45. Rees SS, Murphy AJ, Watsford ML. Effects of whole-body vibration exercise on lower-extremity muscle strength and power in an older population: a randomized clinical trial. Phys Ther 2008;88:462-70.

46. Rees S, Murphy A, Watsford M. Effects of vibration exercise on muscle performance and mobility in an older population. J Aging Phys Act 2007;15:367-81.

47. Rehn B, Lidstrom J, Skoglund J, Lindstrom B. Effects on leg muscular performance from whole-body vibration exercise: a systematic review. Scand J Med Sci Sports 2007;17:2-11.

48. Atha J. Strengthening muscle. Exerc Sport Sci Rev 1981;9:1-73.

49. Hellebrandt FA. Recent advances in methods of hastening convalescence through exercise. Southern Medical Journal 1946;39(May):398-401.

50. Hettinger T, Muller EA. [Muscle capacity and muscle training.]. Arbeitsphysiologie 1953;15:111-26.

51. McCloy CH. Something new has been added. The Journal of the Association for Physical and Mental Rehabilitation 1955;9:46-61.

52. Muller EA. Training muscle strength. Ergonomics 1959;2:216-22.

53. Hunsicker PGG. Studies in human strength. Res Q 1957;28:109-22.

54. Hettinger T, Muller EA. Progress of increase in muscle power after a single maximum training stimulus. Int Z Angew Physiol 1956;16:184-91.

55. Rasch PJ, Morehouse LE. Effects of static and dynamic exercises on muscle strength and hypertrophy. J Appl Physiol 1957;11:29-34.

56. Muller EA. Influence of training and of inactivity on muscle strength. Arch Phys Med Rehabil 1970;51:449-62.

57. Clarke DH. Adaptations in strength and muscular endurance resulting from exercise. Exerc Sport Sci Rev 1973;(1):73-102.

58. Komi PV, Viitasalo JT, Rauramaa R, Vihko V. Effect of isometric strength training of mechanical, electrical, and metabolic aspects of muscle function. Eur J Appl Physiol Occup Physiol 1978;40:45-55.

59. Hettinger T, Muller EA. [Muscle capacity and muscle training.] Arbeitsphysiologie 1953;15:111-26.

60. Bonde-Petersen F. Muscle training by static, concentric, and eccentric contractions. Acta Physiol Scand 1960;48:406-16.

61. Royce J. Re-evaluation of isometric methods and results -- a must. Res Q 1964;35:215-6.

62. Cotten D. Relationship of the duration of sustained voluntary isometric contractions to changes in endurance and strength. Res Q 1967;38:366-74.

63. Coleman AE. Comparison of weekly strength changes following isometric and isotonic training. J Sports Med Phys Fitness 1972;12:26-9.

64. Walters CE, Steward RC, LeClaire JF. Effect of short bouts of isometric and isotonic contractions on muscular strength and endurance. Am J Phys Med 1960;39:131-41.

65. Hettinger T. Physiology of Strength. Springfield, IL: Charles C. Thomas, 1961.

66. Berger RA. Effect of varied sets of static training on dynamic strength. Am Correct Ther J 1972;26:52-4.

67. Sukop J, Nelson RC. Effects of isometrical training on the force time characteristics of muscle contractions. In: R.C. Nelson & C.A. Morehouse, ed. International Series on Sport Sciences, Biomechanics IV(1). Baltimore: University Park Press 1974.

68. Singh M, Karpovich PV. Isotonic and isometric forces of forearm flexors and extensors. J Appl Physiol 1966;21:1435-7.

69. Garg A, Chaffin DB. A biomedical computerized simulation of human strength. AIIE Transactions 1975;7:1-15.

70. Lindh M. Increase of muscle strength from isometric quadriceps exercises at different knee angles. Scand J Rehabil Med 1979;11:33-6.

71. McKethan JF, Mayhew JL. Effects of isometrics, isotonics, and combined isometrics-isotonics on quadriceps strength and vertical jump. J Sports Med Phys Fitness 1974;14:224-9.

72. Hetherington MR. Effect of isometric training on the elbow flexion force torque of grade five boys. Res Q 1976;47:41-7.

73. Rosentswieg J, Hinson MM. Comparison of isometric, isotonic and isokinetic exercises by electromyography. Arch Phys Med Rehabil 1972;53:249-52.

74. Whitley JD. The influence of static and dynamic training on angular strength performance. Ergonomics 1967;10:305-10.

75. Del Balso C., Cafarelli E. Adaptations in the activation of human skeletal muscle induced by short-term isometric resistance training. J Appl Physiol 2007;103:402-11.

76. Bojsen-Moller J, Magnusson SP, Rasmussen LR, Kjaer M, Aagaard P. Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. J Appl Physiol 2005;99:986-94.

77. Cannon RJ, Cafarelli E. Neuromuscular adaptations to training. J Appl Physiol 1987;63:2396-402.

78. Griffen L, Carafelli E. Neural excitability following resistance training studied with transcranial magnetic stimulation. Med Sci Sports Exerc : supplement 2003;35:S293.

79. Moritani T, deVries HA. Neural factors versus hypertrophy in the time course of muscle strength gain. Am J Phys Med 1979;58:115-30.

80. Garfinkel S, Cafarelli E. Relative changes in maximal force, EMG, and muscle cross-sectional area after isometric training. Med Sci Sports Exerc 1992;24:1220-7.

81. Narici MV, Maganaris CN. Adaptability of elderly human muscles and tendons to increased loading. J Anat 2006;208:433-43.

82. Abate M, Di IA, Di RD, Paganelli R, Saggini R, Abate G. Frailty in the elderly: the physical dimension. Eura Medicophys 2007;43:407-15.

83. Degens H. Age-related skeletal muscle dysfunction: causes and mechanisms. J Musculoskelet Neuronal Interact 2007;7:246-52.

84. Doherty TJ. Invited review: Aging and sarcopenia. J Appl Physiol 2003;95:1717-27.

85. Hollmann W, Struder HK, Tagarakis CV, King G. Physical activity and the elderly. Eur J Cardiovasc Prev Rehabil 2007;14:730-9.

86. Ryall JG, Schertzer JD, Lynch GS. Cellular and molecular mechanisms underlying age-related skeletal muscle wasting and weakness. Biogerontology 2008;9:213-28.

87. Lynch GS, Ryall JG. Role of beta-adrenoceptor signaling in skeletal muscle: implications for muscle wasting and disease. Physiol Rev 2008;88:729-67.

88. Bassey EJ, Fiatarone MA, O'Neill EF, Kelly M, Evans WJ, Lipsitz LA. Leg extensor power and functional performance in very old men and women. Clin Sci (Lond) 1992;82:321-7.

89. Fiatarone MA, O'Neill EF, Ryan ND et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 1994;330:1769-75.

90. Fiatarone MA, Evans WJ. The etiology and reversibility of muscle dysfunction in the aged. J Gerontol 1993;48 Spec No:77-83.

91. Fiatarone MA, O'Neill EF, Doyle N et al. The Boston FICSIT study: the effects of resistance training and nutritional supplementation on physical frailty in the oldest old. J Am Geriatr Soc 1993;41:333-7.

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

93. Brown AB, McCartney N, Sale DG. Positive adaptations to weight-lifting training in the elderly. J Appl Physiol 1990;69:1725-33.

94. Reeves ND, Maganaris CN, Narici MV. Effect of strength training on human patella tendon mechanical properties of older individuals. J Physiol 2003;548:971-81.

95. Moritani T, deVries HA. Potential for gross muscle hypertrophy in older men. J Gerontol 1980;35:672-82.

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

97. Capaccio JA, Kurowski TT, Czerwinski SM, Chatterton RT, Jr., Hickson RC. Testosterone fails to prevent skeletal muscle atrophy from glucocorticoids. J Appl Physiol 1987;63:328-34.

98. Hickson RC, Heusner WW, Van Huss WD. Skeletal muscle enzyme alterations after sprint and endurance training. J Appl Physiol 1976;40:868-71.

99. Hickson RC, Bomze HA, Holloszy JO. Linear increase in aerobic power induced by a strenuous program of endurance exercise. J Appl Physiol 1977;42:372-6.

100. Tsuzuku S, Shimokata H, Ikegami Y, Yabe K, Wasnich RD. Effects of high versus low-intensity resistance training on bone mineral density in young males. Calcif Tissue Int 2001;68:342-7.

101. Tsuzuku S, Ikegami Y, Yabe K. Effects of high-intensity resistance training on bone mineral density in young male powerlifters. Calcif Tissue Int 1998;63:283-6.

102. Hickson RC, Foster C, Pollock ML, Galassi TM, Rich S. Reduced training intensities and loss of aerobic power, endurance, and cardiac growth. J Appl Physiol 1985;58:492-9.

103. Hickson RC, Hagberg JM, Ehsani AA, Holloszy JO. Time course of the adaptive responses of aerobic power and heart rate to training. Med Sci Sports Exerc 1981;13:17-20.