Aquatic Therapy: Scientific Foundations and Clinical Rehabilitation Applications

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The aquatic environment has broad rehabilitative potential, extending from the treatment of acute injuries through health maintenance in the face of chronic diseases, yet it remains an underused modality. There is an extensive research base supporting aquatic therapy, both within the basic science literature and clinical literature. This article describes the many physiologic changes that occur during immersion as applied to a range of common rehabilitative issues and problems. Because of its wide margin of therapeutic safety and clinical adaptability, aquatic therapy is a very useful tool in the rehabilitative toolbox. Through a better understanding of the applied physiology, the practitioner may structure appropriate therapeutic programs for a diverse patient population.

INTRODUCTION

Since the earliest recorded history, water has always been believed to promote healing and has therefore been widely used in the management of medical ailments. Through observation and centuries of trial and error, and scientific methodology, traditions of healing through aquatic treatments have evolved. This review will detail the current scientific understanding of the many physiologic changes that occur during aquatic immersion. Aquatic immersion has profound biological effects, extending across essentially all homeostatic systems. These effects are both immediate and delayed and allow water to be used with therapeutic efficacy for a great variety of rehabilitative problems. Aquatic therapies are beneficial in the management of patients with musculoskeletal problems, neurologic problems, cardiopulmonary pathology, and other conditions. In addition, the margin of therapeutic safety is wider than that of almost any other treatment milieu. Knowledge of these biological effects can aid the skilled rehabilitative clinician to create an optimal treatment plan, through appropriate modification of aquatic activities, immersion temperatures, and treatment duration.

REHABILITATION HISTORY

Historically, the field of Physical Medicine viewed hydrotherapy as a central treatment methodology. In 1911, Charles Leroy Lowman, the founder of the Orthopaedic Hospital in Los Angeles, which later became Rancho Los Amigos, began using therapeutic tubs to treat spastic patients and those with cerebral palsy after a visit to the Spaulding School for Crippled Children in Chicago, where he observed paralyzed patients exercising in a wooden tank. On returning to California, he transformed the hospital's lily pond into 2 therapeutic pools [1]. At Warm Springs, Georgia, Leroy Hubbard developed his famous tank, and in 1924, Warm Springs received its most famous aquatic patient, Franklin D. Roosevelt. A wealth of information, research, and articles on spa therapy and pool treatments appeared in professional journals during the 1930s. At Hot Springs, Arkansas, a warm swimming pool was installed for special underwater physical therapy exercises and pool therapy treatments with chronic arthritic patients [2]. By 1937, Dr. Charles Leroy Lowman published his *Technique of Underwater Gymnastics: A Study in Practical Application,* in which he detailed aquatic therapy methods for specific underwater exercises that "carefully regulated dosage, character, frequency, and duration for remedying bodily deformities and restoring muscle function" [3]. During the 1950s, the National Foundation for Infantile Paralysis supported

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the corrective swimming pools, and hydrogymnastics of Charles L. Lowman and the therapeutic use of pools and tanks for the treatment of poliomyelitis. In 1962, Dr. Sidney Licht and a group of physiatrists organized the American Society of Medical Hydrology and Climatology, which historically met at the annual meeting of the American Academy of Physical Medicine and Rehabilitation.

THE PHYSICAL PRINCIPLES OF WATER

Nearly all the biological effects of immersion are related to the fundamental principles of hydrodynamics. These principles should be understood to make the medical application process more rational. The essential physical properties of water that effect physiologic change are density and specific gravity, hydrostatic pressure, buoyancy, viscosity, and thermodynamics.

Density

Although the human body is mostly water, the body's density is slightly less than that of water and averages a specific gravity of 0.974, with men averaging higher density than women. Lean body mass, which includes bone, muscle, connective tissue, and organs, has a typical density near 1.1, whereas fat mass, which includes both essential body fat plus fat in excess of essential needs, has a density of about 0.9 [4]. Highly fit and muscular men tend toward specific gravities greater than one, whereas an unfit or obese man might be considerably less. Consequently, the human body displaces a volume of water weighing slightly more than the body, forcing the body upward by a force equal to the volume of the water displaced, as discovered by Archimedes (287?-212 BC).

Hydrostatic Pressure

Pressure is directly proportional to both the liquid density and to the immersion depth when the fluid is incompressible. Water exerts a pressure of 22.4 mm Hg/ft of water depth, which translates to 1 mm Hg/1.36 cm (0.54 in.) of water depth. Thus a human body immersed to a depth of 48 inches is subjected to a force equal to 88.9 mm Hg, slightly greater than normal diastolic blood pressure. Hydrostatic pressure is the force that aids resolution of edema in an injured body part.

Hydrostatic pressure effects begin immediately on immersion, causing plastic deformation of the body over a short period. Blood displaces cephalad, right atrial pressure begins to rise, pleural surface pressure rises, the chest wall compresses, and the diaphragm is displaced cephalad.

Buoyancy

A human with specific gravity of 0.97 reaches floating equilibrium when 97% of his or her total body volume is submerged. As the body is gradually immersed, water is displaced, creating the force of buoyancy, progressively offloading immersed joints. With neck-depth immersion, only about 15 lb of compressive force (the approximate weight of the head) is exerted on the spine, hips, and knees. A person immersed to the symphysis pubis has effectively offloaded 40% of his or her body weight, and when further immersed to the umbilicus, approximately 50%. Xiphoid immersion offloads body weight by 60% or more, depending on whether the arms are overhead or beside the trunk. Buoyancy may be of great therapeutic utility. For example, a fractured pelvis may not become mechanically stable under full body loading for a period of many weeks. With water immersion, gravitational forces may be partially or completely offset so that only muscle torque forces act on the fracture site, allowing active assisted range-of-motion activities, gentle strength building, and even gait training. Similarly, a lower extremity patient with weight-bearing restrictions may be placed in an aquatic depth where it is nearly impossible to exceed those restrictions.

Viscosity

Viscosity refers to the magnitude of internal friction specific to a fluid during motion. A limb moving relative to water is subjected to the resistive effects of the fluid called drag force and turbulence when present. Under turbulent flow conditions, this resistance increases as a log function of velocity. Viscous resistance increases as more force is exerted against it, but that resistance drops to 0 almost immediately on cessation of force because there is only a small amount of inertial moment as viscosity effectively counteracts inertial momentum. Thus, when a person rehabilitating in water feels pain and stops movement, the force drops precipitously as water viscosity damps movement almost instantaneously. This allows enhanced control of strengthening activities within the envelope of patient comfort [5].

Thermodynamics

Water's heat capacity is 1,000 times greater than an equivalent volume of air. The therapeutic utility of water depends greatly on both its ability to retain heat and its ability to transfer heat energy. Water is an efficient conductor, transferring heat 25 times faster than air. This thermal conductive property, in combination with the high specific heat of water, makes the use of water in rehabilitation very versatile because water retains heat or cold while delivering it easily to the immersed body part. Water may be used therapeutically over a wide range of temperatures (Figure 1). Cold plunge tanks are often used in athletic training at temperatures of 10°–15°C to produce a decrease in muscle pain and speed recovery from overuse injury, although there are some contradictory studies regarding this [6-8]. Most public and competitive pools operate in the range of 27°–29°C, which is often too cool for general rehabilitative populations, because these populations are usually less active in the water. Typical therapy pools operate in the range of 33.5°–35.5°C, temperatures that permit lengthy immersion durations and exercise activities sufficient to produce therapeutic effects without chilling or overheating. Hot tubs are usually maintained at

	Aquatic Temperatures				
Suitable activities	Cold (10°-15° C)	Cool (26°-29.5° C)	Neutral (33.5°-35.5° C)	Warm (36°-38.5° C)	Hot (37.5°-41°)
Post-exertional recovery	✔				
Contrast baths	✔			✔	✔
Vigorous exercise		✔			
Arthritis exercise			✔		
Typical Aquatic Therapy			✔		
Cardiac Rehab			✔		
Multiple Sclerosis exercise		✔			
SCI programs			✔		
Parkinson's programming			✔		
Relaxation				✔	✔

Figure 1. Immersion temperatures for rehabitative issues.

37.5°–41°C, although the latter temperature is rarely comfortable for more than a few minutes, and even the lower typical temperature does not allow for active exercise.

Heat transfer begins immediately on immersion, and as the heat capacity of the human body is less than that of water (0.83 versus 1.00), the body equilibrates faster than water does.

APPLICATIONS IN CARDIOVASCULAR AND CARDIOPULMONARY REHABILITATION

Because an individual immersed in water is subjected to external water pressure in a gradient, which within a relatively small depth exceeds venous pressure, blood is displaced upward through the venous and lymphatic systems, first into the thighs, then into the abdominal cavity vessels, and finally into the great vessels of the chest cavity and into the heart. Central venous pressure rises with immersion to the xiphoid and increases until the body is completely immersed [9]. There is an increase in pulse pressure as a result of the increased cardiac filling and decreased heart rate during thermoneutral or cooler immersion [10,11]. Central blood volume increases by approximately 0.7 L during immersion to the neck, a 60% increase in central volume, with one-third of this volume taken up by the heart and the remainder by the great vessels of the lungs [9]. Cardiac volume increases 27%–30% with immersion to the neck [12]. Stroke volume increases as a result of this increased stretch. Although normal resting stroke volume is about 71 mL/beat, the additional 25 mL resulting from immersion equals about 100 mL, which is close to the exercise maximum for a sedentary deconditioned individual on land and produces both an increase in end-diastolic volume and a decrease in end-systolic volume [13]. Mean stroke volume thus increases 35% on average during neck depth immersion even at rest. As cardiac filling and stroke volume increase with progress in immersion depth from symphysis to xiphoid, the heart rate typically drops and typically at average pool temperatures the rate lowers by 12%–15% [14,15]. This drop is variable, with the amount of decrease dependent on water temperature. In warm water, heart rate generally rises significantly, contributing to yet a further rise in cardiac output at high temperatures [16,17].

During aquatic treadmill running, oxygen consumption (VO_2) is 3 times greater at a given speed of ambulation (53 m/min) in water than on land, thus a training effect may be achieved at a significantly slower speed than on land [18-20]. The relationship of heart rate to VO_2 during water exercise parallels that of land-based exercise, though water heart rate averages 10 beats/min less, for reasons discussed elsewhere [9]. Metabolic intensity in water, as on land, may be predicted from monitoring heart rate.

Cardiac output increases by about 1,500 mL/min during clavicle depth immersion, of which 50% is directed to increased muscle blood flow [17]. Because immersion to this depth produces a cardiac stroke volume of about 100 mL/beat, a resting pulse of 86 beats/min produces a cardiac output of 8.6 L/min and is already producing an increased cardiac workload. The increase in cardiac output appears to be somewhat age-dependent, with younger subjects demonstrating greater increases (up 59%) than older subjects (up only 22%) and is also highly temperature-dependent, varying directly with temperature increase, from 30% at 33°C to 121% at 39°C [17,21].

During immersion to the neck, decreased sympathetic vasoconstriction reduces both peripheral venous tone and systemic vascular resistance by 30% at thermoneutral temperatures, dropping during the first hour of immersion and lasting for a period of hours thereafter [9]. This decreases end-diastolic pressures. Systolic blood pressure increases with increasing workload, but generally is approximately 20% less in water than on land [17]. Most studies show either no change in mean blood pressure or a drop in pressures during immersion in normal pool temperatures. Sodium-sensitive hypertensive patients have been noted to show even greater drops (−18 to −20 mm Hg) than normotensive patients, and sodium-insensitive patients smaller drops (−5 to −14 mm Hg) [22]. Based on a substantial body of research, aquatic therapy in pool temperatures between 31°–38°C appears to be a safe and potentially therapeutic envi-

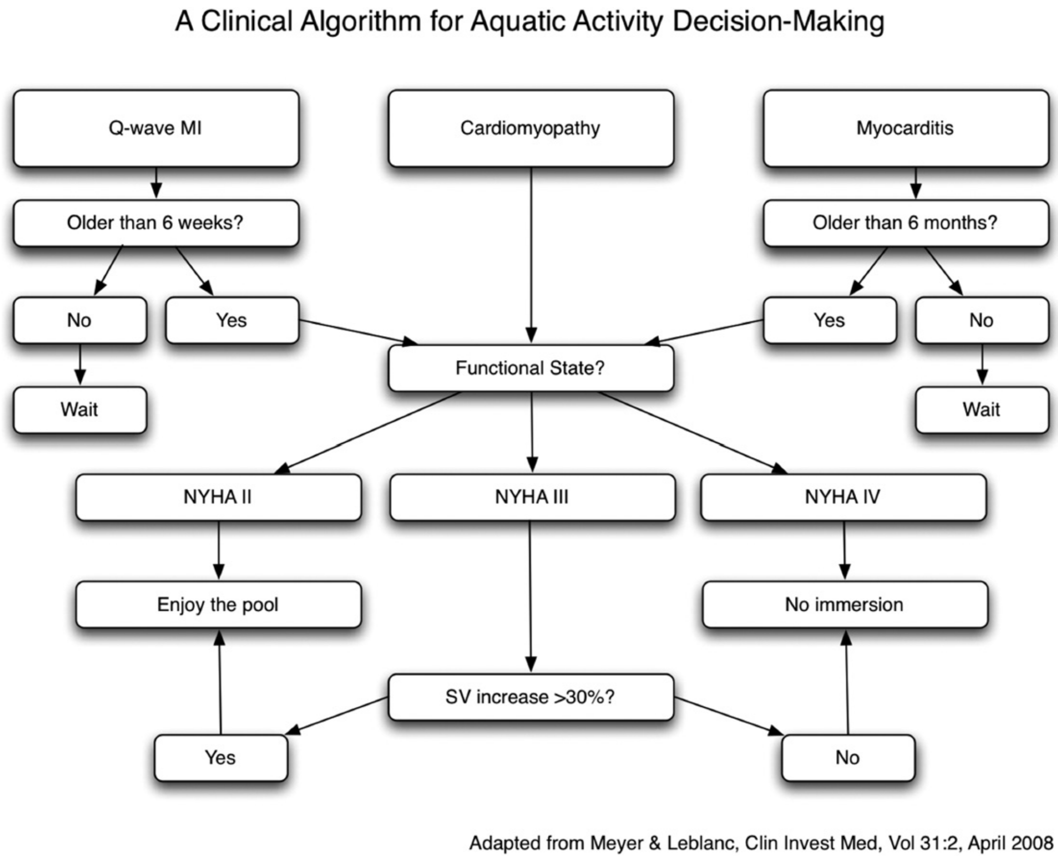

Figure 2. An aquatic therapy clinical decision-making algorithm for patients with cardiac disease (30).

ronment for both normotensive and hypertensive patients, in contrast to widespread belief as manifested by public signage.

Recent research has generally supported the use of aquatic environments in cardiovascular rehabilitation after infarct and ischemic cardiomyopathy. Japanese investigators studied patients with severe congestive heart failure (mean ejection fractions 25 ± 9%), under the hypothesis that in this clinical problem, the essential pathology was the inability of the heart to overcome peripheral vascular resistance. They reasoned that because exposure to a warm environment causes peripheral vasodilatation, a reduction in vascular resistance and cardiac afterload might be therapeutic. During a series of studies, these researchers found that during a single 10-min immersion in a hot water bath (41°C), both pulmonary wedge pressure and right atrial pressure dropped by 25%, whereas cardiac output and stroke volume both increased [23,24]. In a subsequent study of patients using warm water immersion or sauna bath one to 2 times per day, 5 days per week for 4 weeks, they found improvement in ejection fractions of nearly 30% accompanied by reduction in left ventricular end-diastolic dimension, along with subjective improvement in quality of life, sleep quality, and general well-being [25]. Studies of elderly individuals with systolic congestive heart failure during warm water immersion found that most such individuals demonstrated an increase in cardiac output and ejection fractions during immersion [26,27].

Caution is prudent when working with individuals with severe valvular insufficiency, because cardiac enlargement may mechanically worsen this problem during full immersion. Swiss researchers have studied individuals with more severe heart failure and concluded that aquatic therapy also is probably not safe for individuals with very severe or uncontrolled failure, or very recent myocardial infarction [28-30]. That said, a recent summary of published research in this areas has concluded that aquatic and thermal therapies may be a very useful rehabilitative technique in individuals with mild to moderate heart failure [31]. It is entirely reasonable however to conclude that uncompensated congestive failure or very recent myocardial infarction should be a contraindication to aquatic therapy, to hot tub exposure and perhaps even to deep bathing. Programs typically used include aerobic exercise at light to moderate levels in a neutral temperature environment. See the clinical decision-making algorithm by Bücking and colleagues (Figure 2) [30].

APPLICATIONS IN RESPIRATORY AND ATHLETIC REHABILITATION

The pulmonary system is profoundly affected by immersion of the body to the level of the thorax. Part of the effect is due to shifting of blood into the chest cavity, and part is due to compression of the chest wall itself by water. The combined effect is to alter pulmonary function, increase the work of breathing, and change respiratory dynamics. Vital capacity decreases by 6%–9% when comparing neck submersion to controls submerged to the xiphoid with about half of this reduction due to increased thoracic blood volume, and half due to hydrostatic forces counteracting the inspiratory musculature [32,33]. The combined effect of all these changes is to increase the total work of breathing when submerged to the neck. The total work of breathing at rest for a tidal volume of 1 liter increases by 60% during submersion to the neck. Of this increased effort three-fourths is attributable to redistribution of blood from the thorax, and the rest to increased airway resistance and increased hydrostatic force on the thorax [32,34-36]. Most of the increased work occurs during inspiration. Because fluid dynamics enter into both the elastic workload component as well as the dynamic component of breathing effort, as respiratory rate increases turbulence enters into the equation. Consequently there must be an exponential workload increase with more rapid breathing, as during high level exercise with rapid respiratory rates.

Inspiratory muscle weakness is an important component of many chronic diseases, including congestive heart failure and chronic obstructive lung disease [37]. Because the combination of respiratory changes makes for a significantly challenging respiratory environment, especially because respiratory rates increase during exercise, immersion may be used for respiratory training and rehabilitation. For an athlete used to land-based conditioning exercises, a program of water-based exercise results in a significant workload demand on the respiratory apparatus, primarily in the muscles of inspiration [36]. Because inspiratory muscle fatigue seems to be a rate- and performance-limiting factor even in highly trained athletes, inspiratory muscle strengthening exercises have proven to be effective in improving athletic performance in elite cyclists and rowers [38-59]. The challenge of inspiratory resistance posed during neck-depth immersion could theoretically raise the respiratory muscular strength and endurance if the time spent in aquatic conditioning is sufficient in intensity and duration to achieve respiratory apparatus strength gains. This theory is supported by research finding that competitive women swimmers adding inspiratory training to conventional swim training realized no improvement in inspiratory endurance compared to the conventional swim trained controls, as these aquatic athletes had already achieved a ceiling effect in respiratory training [60]. These results have been confirmed by more recent studies at the University of Indiana and the University of Toronto [61,62]. The author has had a number of elite athletes comment on this phenomenon when returning to land-based competition after a period of intense water-based aquatic rehabilitation sufficient to strengthen the respiratory musculature. The common response is a perception of easier breathing at peak exercise levels, effects similar to the studies quoted in elite cyclists and cyclists. This is not surprising in view of the data existing on competitive swimmers who routinely train in the aquatic environment [60-68]. Comparative studies of young swimmers have consistently shown a larger lung capacity (both vital capacity and total lung capacity) and improved forced expiratory capacity, and a number of studies have also shown improvement in inspiratory capacity [60-62,64,66, 68-73].

Respiratory strengthening may be a very important aspect of high level athletic performance, as demonstrated in some of the studies above. When an athlete begins to experience respiratory fatigue, a cascade of physiologic changes follows. The production of metabolites, plus neurologic signaling through the sympathetic nervous system, sends a message to the peripheral arterial tree to shunt blood from the locomotor musculature [38,74-76]. With a decline in perfusion of the muscles of locomotion, the rate of fatigue increases quite dramatically [39,75]. A considerable body of literature supports the plasticity of the respiratory musculature to strengthening with appropriately designed exercise in various disease conditions, although not specifically through aquatic activity [41,55,57,58,62,77-82]. Respiratory muscle weakness, especially in the musculature of inspiration, has been found in chronic heart failure patients and this weakness is correlated closely with cardiac function and may be a significant factor in the impaired exercise capacity seen in individuals with chronic heart failure [83-87]. Because the added work of respiration during immersion occurs almost entirely during the inspiratory phase, it is intriguing to speculate that a period of inspiratory muscle strengthening through immersed activity might improve exercise capacity in these individuals, but this has not been studied to date.

Aquatic therapy may be very useful in the management of patients with neuromuscular impairment of the respiratory system, such as is seen in spinal cord injury and muscular dystrophy [88-91]. A lengthy study of swimming training on cardiorespiratory fitness in individuals with spinal cord injuries was done in the late 1970s in Poland. The authors found a 442% increase in fitness levels, as contrasted with a 77% increase seen in patients with spinal cord injury in a standard land-based training program over the same period [92]. A review in 2006 concluded that respiratory muscle training tended to improve expiratory muscle strength, vital capacity, and residual volume in individuals with spinal cord injury, but that insufficient data were available to make conclusions concerning the effects on inspiratory muscle strength, respiratory muscle endurance, quality of life, exercise performance and respiratory complications [93].

Programs typically used include chest-depth aerobic activity for general rehabilitation populations usually at therapy pool temperatures. For chronic obstructive pulmonary disease patients, depth should start at waist level, and progress into deeper water as strength and respiratory tolerance improves. A simple technique for expiratory muscular exercise uses a 1" PVC tube 16" in length, with the patient blowing out into the water with the end of the tube submerged, beginning with the tube end 2-3 feet below water surface and progressing deeper as strength builds. This can be quantified as a measure of expiratory force increase, both by measuring depth of the tube end and number of full exhalations completed.

APPLICATIONS IN MUSCULOSKELETAL REHABILITATION

Water immersion causes significant effects on the musculoskeletal system. The effects are caused by the compressive effects of immersion as well as reflex regulation of blood vessel tone. During immersion, it is likely that most of the increased cardiac output is redistributed to skin and muscle rather than to the splanchnic beds [94]. Resting muscle blood flow has been found to increase from a dry baseline of 1.8 mL/min/100 g tissue to 4.1 mL/min/100 g tissue with neck immersion. With muscle blood flow increased 225% above dry land flow, even higher than the rise in cardiac output during immersion, it is therefore reasonable to conclude that oxygen availability to muscles is significantly increased during immersion at rest [95]. Blood flow during exercise is likely enhanced as well and there is research that supports this supposition, finding a 20% increase in blood flow in sedentary middle-aged subjects subjected to 12 weeks of swim training [96].

The hydrostatic effects of immersion, possibly combined with temperature effects, have been shown to significantly improve dependent edema and subjective pain symptoms in patients with venous varicosities [97]. Similarly, a rehabilitation program of hydrotherapy using contrasting temperatures produced subjective improvement, systolic blood pressure increases in the extremities, and significant increases in ambulation in patients with intermittent claudication [98-102]. Where peripheral circulation is severely compromised, it is prudent to maintain immersion temperatures at a level below those potentially increasing metabolic demand that cannot be met by available circulation (ie, below thermoneutrality [37°C]).

An aquatic exercise program may be designed to vary the amount of gravity loading by using buoyancy as a counterforce. For acute injury, such as tibial stress fracture, programs typically should start at non–weight-bearing depths, limiting activity below pain onset, and progressing in weight bearing and exercise levels as symptoms permit. Rehabilitative programs for specific joints may be more effective as either closed or open kinetic chain programs. Shallow-water vertical exercises generally approximate closed chain exercise, albeit with reduced joint loading because of the counterforce produced by buoyancy. Deep water exercises more generally approximate an open chain system, as do horizontal exercises, such as swimming. Paddles and other resistive equipment tend to close the kinetic chain. Aquatic programs, however, offer the ability to damp the force of movement instantaneously because of the viscous properties of water. Offloading of body weight occurs as a function of immersion, but the water depth chosen may be adjusted for the amount of loading desired [103]. The spine is especially well protected during aquatic exercise programs, which facilitates early rehabilitation from back injuries [104-108]. Spine rehabilitation programs will typically include aquatic spinal stabilization techniques as well as an aerobic component of exercise activity. The former is best done with a therapist in the water one-on-one with the patient.

Arthritis and Fibromyalgia

Aquatic exercise has been studied extensively in individuals with arthritis as well as fibromyalgia patients. The physiology behind efficacy remains enigmatic, but improvements in joint mobility and reductions in pain have been extensively reported [109-113]. Acute joint symptoms may respond to warm water immersion and gentle active or active assisted range of motion, whereas subacute or chronic arthritis often responds to more active exercise regimens [114-116]. The YMCA Arthritis Exercise program has been found effective in reducing disability and improving functional fitness and strength in older adults with arthritis and these programs are widely available in many communities [117,118]. Numerous studies of fibromyalgic patients have demonstrated reduction in pain, improvement in sleep patterns, fibromyalgia impact, mood state disorders, and when compared with land-based exercise programs, the aquatic groups typically showed faster and larger gains, with longer post-study improvements [119-129]. Typical programs for fibromyalgia include both deep-water flotation assisted exercise, and chest depth aerobic exercise programs, but programs such as Ai Chi, an aquatic equivalent of Tai Chi have been found to be effective as well.

APPLICATIONS IN ATHLETIC TRAINING

There is a substantial volume of literature that supports the potential value of using aquatic exercise as a cross-training mode [130-133]. Much of the literature dealing with deep-water running with flotation belts concludes that skill levels determine maximal oxygen consumption, but that training levels can easily be achieved equal to land-based training [102,131-138]. It does need to be recognized that while aquatic cross training can present a very significant aerobic challenge to the athlete, there are differences in motor activity, muscle recruitment and cardiovascular performance [137]. While there are some significant differences in cardiovascular function, the overall cardiac demand appears to be at the least, equivalent [100-102]. For maintenance of cardiorespiratory conditioning in highly fit individuals, water running equals dry land running in its effect on maintenance of maximum VO_2 when training intensities and frequencies are matched for training periods of up to 6 weeks, currently the longest published training studies [139-141]. Similarly, when aquatic exercise is compared with land-based equivalent exercise in effect on maximum VO_2 gains in unfit individuals, aquatic exercise is seen to achieve equivalent results, and when water temperature is below thermoneutral (37°C), the gains achieved are usually accompanied by a lower heart rate [142]. Thus, water-based exercise programs may be used effectively to sustain or increase aerobic conditioning in athletes who need to keep weight off a joint, such as when in injury recovery or during an intensive training program in which joint or bone microtrauma is likely with exclusively land-based training. Although research has shown aquatic exercise to be at least the equivalent in aerobic training value to land-based training, a key question frequently raised is whether aquatic exercise programs have sufficient specificity to provide a reasonable training venue for athletes in this situation [100-102,143,144]. A study by Kilgore and coworkers specifically addressed the issue of running kinematics during deep water running as compared with treadmill running and found a very close comparison between the 2 when using a cross-country skiing pattern with respect to knee and ankle kinematics, whereas high-kick running styles did not match the treadmill kinematics [145]. A 2006 study assessed aquatic training in plyometric performance, finding comparable performance improvement to land plyometric training but with reduced post-training muscle soreness, and of course decreased joint loading [146]. It is unlikely that aquatic training can substantially improve dry land performance in coordination skills such as hurdles, high jump, or other complex coordination activities, where reflex timing becomes a major part of the performance success. But for many athletic activities, aquatic cross-training can sustain or even build aerobic fitness, with the side benefits of reduced joint loading, decreased muscle soreness and improved performance, and a significant potential for improved respiratory function. Programs typically used for vertical water exercise include buoyancy-assisted deep water running and cross-country skiing, aquatic treadmill running, waist-depth aqua-running, and upper extremity work using resistive devices in cool pool environments.

APPLICATIONS IN GERIATRIC AND OSTEOPOROSIS REHABILITATION

Aquatic exercise has been successfully used to improve balance and coordination in older individuals, who face an increased risk of falling. A 2008 study assessed different forms of aquatic exercise in a group of older subjects, finding that deep-water running had statistical advantage over typical chest-depth aquatic exercise in reducing balance sway distance and that both exercise forms improved reaction times and movement speed [147]. The hypothesis was that an open chain exercise such as a deep-water program would add an additional balance challenge to the closed chain exercises typically done. An earlier study assessing aquatic exercise in people with lower extremity arthritis found statistically significant reductions of 18%–30% in postural sway after 6 weeks of closed chain training [148]. It may be concluded that both open and closed chain exercise in the aquatic environment can produce significant gains in balance, with some evidence that the former adds increased challenge. Whether these gains lead to a reduction in falls remains an open question, although rehab programs are typically built around this hypothesis and a recent Cochrane review supports the belief [149]. Aquatic balance-building programs will typically use techniques such as Ai Chi, Yogalates (a hybrid aquatic yoga/Pilates program), and balance drills in waist-depth water.

Because aquatic exercise, whether through swimming or vertical water exercise is either limited or non–weight-bearing, the question has long existed as to its value in the development of significant bone mineral stores, and in the management of osteoporosis. These are really 2 separate questions. In young men and women, bone mineral content develops as a function of growth in body mass and bone loading. There has been extensive study of the effects of various types exercise on bone growth and mineral content in the early years of life in men and women, both pre- and postpuberty [150-158]. The effect of exercise, both impact loading such as running and of nonimpact exercise such as cycling and swimming appears to clearly favor impact-loading exercise in both young men and women. This advantage appears to hold through early adulthood as measured in elite competitive athletes [151,159-165]. There does seem to be a slight difference between men and women during these later competitive years, with men building slightly more bone than women [150,151,159,165,166]. Even in later years, the athletes have greater bone mineral content than nonathletic controls, which demonstrates the value of early-life athletic activity, especially for women who are at greater risk for osteoporosis. The youthful swimmers in most of these studies seem to have higher bone mineral content than nonexercising controls, but generally less than athletes practicing gymnastics, cheerleading, or similar activities.

The question of the role of aquatic exercise in later years, especially for women at risk for osteoporosis is more problematic. Bravo et al studied a group of postmenopausal women for more than a year, with participants performing a specially created aquatic exercise routine emphasizing impact loading, such as jumping and landing in waist-depth water. Although they found a great many positive changes in the study group, including improvements in functional fitness, specifically flexibility, agility, strength/endurance, cardiorespiratory endurance, and gains in psychological well-being, they did not find an increase in either spine or femoral neck bone mineral density as measured through dual-energy X-ray absorptiometry (DEXA) scanning, although femoral neck mineral content did not decrease over the year [167]. A Turkish study did find gains in calcaneal bone density after a 6-month study of aquatic exercise in a group of 41 postmenopausal women, but did not study either the spine or femoral neck, both areas of major concern for osteoporotic fractures [168]. A Japanese study of postmenopausal women did find that active exercisers preserved better forearm bone mineral density than nonexercisers, with high-impact activity preserving better than low impact such as swimming, but again did not study sites of particular concern for fractures [169]. Aquatic exercise does have a fitness role in women at risk for or with osteoporosis as there is considerable data that such programs can build strength and endurance, and there is generally an accompanying improvement in balance skills, self-efficacy, and well-being [104,109,110,112,113,117,123,124,167,170-177]. Because of the safety of aquatic exercise, the risk of injury during the exercise period is extremely small, and a fall, should it occur, will generally only cause a person to get their hair wet. Thus it is quite reasonable to begin an active exercise regimen in the pool, either through swimming or vertical exercise. When feasible, transition to a land-based exercise regimen that does involve more impact loading should follow as it remains likely that aquatic exercise alone will not provide a major osteogenic stimulus.

RELEVANT THERMOREGULATORY EFFECTS AND PREGNANCY

The 2 major compensatory mechanisms that assist cooling in warm air temperatures are peripheral vasodilatation combined with increased cardiac output. These mechanisms work to counterpurposes in warm water (greater than 37°C), because they facilitate heat gain when the surrounding environment does not allow evaporative and radiant cooling. Immersion at 40°C (104°F), which is a common hot tub temperature, produces a rectal (core) temperature rise which equates to approximately 0.1°F/min of immersion [178]. This is not a problem in the neurologically intact human, as somatic awareness warns when core temperature rises much beyond a degree centigrade or even less. But when alcohol or other drugs alter awareness, there is a serious risk of hyperthermia in a relatively brief period. There is also a risk when the metabolic ability of the tissues to respond is impaired, such as in vascular insufficiency.

Pregnancy creates a special problem, as small rises of core temperature (1.5°C) have been noted to alter the growth of fetal neuronal tissue, although in the study quoted, the temperature increases were the result of infectious processes, which may not be entirely relevant to short-term warm water immersion [179]. There have been no reports of fetal abnormalities associated with short low-level increases in core temperature lower than 38.9°C [180]. In general, pregnant women are quite sensitive to core temperature elevations, and usually depart the hot tub well before core temperature increases are near teratogenic levels [180]. McMurray et al have demonstrated the safe maintenance of core temperature during pregnancy when performing aquatic exercise in 30°C water [181-184]. A prudent guideline might be to limit hot tub immersion in 40°C tubs to periods of less than 15 minutes for pregnant women. Aquatic exercise at conventional pool temperatures has been shown to be safe during all trimesters of pregnancy, and facilitate aerobic conditioning, while reducing joint loading [185]. Aquatic exercise at conventional temperatures has also been shown to improve amniotic fluid production, which may be a useful side effect [186]. Typical prenatal programs should include cool to neutral temperature pool aerobic exercise at chest or deeper depth, along with spinal stabilization drills.

APPLICATIONS IN PAIN AND PSYCHIATRIC REHABILITATION

Many effects have been observed anecdotally throughout centuries of aquatic environment use for health maintenance and restoration but they are difficult to study. Predominant among these are the relaxation effect of water immersion and the effect that water immersion has on pain perception. Skin sensory nerve endings are stimulated. Both animal and human studies suggest that sensory overflow may be the mechanism by which pain is less well perceived when the affected body part is immersed in water [187,188]. Pain modulation is consequently affected with a rise in pain threshold, which increases with temperature and water turbulence, producing the proposed therapeutic effect of agitated whirlpool immersion [189,190]. Numerous studies of pain in persons with fibromyalgia have shown statistically significant improvement in pain and function [119,120,122,127,129]. A 1998 study of postoperative pain found warm water immersion treatments to reduce pain and possibly promote wound healing [189].

Studies have shown that aquatic exercise reduces anxiety scores and increases perceived well-being, equal to or superior to the effects noted with land exercise activity [190,191]. Heart rate variability can be analyzed to assess the impact of respiration and autonomic nervous system activity. During relaxation states, heart rate variability demonstrates an autonomic bias toward vagal or parasympathetic nervous system control, whereas during stressed states, sympathetic nervous system influence predominates and heart rate variability decreases [192,193]. The heart rate variability pattern seen during immersion is that of vagal or parasympathetic control, indicating perhaps an inherent bias toward the relaxation state [194]. In work done in the author's laboratory studying heart rate variability, peripheral circulation and core temperature during cool, neutral, and warm water immersion in both younger (ages 18-30) and older (ages 40-65) subjects [195], the authors found a dramatic decrease in sympathetic nervous system activity during warm water immersion, but less so during neutral immersion and an increase in sympathetic bias during cool water immersion. During warm water immersion, the authors also found a significant increase in sympathovagal balance, the interplay between the 2 components of the autonomic nervous system. Both groups of subjects responded similarly, although the older group had a more muted response. During the same study, the authors found consistent decreases in diastolic blood pressures and dramatically increased distal circulation. Aquatic therapy techniques for pain management may include Watsu, an aquatic technique derived from Shiatsu massage and Bad Ragaz, a floating technique focusing on carefully controlled movement and breathing, and gently progressive strengthening combined with aerobic exercise.

APPLICATIONS IN OBESITY REHABILITATION

Aquatic exercise would seem to offer the safest and most protective environment for obese individuals because of the buoyancy effects of immersion, which minimizes the risk of joint injury. With body weight reduced to essentially negligible levels, the immersed individual can exercise vigorously and is capable of producing increases in VO_2max over relatively short periods [196]. Aquatic exercise programs may be highly beneficial in the restoration of fitness in obese patients because of the protective effects against heavy joint loading in

Aquatic Techniques	Neuromuscular disease	Multiple Sclerosis	Parkinsonism	Cerebral Palsy	SCI	Spine and fracture	Obesity	Arthritis	Pregnancy	Athletic rehab	Cross-training
One-on-one therapies	✔	✔	✔	✔	✔	✔				✔	
Respiratory training	✔	✔		✔	✔						
Aquatic spine stabilization						✔			✔	✔	
Deep water joint mobilization					✔	✔		✔		✔	
Watsu	✔	✔		✔	✔						
Group warm water therapies	✔						✔	✔			
Balance programs		✔	✔								
YMCA Arthritis								✔			
Ai Chi			✔			✔		✔			
Yogalates			✔				✔	✔	✔		
Aquarobics							✔	✔	✔		✔
Aquajogging							✔		✔	✔	
Aquarunning etc. (deep water)											✔
Aquatic plyometrics											✔
Aquatic treadmill			✔				✔			✔	✔

Figure 3. Aquatic activities appropriate to rehabilitation issues.

the aquatic environment. On dry land, the ability to achieve an aerobic exercise level for sufficient time to produce a conditioning effect may be difficult in this population, and a program that begins in water and moves to land as strength, endurance, and tolerance builds may be a more effective method of achieving both conditioning and weight loss. A 2006 study compared the effects of a land-based aerobic exercise program with a swimming group and a water-walking group of obese subjects over a 13-week period and found no statistical differences between the groups, all losing weight (5.9 kg) and body fat percentages (3.7%) [197]. The advantages of aquatic exercise also include the heat conductive effects of water, which greatly reduces risk of heat stress when done in cooler pools [196,198]. Aquatic therapy programs for this population should include chest depth or deeper sustained aerobic exercise, alternated with balance and coordination drills.

CONCLUSION

Figure 3 details techniques appropriate for various populations seen in physiatry. As research demonstrates, immersing the body in water produces many physiologic effects that have been used therapeutically over centuries of medical history.

Aquatic exercise and rehabilitation remains vastly underused despite its recent increase in popularity. The health benefits of aquatic exercise have been shown to equal or surpass other forms of exercise including walking and running in studies of the Cooper Clinic database of more than 30,000 men and women [171,199]. These studies assessed overall health benefits of aquatic exercise with land-based walking and running, finding health effects comparable to both land activities, with the potential added value of aquatic activities broader range of clinical applicability in specific populations. Review of the Cooper Clinic database of more than 40,000 men showed exercise swimmers to have less than half the mortality risk of sedentary men, and, surprisingly, approximately half the mortality risk of exercise walkers and runners [200]. All these effects are good reasons to use the aquatic environment in training and rehabilitation.

Aquatic facilities are widely available, and public acceptance is already high, so there are tremendous potential public health benefits to be achieved through programs targeted at the most costly chronic diseases: hypertension, cardiovascular disease, arthritis, and other musculoskeletal pathology, obesity, and deconditioning. Aquatic programs for achieving fitness and restoring function may be designed for a broad range of individuals through an understanding of the fundamental principles of aquatic physics and the application of those principles to human physiology. There are unique attributes to aquatic therapy that seem to both preserve and protect health and longevity.

REFERENCES

1. deVierville J. A history of aquatic rehabilitation. In: Cole A, Becker B, eds. Comprehensive Aquatic Rehabilitation. 2nd ed. Philadelphia PA: Butterworth-Heinemann; 2004:1-18.
2. Smith E. Hydrotherapy in arthritis: Underwater therapy applied to chronic atrophic arthritis. Paper presented at: 14th Annual Session of the American Congress of Physical Therapy; September 11, 1935, 1935; Kansas City, MO.

3. Lowman CL. Technique of Underwater Gymnastics: A Study in Practical Application. Los Angeles: American Publications; 1937.
4. Bloomfield J, Fricker P, Fitch K. Textbook of Science and Medicine in Sport. Champaign IL: Human Kinetics Books; 1992.
5. Poyhonen T, Keskinen KL, Hautala A, Malkia E. Determination of hydrodynamic drag forces and drag coefficients on human leg/foot model during knee exercise. Clin Biomech (Bristol, Avon) 2000;15: 256-260.
6. Bailey DM, Erith SJ, Griffin PJ, et al. Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. J Sports Sci 2007;25:1163-1170.
7. Crowe MJ, O'Connor D, Rudd D. Cold water recovery reduces anaerobic performance. Int J Sports Med 2007;28:994-998.
8. Peiffer JJ, Abbiss CR, Nosaka K, Peake JM, Laursen PB. Effect of cold water immersion after exercise in the heat on muscle function, body temperatures, and vessel diameter. J Sci Med Sport 2007;12:91-96.
9. Arborelius M, Jr., Balldin UI, Lilja B, Lundgren CE. Hemodynamic changes in man during immersion with the head above water. Aerosp Med 1972;43:592-598.
10. Gabrielsen A, Johansen LB, Norsk P. Central cardiovascular pressures during graded water immersion in humans. J Appl Physiol 1993;75: 581-585.
11. Gabrielsen A, Warberg J, Christensen NJ, et al. Arterial pulse pressure and vasopressin release during graded water immersion in humans. Am J Physiol Regul Integr Comp Physiol 2000;278:R1583-R1588.
12. Risch WD, Koubenec HJ, Gauer OH, Lange S. Time course of cardiac distension with rapid immersion in a thermo- neutral bath. Pflugers Arch 1978;374:119-120.
13. Schlant RC, Sonnenblick EH. Normal physiology of the cardiovascular system. In: Hurst J, ed. The Heart. 6th ed. New York: McGraw-Hill; 1986:51.
14. Risch WD, Koubenec HJ, Beckmann U, Lange S, Gauer OH. The effect of graded immersion on heart volume, central venous pressure, pulmonary blood distribution, and heart rate in man. Pflugers Arch 1978;374:115-118.
15. Haffor AS, Mohler JG, Harrison AC. Effects of water immersion on cardiac output of lean and fat male subjects at rest and during exercise. Aviation Space Environ Med 1991;62:123-127.
16. Dressendorfer RH, Morlock JF, Baker DG, Hong SK. Effects of head-out water immersion on cardiorespiratory responses to maximal cycling exercise. Undersea Biomed Res 1976;3:177-187.
17. Weston CF, O'Hare JP, Evans JM, Corrall RJ. Haemodynamic changes in man during immersion in water at different temperatures. Clin Sci 1987;73:613-616.
18. Gleim GW, Nicholas JA. Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. Am J Sports Med 1989;17:248-252.
19. McArdle WD, Katch FI, Katch VL. Functional Capacity of the Cardiovascular System. Exercise Physiology. 3rd ed. Malvern PA: Lea & Febiger; 1991:330-331.
20. Evans BW, Cureton KJ, Purvis JW. Metabolic and circulatory responses to walking and jogging in water. Res Q 1978;49:442-449.
21. Tajima F, Sagawa S, Iwamoto J, Miki K, Claybaugh JR, Shiraki K. Renal and endocrine responses in the elderly during head-out water immersion. Am J Physiol 1988;254:R977-R983.
22. Coruzzi P, Biggi A, Musiari L, Ravanetti C, Novarini A. Renin-aldosterone system suppression during water immersion in renovascular hypertension. Clin Sci (Colch) 1985;68:609-612.
23. Tei C, Horikiri Y, Park JC, et al. Acute hemodynamic improvement by thermal vasodilation in congestive heart failure. Circulation 1995;91: 2582-2590.
24. Tei C, Tanaka N. Thermal vasodilation as a treatment of congestive heart failure: A novel approach. J Cardiol 1996;27:29-30.
25. Tei C, Tanaka N. Comprehensive therapy for congestive heart failure: A novel approach incorporating thermal vasodilation. Intern Med 1996;35:67-69.
26. Cider A, Sunnerhagen KS, Schaufelberger M, Andersson B. Cardiorespiratory effects of warm water immersion in elderly patients with chronic heart failure. Clin Physiol Funct Imaging 2005;25:313-317.
27. Cider A, Svealv BG, Tang MS, Schaufelberger M, Andersson B. Immersion in warm water induces improvement in cardiac function in patients with chronic heart failure. Eur J Heart Fail 2006;8:308-313.
28. Meyer K. Left ventricular dysfunction and chronic heart failure: Should aqua therapy and swimming be allowed? Br J Sports Med 2006;40:817-818.
29. Meyer K, Bucking J. Exercise in heart failure: Should aqua therapy and swimming be allowed? Med Sci Sports Exer 2004;36:2017-2023.
30. Meyer K, Leblanc MC. Aquatic therapies in patients with compromised left ventricular function and heart failure. Clin Invest Med 2008;31:E90-E97.
31. Mussivand T, Alshaer H, Haddad H, et al. Thermal therapy: A viable adjunct in the treatment of heart failure? Congest Heart Failure (Greenwich, Conn) 2008;14:180-186.
32. Hong SK, Cerretelli P, Cruz JC, Rahn H. Mechanics of respiration during submersion in water. J Appl Physiol 1969;27:535-538.
33. Agostoni E, Gurtner G, Torri G, Rahn H. Respiratory mechanics during submersion and negative-pressure breathing. J Appl Physiol 1966;21:251-258.
34. Taylor NA, Morrison JB. Pulmonary flow-resistive work during hydrostatic loading. Acta Physiol Scand 1991;142:307-312.
35. Taylor NA, Morrison JB. Static and dynamic pulmonary compliance during upright immersion. Acta Physiol Scand 1993;149:413-417.
36. Taylor NA, Morrison JB. Static respiratory muscle work during immersion with positive and negative respiratory loading. J Appl Physiol 1999;87:1397-1403.
37. Mangelsdorff G, Borzone G, Leiva A, Martinez A, Lisboa C. [Strength of inspiratory muscles in chronic heart failure and chronic pulmonary obstructive disease]. Rev Med Chil 2001;129:51-59.
38. Dempsey JA, Miller JD, Romer L, Amann M, Smith CA. Exercise-induced respiratory muscle work: Effects on blood flow, fatigue and performance. Adv Exp Med Biol 2008;605:209-212.
39. Dempsey JA, Amann M, Romer LM, Miller JD. Respiratory system determinants of peripheral fatigue and endurance performance. Med Sci Sports Exer 2008;40:457-461.
40. Dempsey JA, Romer L, Rodman J, Miller J, Smith C. Consequences of exercise-induced respiratory muscle work. Resp Physiol Neurobiol 2006;151:242-250.
41. McConnell AK, Romer LM. Respiratory muscle training in healthy humans: Resolving the controversy. Int J Sports Med 2004;25:284-293.
42. Litchke LG, Russian CJ, Lloyd LK, Schmidt EA, Price L, Walker JL. Effects of respiratory resistance training with a concurrent flow device on wheelchair athletes. J Spinal Cord Med 2008;31:65-71.
43. Witt JD, Guenette JA, Rupert JL, McKenzie DC, Sheel AW. Inspiratory muscle training attenuates the human respiratory muscle metaboreflex. J Physiol 2007;584:1019-1028.
44. Lindholm P, Wylegala J, Pendergast DR, Lundgren CE. Resistive respiratory muscle training improves and maintains endurance swimming performance in divers. Undersea Hyperb Med 2007;34:169-180.
45. Johnson MA, Sharpe GR, Brown PI. Inspiratory muscle training improves cycling time-trial performance and anaerobic work capacity but not critical power. Eur J Appl Physiol 2007;101:761-770.
46. Griffiths LA, McConnell AK. The influence of inspiratory and expiratory muscle training upon rowing performance. Eur J Appl Physiol 2007;99:457-466.
47. Padula CA, Yeaw E. Inspiratory muscle training: integrative review. Res Theory Nurs Pract 2006;20:291-304.
48. Guenette JA, Martens AM, Lee AL, et al. Variable effects of respiratory muscle training on cycle exercise performance in men and women. Appl Physiol Nutr Metab 2006;31:159-166.
49. Enright SJ, Unnithan VB, Heward C, Withnall L, Davies DH. Effect of high-intensity inspiratory muscle training on lung volumes, diaphragm thickness, and exercise capacity in subjects who are healthy. Phys Ther 2006;86:345-354.

50. McConnell AK, Sharpe GR. The effect of inspiratory muscle training upon maximum lactate steady-state and blood lactate concentration. Eur J Appl Physiol 2005;94:277-284.
51. Gething AD, Williams M, Davies B. Inspiratory resistive loading improves cycling capacity: A placebo controlled trial. Br J Sports Med 2004;38:730-736.
52. Gething AD, Passfield L, Davies B. The effects of different inspiratory muscle training intensities on exercising heart rate and perceived exertion. Eur J Appl Physiol 2004;92:50-55.
53. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training on time-trial performance in trained cyclists. J Sports Sci 2002;20:547-562.
54. Romer LM, McConnell AK, Jones DA. Inspiratory muscle fatigue in trained cyclists: effects of inspiratory muscle training. Med Sci Sports Exer 2002;34:785-792.
55. Romer LM, McConnell AK, Jones DA. Effects of inspiratory muscle training upon recovery time during high intensity, repetitive sprint activity. Int J Sports Med 2002;23:353-360.
56. Volianitis S, McConnell AK, Koutedakis Y, McNaughton L, Backx K, Jones DA. Inspiratory muscle training improves rowing performance. Med Sci Sports Exer 2001;33:803-809.
57. Sonetti DA, Wetter TJ, Pegelow DF, Dempsey JA. Effects of respiratory muscle training versus placebo on endurance exercise performance. Resp Physiol 2001;127:185-199.
58. Inbar O, Weiner P, Azgad Y, Rotstein A, Weinstein Y. Specific inspiratory muscle training in well-trained endurance athletes. Med Sci Sports Exer 2000;32:1233-1237.
59. Volianitis S, McConnell AK, Koutedakis Y, Jones DA. Specific respiratory warm-up improves rowing performance and exertional dyspnea. Med Sci Sports Exer 2001;33:1189-1193.
60. Clanton TL, Dixon GF, Drake J, Gadek JE. Effects of swim training on lung volumes and inspiratory muscle conditioning. J Appl Physiol 1987;62:39-46.
61. Mickleborough TD, Stager JM, Chatham K, Lindley MR, Ionescu AA. Pulmonary adaptations to swim and inspiratory muscle training. Eur J Appl Physiol 2008;103:635-646.
62. Wells GD, Plyley M, Thomas S, Goodman L, Duffin J. Effects of concurrent inspiratory and expiratory muscle training on respiratory and exercise performance in competitive swimmers. Eur J Appl Physiol 2005;94:527-540.
63. Bjurstrom RL, Schoene RB. Control of ventilation in elite synchronized swimmers. J Appl Physiol 1987;63:1019-1024.
64. Cordain L, Tucker A, Moon D, Stager JM. Lung volumes and maximal respiratory pressures in collegiate swimmers and runners. Res Q Exerc Sport 1990;61:70-74.
65. Courteix D, Obert P, Lecoq AM, Guenon P, Koch G. Effect of intensive swimming training on lung volumes, airway resistance and on the maximal expiratory flow-volume relationship in prepubertal girls. Eur J Appl Physiol Occup Physiol 1997;76:264-269.
66. Engstrom I, Eriksson BO, Karlberg P, Saltin B, Thoren C. Preliminary report on the development of lung volumes in young girl swimmers. Acta Paediatr Scand Suppl 1971;217:73-76.
67. Hill NS, Jacoby C, Farber HW. Effect of an endurance triathlon on pulmonary function. Med Sci Sports Exer 1991;23:1260-1264.
68. Kesavachandran C, Nair HR, Shashidhar S. Lung volumes in swimmers performing different styles of swimming. Ind J Med Sci 2001; 55:669-676.
69. Cordain L, Stager J. Pulmonary structure and function in swimmers. Sports Med (Auckland, N.Z.) 1988;6:271-278.
70. Doherty M, Dimitriou L. Comparison of lung volume in Greek swimmers, land based athletes, and sedentary controls using allometric scaling. Br J Sports Med 1997;31:337-341.
71. Magel JR. Comparison of the physiologic response to varying intensities of submaximal work in tethered swimming and treadmill running. J Sports Med Phys Fitness 1971;11:203-212.
72. Zinman R, Gaultier C. Maximal static pressures and lung volumes in young female swimmers. Resp Physiol 1986;64:229-239.
73. Zinman R, Gaultier C. Maximal static pressures and lung volumes in young female swimmers: One year follow-up. Pediatr Pulmonol 1987; 3:145-148.
74. Dempsey JA, Sheel AW, St Croix CM, Morgan BJ. Respiratory influences on sympathetic vasomotor outflow in humans. Resp Physiol Neurobiol 2002;130:3-20.
75. Sheel AW, Derchak PA, Morgan BJ, Pegelow DF, Jacques AJ, Dempsey JA. Fatiguing inspiratory muscle work causes reflex reduction in resting leg blood flow in humans. J Physiol 2001;537:277-289.
76. Sheel AW, Derchak PA, Pegelow DF, Dempsey JA. Threshold effects of respiratory muscle work on limb vascular resistance. Am J Physiol 2002;282:H1732-1738.
77. Miller JD, Smith CA, Hemauer SJ, Dempsey JA. The effects of inspiratory intrathoracic pressure production on the cardiovascular response to submaximal exercise in health and chronic heart failure. Am J Physiol 2007;292:H580-H592.
78. Watsford ML, Murphy AJ, Pine MJ, Coutts AJ. The effect of habitual exercise on respiratory-muscle function in older adults. J Aging Phys Activity 2005;13:34-44.
79. McConnell AK, Weiner P, Romer LM. Inspiratory muscle training as a tool for the management of patients with COPD. Eur Respir J 2004; 24:510-511; author reply 511.
80. McConnell AK, Romer LM. Dyspnoea in health and obstructive pulmonary disease: The role of respiratory muscle function and training. Sports Med (Auckland, N.Z.) 2004;34:117-132.
81. Covey MK, Larson JL, Wirtz SE, et al. High-intensity inspiratory muscle training in patients with chronic obstructive pulmonary disease and severely reduced function. J Cardiopulm Rehab 2001;21: 231-240.
82. Liaw MY, Lin MC, Cheng PT, Wong MK, Tang FT. Resistive inspiratory muscle training: Its effectiveness in patients with acute complete cervical cord injury. Arch Phys Med Rehabil 2000;81:752-756.
83. O'Brien K, Geddes EL, Reid WD, Brooks D, Crowe J. Inspiratory muscle training compared with other rehabilitation interventions in chronic obstructive pulmonary disease: a systematic review update. J Cardiopulm Rehab Prev 2008;28:128-141.
84. Garcia S, Rocha M, Pinto P, M F Lopes A, Barbara C. Inspiratory muscle training in COPD patients. Rev Portuguesa Pneumol 2008;14:177-194.
85. Magadle R, McConnell AK, Beckerman M, Weiner P. Inspiratory muscle training in pulmonary rehabilitation program in COPD patients. Resp Med 2007;101:1500-1505.
86. Crisafulli E, Costi S, Fabbri LM, Clini EM. Respiratory muscles training in COPD patients. Int J Chronic Obstruct Pulmon Dis 2007;2:19-25.
87. Hill K, Jenkins SC, Philippe DL, et al. High-intensity inspiratory muscle training in COPD. Eur Respir J 2006;27:1119-1128.
88. Adams MA, Chandler LS. Effects of physical therapy program on vital capacity of patients with muscular dystrophy. Phys Ther 1974;54: 494-496.
89. Koessler W, Wanke T, Winkler G, et al. 2 Years' experience with inspiratory muscle training in patients with neuromuscular disorders. Chest 2001;120:765-769.
90. Topin N, Matecki S, Le Bris S, et al. Dose-dependent effect of individualized respiratory muscle training in children with Duchenne muscular dystrophy. Neuromuscul Disord 2002;12:576-583.
91. Wanke T, Toifl K, Merkle M, Formanek D, Lahrmann H, Zwick H. Inspiratory muscle training in patients with Duchenne muscular dystrophy. Chest 1994;105:475-482.
92. Pachalski A, Mekarski T. Effect of swimming on increasing of cardiorespiratory capacity in paraplegics. Paraplegia 1980;18:190-196.
93. Van Houtte S, Vanlandewijck Y, Gosselink R. Respiratory muscle training in persons with spinal cord injury: A systematic review. Resp Med 2006;100:1886-1895.
94. Epstein M. Renal effects of head-out water immersion in humans: A 15-year update. Physiol Rev 1992;72:563-621.
95. Balldin UI, Lundgren CE, Lundvall J, Mellander S. Changes in the elimination of 133 xenon from the anterior tibial muscle in man induced by immersion in water and by shifts in body position. Aerosp Med 1971;42:489-493.

96. Martin WH 3rd, Montgomery J, Snell PG, et al. Cardiovascular adaptations to intense swim training in sedentary middle-aged men and women. Circulation 1987;75:323-330.
97. Ernst E, Saradeth T, Resch KL. A single blind randomized, controlled trial of hydrotherapy for varicose veins. Vasa 1991;20:147-152.
98. Elmstahl S, Lilja B, Bergqvist D, Brunkwall J. Hydrotherapy of patients with intermittent claudication: A novel approach to improve systolic ankle pressure and reduce symptoms. Int Angiol 1995;14:389-394.
99. Pedersen BK, Saltin B. Evidence for prescribing exercise as therapy in chronic disease. Scand J Med Sci Sports 2006;16(Suppl 1):3-63.
100. Sheldahl LM, Tristani FE, Clifford PS, Hughes CV, Sobocinski KA, Morris RD. Effect of head-out water immersion on cardiorespiratory response to dynamic exercise. J Am Coll Cardiol 1987;10:1254-1258.
101. Sheldahl LM, Tristani FE, Clifford PS, Kalbfleisch JH, Smits G, Hughes CV. Effect of head-out water immersion on response to exercise training. J Appl Physiol 1986;60:1878-1881.
102. Svedenhag J, Seger J. Running on land and in water: Comparative exercise physiology. Med Sci Sports Exer 1992;24:1155-1160.
103. Harrison RA, Hillman M, Bulstrode S. Loading of the lower limb when walking partially immersed. Physiotherapy 1992;78:165.
104. Ariyoshi M, Sonoda K, Nagata K, et al. Efficacy of aquatic exercises for patients with low-back pain. Kurume Med J 1999;46:91-96.
105. Balogh Z, Ordogh J, Gasz A, Nemet L, Bender T. Effectiveness of balneotherapy in chronic low back pain—A randomized single-blind controlled follow-up study. Forsch Komplementarmed Klass Naturheilkd 2005;12:196-201.
106. Guillemin F, Constant F, Collin JF, Boulange M. Short and long-term effect of spa therapy in chronic low back pain. Br J Rheumatol 1994;33:148-151.
107. LeFort SM, Hannah TE. Return to work following an aquafitness and muscle strengthening program for the low back injured. Arch Phys Med Rehabil 1994;75:1247-1255.
108. Waller B, Lambeck J, Daly D. Therapeutic aquatic exercise in the treatment of low back pain: a systematic review. Clin Rehabil 2009; 23:3-14.
109. Wang TJ, Belza B, Elaine Thompson F, Whitney JD, Bennett K. Effects of aquatic exercise on flexibility, strength and aerobic fitness in adults with osteoarthritis of the hip or knee. J Adv Nurs 2007;57:141-152.
110. Hinman RS, Heywood SE, Day AR. Aquatic physical therapy for hip and knee osteoarthritis: results of a single-blind randomized controlled trial. Phys Ther 2007;87:32-43.
111. Eversden L, Maggs F, Nightingale P, Jobanputra P. A pragmatic randomised controlled trial of hydrotherapy and land exercises on overall well being and quality of life in rheumatoid arthritis. BMC Musculoskelet Disord 2007;8:23.
112. Bartels EM, Lund H, Hagen KB, Dagfinrud H, Christensen R, Danneskiold-Samsoe B. Aquatic exercise for the treatment of knee and hip osteoarthritis. Cochrane Database Syst Rev 2007(4):CD005523.
113. Lin SY, Davey RC, Cochrane T. Community rehabilitation for older adults with osteoarthritis of the lower limb: A controlled clinical trial. Clin Rehabil 2004;18:92-101.
114. Balint G, Bender T, Szabo E. Spa treatment in arthritis. J Rheumatol 1993;20:1623-1625.
115. Scott DL, Wolman RL. Rest or exercise in inflammatory arthritis? Br J Hosp Med 1992;48:445-447.
116. Hicks JE. Exercise in patients with inflammatory arthritis and connective tissue disease. Rheum Dis Clin North Am 1990;16:845-870.
117. Suomi R, Collier D. Effects of arthritis exercise programs on functional fitness and perceived activities of daily living measures in older adults with arthritis. Arch Phys Med Rehabil 2003;84:1589-1594.
118. Suomi RLS. Effectiveness of Arthritis Foundation Aquatic Program on strength and range of motion in women with arthritis. J Aging Phys Activity 1997:341-351.
119. Assis MR, Silva LE, Alves AM, et al. A randomized controlled trial of deep water running: clinical effectiveness of aquatic exercise to treat fibromyalgia. Arthritis Rheum 2006;55:57-65.
120. Busch A, Schachter CL, Peloso PM, Bombardier C. Exercise for treating fibromyalgia syndrome. Cochrane Database Syst Rev 2002(3): CD003786.
121. Evcik D, Yigit I, Pusak H, Kavuncu V. Effectiveness of aquatic therapy in the treatment of fibromyalgia syndrome: A randomized controlled open study. Rheumatol Int 2008;28:885-890.
122. Gowans SE, deHueck A. Pool exercise for individuals with fibromyalgia. Curr Opin Rheumat 2007;19:168-173.
123. Gusi N, Tomas-Carus P, Hakkinen A, Hakkinen K, Ortega-Alonso A. Exercise in waist-high warm water decreases pain and improves health-related quality of life and strength in the lower extremities in women with fibromyalgia. Arthritis Rheum 2006;55:66-73.
124. Jentoft ES, Kvalvik AG, Mengshoel AM. Effects of pool-based and land-based aerobic exercise on women with fibromyalgia/chronic widespread muscle pain. Arthritis Rheum 2001;45:42-47.
125. Mannerkorpi K, Nyberg B, Ahlmen M, Ekdahl C. Pool exercise combined with an education program for patients with fibromyalgia syndrome. A prospective, randomized study. J Rheumatol 2000;27: 2473-2481.
126. McCain GA. Role of physical fitness training in the fibrositis/fibromyalgia syndrome. Am J Med 1986;81:73-77.
127. McCain GA. Nonmedicinal treatments in primary fibromyalgia. Rheum Dis Clin North Am 1989;15:73-90.
128. Munguia-Izquierdo D, Legaz-Arrese A. Assessment of the effects of aquatic therapy on global symptomatology in patients with fibromyalgia syndrome: A randomized controlled trial. Arch Phys Med Rehabil 2008;89:2250-2257.
129. Tomas-Carus P, Hakkinen A, Gusi N, Leal A, Hakkinen K, Ortega-Alonso A. Aquatic training and detraining on fitness and quality of life in fibromyalgia. Med Sci Sports Exerc 2007;39:1044-1050.
130. Frangolias DD, Rhodes EC. Metabolic responses and mechanisms during water immersion running and exercise. Sports Med (Auckland, N.Z.) 1996;22:38-53.
131. Reilly T, Dowzer CN, Cable NT. The physiology of deep-water running. J Sports Sci 2003;21:959-972.
132. Thein JM, Brody LT. Aquatic-based rehabilitation and training for the elite athlete. J Orthop Sports Phys Ther 1998;27:32-41.
133. Haff G, Becker B, Lindle-Chewning J, et al. Aquatic cross-training for athletes: part 1. National Strength and Conditioning Association Journal 2008;30:18-26.
134. Haff G, Becker B, Lindle-Chewning J, et al. Aquatic cross-training for athletes: part 2. National Strength and Conditioning Association Journal 2008;30:67-83.
135. Wilder RP, Brennan DK. Physiological responses to deep water running in athletes. Sports medicine (Auckland, N.Z.) 1993;16:374-380.
136. Bishop PA, Frazier S, Smith J, Jacobs D. Physiological responses to treadmill and water running. Phys Sports Med 1989;17:87.
137. DeMaere JM, Ruby BC. Effects of deep water and treadmill running on oxygen uptake and energy expenditure in seasonally trained cross country runners. J Sports Med Phys Fitness 1997;37:175-181.
138. Gehring MM, Keller BA, Brehm BA. Water running with and without a flotation vest in competitive and recreational runners. Med Sci Sports Exer 1997;29:1374-1378.
139. Gatti CJ, Young RJ, Glad HL. Effect of water-training in the maintenance of cardiorespiratory endurance of athletes. Br J Sports Med 1979;13:161-164.
140. Bushman BA, Flynn MG, Andres FF, Lambert CP, Taylor MS, Braun WA. Effect of 4 wk of deep water run training on running performance. Med Sci Sports Exer 1997;29:694-699.
141. Wilber RL, Moffatt RJ, Scott BE, Lee DT, Cucuzzo NA. Influence of water run training on the maintenance of aerobic performance. Med Sci Sports Exer 1996;28:1056-1062.
142. Avellini BA, Shapiro Y, Pandolf KB. Cardio-respiratory physical training in water and on land. Eur J Appl Physiol Occup Physiol 1983;50: 255-263.
143. Sheldahl LM, Wann LS, Clifford PS, Tristani FE, Wolf LG, Kalbfleisch JH. Effect of central hypervolemia on cardiac performance during exercise. J Appl Physiol 1984;57:1662-1667.

144. Silvers WM, Rutledge ER, Dolny DG. Peak cardiorespiratory responses during aquatic and land treadmill exercise. Med Sci Sports Exer 2007;39:969-975.

145. Killgore GL, Wilcox AR, Caster BL, Wood TM. A lower-extremities kinematic comparison of deep-water running styles and treadmill running. J Strength Cond Res 2006;20:919-927.

146. Robinson LE, Devor ST, Merrick MA, Buckworth J. The effects of land vs. aquatic plyometrics on power, torque, velocity, and muscle soreness in women. J Strength Cond Res 2004;18:84-91.

147. Kaneda K, Sato D, Wakabayashi H, Hanai A, Nomura T. A comparison of the effects of different water exercise programs on balance ability in elderly people. J Aging Physi Activity 2008;16:381-392.

148. Suomi R, Koceja DM. Postural sway characteristics in women with lower extremity arthritis before and after an aquatic exercise intervention. Arch Phys Med Rehabil 2000;81:780-785.

149. Gillespie LD, Gillespie WJ, Robertson MC, Lamb SE, Cumming RG, Rowe BH. Interventions for preventing falls in elderly people. Cochrane Database Syst Rev 2003;(4):CD000340.

150. Tsuji S, Akama H. Weight training may provide a better stimulus for increasing bone mineral content (BMC) than run and swimming training. Med Sci Sports Exer 1991;23:882-883.

151. Orwoll ES, Ferar J, Oviatt SK, McClung MR, Huntington K. The relationship of swimming exercise to bone mass in men and women. Arch Intern Med 1989;149:2197-2200.

152. Hara S, Yanagi H, Amagai H, Endoh K, Tsuchiya S, Tomura S. Effect of physical activity during teenage years, based on type of sport and duration of exercise, on bone mineral density of young, premenopausal Japanese women. Calcif Tissue Int 2001;68:23-30.

153. Falk B, Bronshtein Z, Zigel L, Constantini NW, Eliakim A. Quantitative ultrasound of the tibia and radius in prepubertal and early-pubertal female athletes. Arch Pediatr Adolesc Med 2003;157:139-143.

154. Falk B, Bronshtein Z, Zigel L, Constantini N, Eliakim A. Higher tibial quantitative ultrasound in young female swimmers. Br J Sports Med 2004;38:461-465.

155. Duncan CS, Blimkie CJ, Cowell CT, Burke ST, Briody JN, Howman-Giles R. Bone mineral density in adolescent female athletes: relationship to exercise type and muscle strength. Med Sci Sports Exer 2002;34:286-294.

156. Derman O, Cinemre A, Kanbur N, Dogan M, Kilic M, Karaduman E. Effect of swimming on bone metabolism in adolescents. Turk J Pediatr 2008;50:149-154.

157. Chu KS, Rhodes EC. Physiological and cardiovascular changes associated with deep water running in the young. Possible implications for the elderly. Sports Med (Auckland, N.Z.) 2001;31:33-46.

158. Bellew JW, Gehrig L. A comparison of bone mineral density in adolescent female swimmers, soccer players, and weight lifters. Pediatr Phys Ther 2006;18:19-22.

159. Taaffe DR, Marcus R. Regional and total body bone mineral density in elite collegiate male swimmers. Journal Sports Med Phys Fitness 1999;39:154-159.

160. Heinrich CH, Going SB, Pamenter RW, Perry CD, Boyden TW, Lohman TG. Bone mineral content of cyclically menstruating female resistance and endurance trained athletes. Med Sci Sports Exer 1990; 22:558-563.

161. Fehling PC, Alekel L, Clasey J, Rector A, Stillman RJ. A comparison of bone mineral densities among female athletes in impact loading and active loading sports. Bone 1995;17:205-210.

162. Emslander HC, Sinaki M, Muhs JM, et al. Bone mass and muscle strength in female college athletes (runners and swimmers). Mayo Clinic Proc 1998;73:1151-1160.

163. Dook JE, James C, Henderson NK, Price RI. Exercise and bone mineral density in mature female athletes.Med Sci Sports Exer 1997; 29:291-296.

164. Creighton DL, Morgan AL, Boardley D, Brolinson PG. Weight-bearing exercise and markers of bone turnover in female athletes. J Appl Physiol 2001;90:565-570.

165. Avlonitou E, Georgiou E, Douskas G, Louizi A. Estimation of body composition in competitive swimmers by means of three different techniques. Int J Sports Med 1997;18:363-368.

166. Magkos F, Kavouras SA, Yannakoulia M, Karipidou M, Sidossi S, Sidossis LS. The bone response to non-weight-bearing exercise is sport-, site-, and sex-specific. Clin J Sport Med 2007;17:123-128.

167. Bravo G, Gauthier P, Roy PM, Payette H, Gaulin P. A weight-bearing, water-based exercise program for osteopenic women: Its impact on bone, functional fitness, and well-being. Arch Phys Med Rehabil 1997;78:1375-1380.

168. Ay A, Yurtkuran M. Evaluation of hormonal response and ultrasonic changes in the heel bone by aquatic exercise in sedentary postmenopausal women. Am J Phys Med Rehabil 2003;82:942-949.

169. Nagata M, Kitagawa J, Miyake T, Nakahara Y. Effects of exercise practice on the maintenance of radius bone mineral density in postmenopausal women. J Physiol Anthropol Appl Human Sci 2002;21: 229-234.

170. Barbosa TM, Garrido MF, Bragada J. Physiological Adaptations to head-out aquatic exercises with different levels of body immersion. J Strength Cond Res 2007;21:1255-1259.

171. Chase NL, Sui X, Blair SN. Comparison of the health aspects of swimming with other types of physical activity and sedentary lifestyle habits. Int J Aquatic Res Edu 2008;2:151-161.

172. Danneskiold-Samsoe B, Lyngberg K, Risum T, Telling M. The effect of water exercise therapy given to patients with rheumatoid arthritis. Scand J Rehabil Med 1987;19:31-35.

173. Gehlsen GM, Grigsby SA, Winant DM. Effects of an aquatic fitness program on the muscular strength and endurance of patients with multiple sclerosis. Phys Ther 1984;64:653-657.

174. Seynnes O, Hue O, Ledrole D, Bernard PL. Adapted physical activity in old age: Effects of a low-intensity training program on isokinetic power and fatigability. Aging Clin Exp Res 2002;14:491-498.

175. Stenstrom CH, Lindell B, Swanberg E, Swanberg P, Harms-Ringdahl K, Nordemar R. Intensive dynamic training in water for rheumatoid arthritis functional class II—A long-term study of effects. Scand J Rheumatol 1991;20:358-365.

176. Templeton MS, Booth DL, O'Kelly WD. Effects of aquatic therapy on joint flexibility and functional ability in subjects with rheumatic disease. J Orthop Sports Phys Ther 1996;23:376-381.

177. Tsourlou T, Benik A, Dipla K, Zafeiridis A, Kellis S. The effects of a twenty-four-week aquatic training program on muscular strength performance in healthy elderly women. J Strength Cond Res 2006; 20:811-818.

178. Allison TG, Reger WE. Comparison of responses of men to immersion in circulating water at 40.0 and 41.5 degrees C. Aviation Space Environ Med 1998;69:845-850.

179. Smith DW, Clarren SK, Harvey MA. Hyperthermia as a possible teratogenic agent. J Pediatr 1978;92:878-883.

180. Harvey MA, McRorie MM, Smith DW. Suggested limits to the use of the hot tub and sauna by pregnant women. Can Med Assoc J 1981; 125:50-53.

181. McMurray RG, Berry MJ, Katz VL, Graetzer DG, Cefalo RC. The thermoregulation of pregnant women during aerobic exercise in the water: A longitudinal approach. Eur J Appl Physiol Occup Physiol 1990;61:119-123.

182. McMurray RG, Katz VL. Thermoregulation in pregnancy. Implications for exercise. Sports Med (Auckland, N.Z.) 1990;10:146-158.

183. McMurray RG, Katz VL, Berry MJ, Cefalo RC. Cardiovascular responses of pregnant women during aerobic exercise in water: A longitudinal study. Int J Sports Med 1988;9:443-447.

184. McMurray RG, Katz VL, Meyer-Goodwin WE, Cefalo RC. Thermoregulation of pregnant women during aerobic exercise on land and in the water. Am J Perinatol 1993;10:178-182.

185. Hartmann S, Bung P. Physical exercise during pregnancy—Physiological considerations and recommendations. J Perinat Med 1999;27: 204-215.

186. San Juan Dertkigil M, Cecatti JG, Sarno MA, Cavalcante SR, Marussi EF. Variation in the amniotic fluid index following moderate physical

activity in water during pregnancy. Acta Obstet Gynecol Scand 2007;86:547-552.
187. Benfield RD, Herman J, Katz VL, Wilson SP, Davis JM. Hydrotherapy in labor. Res Nurs Health 2001;24:57-67.
188. Stolberg A, Frenk H. Development of water-immersion produced analgesia. Dev Psychobiol 1995;28:247-255.
189. Juve Meeker B. Whirlpool therapy on postoperative pain and surgical wound healing: an exploration. Patient Educ Couns 1998;33:39-48.
190. Robiner WN. Psychological and physical reactions to whirlpool baths. J Behav Med 1990;13:157-173.
191. Watanabe E, Takeshima N, Okada A, Inomata K. Comparison of water- and land-based exercise in the reduction of state anxiety among older adults. Percept Mot Skills 2000;91:97-104.
192. Dishman RK, Nakamura Y, Garcia ME, Thompson RW, Dunn AL, Blair SN. Heart rate variability, trait anxiety, and perceived stress among physically fit men and women. Int J Psychophysiol 2000;37:121-133.
193. Pieper S, Brosschot JF, van der Leeden R, Thayer JF. Cardiac effects of momentary assessed worry episodes and stressful events. Psychosom Med 2007;69:901-909.
194. Perini R, Milesi S, Biancardi L, Pendergast DR, Veicsteinas A. Heart rate variability in exercising humans: Effect of water immersion. Eur J Appl Physiol 1998;77:326-332.
195. Becker B, Hildenbrand K, Whitcomb B, Sanders J. Biophysiologic effects of warm water immersion. Int J Aquatic Res Educ 2009;3:24-37.
196. Sheldahl LM. Special ergometric techniques and weight reduction. Med Sci Sports Exer 1986;18:25-30.
197. Gappmaier E, Lake W, Nelson AG, Fisher AG. Aerobic exercise in water versus walking on land: Effects on indices of fat reduction and weight loss of obese women. Med Sci Sports Exer 2006;46:564-569.
198. Xu X, Castellani JW, Santee W, Kolka M. Thermal responses for men with different fat compositions during immersion in cold water at two depths: Prediction versus observation. Eur J Appl Physiol 2007;100:79-88.
199. Chase NL, Sui X, Blair SN. Swimming and all-cause mortality risk compared with running, walking and sedentary habits in men. Int J Aquatic Res Educ 2008;2:213-223.
200. Chase NL, Sui X, Blair SN. Comparison of the health aspects of swimming with other types of physical activity and sedentary lifestyle. Int J Aquatic Res Educ 2008;2:151-161.

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