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Research article

Effects of an 8-month yoga intervention on arterial compliance and muscle strength in premenopausal women

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Abstract
Previous studies have indicated that Yoga exercise has a positive effect on reducing blood pressure and heart rate. However, no randomized controlled studies to date have investigated its effects on arterial compliance. The purpose of this study was to investigate the effects of an 8-month Yoga intervention on arterial compliance and muscle strength in normal premenopausal women 35-50 years of age. Thirty-four women were randomly assigned either to a Yoga exercise group (YE, n = 16) or a control group (CON, n = 18). Participants in YE group performed 60 minutes of an Ashtanga Yoga series 2 times/week with one day between sessions for 8 months. Each Yoga session consisted of 15 minutes of warm-up exercises, 35 minutes of Ashtanga Yoga postures and 10 minutes of cool-down with relaxation; and the session intensity was progressively increased during the 8 months. Participants in CON were encouraged to maintain their normal daily lifestyles monitored by the bone-specific physical activity questionnaire at 2 month intervals for 8 months. Arterial compliance (pulse contour analysis) and muscle strength (1 Repetition Maximum) were assessed at baseline and after the intervention. Arterial compliance of the large and small arteries was not affected by the 8 month Yoga training ($p > 0.05$). Also, there were no significant ($p > 0.05$) group, time, or group × time interaction effects for cardiovascular variables. YE group significantly ($p < 0.01$) improved leg press muscle strength compared to CON (11.4% vs. -6.5%). Eight months of Ashtanga Yoga training was beneficial for improving leg press strength, but not arterial compliance in premenopausal women.

Key words: Ashtanga Yoga, arterial stiffness, blood pressure.

Introduction

Arterial compliance (AC) describes the ability of an artery to distend in response to a change in intravascular pressure (Gates and Seals, 2006); and its impairment is strongly associated with cardiovascular disease (CVD) (Cohn et al., 1995; Lehmann et al., 1998). Thus, AC may be an important risk factor for CVD (Arnett et al., 1994) as well as an early marker to prevent subsequent cardiovascular events (Cohn, 1999). AC can be measured by noninvasive methodologies such as pulse wave velocity (PWV), a technique that determines the change in artery diameter relative to distending pressure using ultrasound and applanation tonometry; and the assessment arterial pressure waveforms (Oliver and Webb, 2003). Pulse contour analysis uses a modified Windkessel model to analyze components of the diastolic waveform to determine a large artery elasticity index (C1, capacitive arterial compliance) and a small artery elasticity index (C2, oscillatory or reflective arterial compliance) (Finkelstein and Cohn, 1992; Rietzschel et al., 2001). This method also measures hemodynamic variables that are related to blood vessel function, including heart rate, systolic and diastolic blood pressures, pulse pressure (PP), systemic vascular resistance (SVR), and total vascular impedance (TVI). Winer et al. (2001) reported that SVR and TVI were inversely correlated with arterial elasticity variables and they both were significant predictors of C1 and C2 in men and women (18-36 years). Other studies have shown that both C1 and C2 are highly associated with blood pressure (BP) (Ge et al., 2008; Resnick et al., 2000; Winer et al., 2001) and pulse pressure (O'Rourke, 1990). Since decreased AC is an independent predictor for CVD (Rowe, 1987; Hodes et al., 1995), it is important to develop interventions that improve AC. Regular aerobic exercise is associated with positive effects on blood vessel function, such as increased arterial compliance (Boreham et al., 2004; Cameron and Dart,1994), and attenuation of the age-related increase in arterial stiffness (Seals et al., 2008). The mode and intensity of exercise are important factors for modifying AC, as several studies reported decreases in AC with high intensity resistance training (Cortez-Cooper et al., 2005; Miyachi et al., 2004).

Yoga is a non-traditional form of exercise that has been shown to have positive effects on various health components. For example, Yoga may decrease CVD risk by reducing BP in both clinical and healthy populations (Field, 2011; Yang, 2007). Muscle function also may be improved with Yoga, as Tran et al. (2001) reported that the 8 week Hatha Yoga training increased muscular strength in young participants. However, it is not clear whether Yoga can elicit a sufficient intensity stimulus to improve AC. Only one cross-sectional study (Duren et al., 2008) examined the influence of physical activity and Yoga on central arterial stiffness in middle-aged adults using carotid artery distensibility and PWV. They found that Yoga and aerobic groups did not differ in arterial stiffness (inverse of AC) measures, but they both had more favorable carotid artery distensibility and PWV values than the sedentary group. Generally, Yoga is considered to be a low intensity physical activity. For example, Hagins et al. (2007) reported that the metabolic costs of Yoga averaged across the entire session represent low levels of physical activity. In addition, there are many different types of Yoga in terms of breathing exercises, postures, and spirituality. Hatha Yoga is more likely to be a slow-paced stretching, whereas Ashtanga Yoga (referred as power Yoga) is a vigorous intensity style of practice (Hayes and Chase, 2010). Cowen et al. (2007) found that Ashtanga Yoga elicited significantly higher

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heart rates than either Hatha or gentle Yoga, therefore, this high intensity style of Yoga may be more likely to elicit positive changes in AC than the other types of Yoga. Since 72% of Yoga participants are women (Yoga Journal, 2008), we targeted middle-aged women who may be at higher risk of developing CVD for this randomized control intervention study. Therefore, the primary purpose of this study was to investigate the effects of an 8-month Yoga intervention on AC in premenopausal women between the ages of 35-50 years. Also, a secondary purpose was to measure muscular strength by one repetition maximum (1RM) to determine whether progressively increasing Sun Salutations (SS) over the 8 month intervention improved upper and lower body strength. We hypothesized that AC and muscle strength would increase in Yoga group compared to control group.

Methods

Participants

Healthy premenopausal women between the ages of 35 and 50 years were recruited from the University of Oklahoma and the surrounding Oklahoma City metro area via flyers posted in public areas, an advertisement in local newspapers, and mailed to prospective participants at the University of Oklahoma, Norman campus. Participants had not been engaged in resistance training or in Yoga exercise for at least 12 months prior to the study. Participants were free of chronic back or joint problems, cardiovascular disease, non-smokers, not pregnant, not taking antihypertensive drugs. Participants were not taking hormonal contraception and they self-reported having regular menstrual cycles. They were medically stable, ambulatory, and capable of undergoing physical strength testing and training. All methods and procedures were approved by the University of Oklahoma Institutional Review Board.

A total of 91 women initially volunteered for the study, however, 44 potential participants were excluded as they did not meet the inclusion/exclusion criteria. After recruitment, 47 participants were originally enrolled and randomized to Yoga (n = 27) and control (n = 20) groups. Thirteen participants did not complete the intervention: 4 because of time commitments; 6 because of recent diagnoses of serious migraine, high blood pressure, hypothyroidism, tumor, menopausal symptoms, or chronic fatigue; 1 participant was excluded from the analyses due to poor attendance (below 80%); 1 could not be contacted, and 1 did not want to participate in post testing due to personal reasons. None of the reasons for dropping out were related to Yoga intervention. Thirty-four participants (YE, n = 16; CON, n = 18) completed the entire 32 weeks (Figure 1). The average attendance rate of YE participants was 92.6% for the 8 months.

All participants visited the Bone Density Laboratory at the University of Oklahoma to complete the informed consent form, health and menstrual history questionnaires. Participants in CON group did not receive the Yoga exercise intervention, and they were encouraged to maintain normal daily physical activities. We

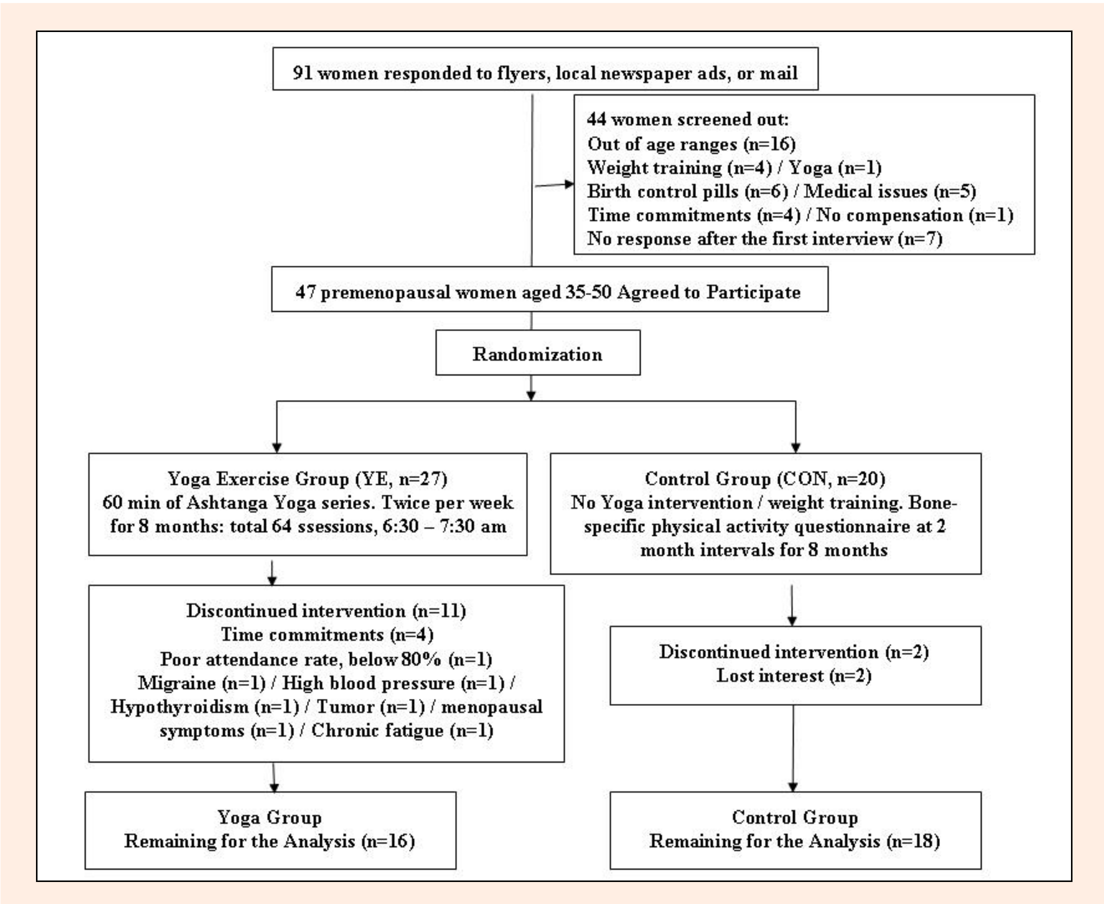

Figure 1. Flow chart of the recruitment process and research design.

administered the bone-specific physical activity questionnaire (BPAQ)(Weeks and Beck, 2008) at 2 month intervals for 8 months to monitor changes in physical activity during the study (data not shown).

Body composition

Dual Energy X-ray Absorptiometry (DXA, GE Lunar Prodigy) was used to measure body composition of the whole body. The DXA was calibrated daily following the Quality Assurance (QA) calibration procedures to monitor the machine's performance and to ensure no machine drift during the intervention period. All metal, plastic objects or other high density objects associated with the participant's clothes were removed. The participants were asked to lie down on the DXA table in the supine position. The participant was centered on the table within 60 cm of the scanning area. The participant's shoulders and hips were centered, and the hands were placed by the side of the legs. Velcro straps were placed around the knees and ankles to hold feet together for the duration of the scan. A single qualified technician performed all of the total body scans at baseline and after training. Short term precision for body composition variables was determined by a laboratory study of 15 adult men and women (20 – 50 years old) measured on 2 separate days within one week. The coefficients of variation (CV %) for percent fat and total fat mass variables are 1.87% and 1.62%, respectively.

Pulse contour analysis

We measured AC using the HDI/Pulsewave™CR-2000 and the CVProfilor™ DO-2020 CardioVascular Profiling System (Hypertension Diagnostic, Inc., Eagan, Minnesota, USA). Participants came to the laboratory in the morning with a minimum of 8 hours fast to avoid diurnal variation in the cardiovascular variables. A refractometer (VEE GEE®, Model CLX-1) was used to measure urine specific gravity for hydration status. All participants were within the normal range (1.001-1.030). They also were instructed to abstain from caffeine and vigorous exercises prior to the testing. After the participant's height and weight were obtained using a wall stadiometer and a Tanita BWB-800 digital scale (Tanita Corporation of America, Inc., Arlington Heights, IL), each participant rested in a supine position on a padded table for approximately 5 minutes. An appropriate-sized cuff was wrapped around the participant's upper left arm. A rigid plastic wrist stabilizer was placed on the participant's right wrist to minimize movement and stabilize the radial artery during the three 30-s collection of blood pressure waveform data. A noninvasive Arterial PulseWave™ Sensor was positioned on the surface of the skin overlying the right radial artery at the point of strongest pulsation to capture an analog blood pressure waveform. The sensor was adjusted to the highest relative signal strength without occluding the artery.

Three consecutive trials were averaged for the subsequent analyses and the large and small AC measurements were obtained during 30 seconds of blood pressure waveform collections. Other cardiovascular parameters that were assessed by this instrument during the testing included resting systolic and diastolic BP, pulse pressure (PP), resting heart rate (RHR), SVR, and TVI. This technique has been validated with invasive measurements (Cohn et al., 1995) and has been shown to be reproducible in healthy subjects (Zimlichman et al., 2005). In our laboratory based on a precision study of adult men and women (n=9), the CV% for large artery and small artery compliance variables are 6.7% and 10.6%, respectively, and the test-retest intra class correlation coefficients are 0.918 for large artery compliance and 0.985 for small artery compliance.

Strength testing

Participants in the YE and CON groups performed 1RM testing to determine their upper and lower body muscle strength using our standardized laboratory procedures (Seo et al., in press). Specifically, participants began with a proper warm-up of either walking on a treadmill or riding the stationary bicycle for 5 minutes. After familiarization with resistance machines (Cybex Inc., Medway, MA), participants performed lat pull down, shoulder press, and bicep curl for upper body and leg press, knee extension, and knee flexion isotonic resistance exercises for lower body at 8-10 repetitions of a light load (~ 50% of predicted 1RM) for warm-up. Following a 1 minute rest period, participants performed a load (~80% of estimated 1RM) through the full range of motion. 1RM was determined within 5 attempts. 1RM testing was supervised and recorded by trained staff.

Yoga exercise training

We offered 64 Yoga sessions on Mondays and Wednesdays each week, from 6:30 to 7:30 AM for 8 months. Participants performed 60 minutes of an Ashtanga Yoga series and each Yoga session consisted of 15 minutes of warm-up exercises, 35 minutes of Ashtanga Yoga postures and 10 minutes of cool-down with relaxation. Dynamic and static stretching was introduced during the warm-up at the beginning with either sitting, supine, or standing postures. A certified Yoga instructor led all Yoga sessions and precisely taught Yoga postures with consistent instructions. Modified postures were taught to participants who were not able to perform the standard postures. We provided the Yoga blocks and straps for participants who were willing to use them. Thirty-five minutes of postures consisted of SS (I, II), standing, balancing, sitting, and supine postures. During the first 4 months, SS I (Mountain, Prayer, Upward hand, Standing forward bend, Plank, Four-limbed staff, Upward-facing dog, Downward-facing dog, Standing forward bend, Upward hand, Prayer poses) with a triangle pose and warrior series were instructed and jumping was progressively included. SS II (Mountain, Prayer, Chair, Standing forward bend, Half sand forward bend, Plank, Four-limbed staff, Upward-facing dog, Downward-facing dog, Warrior I / II / Reverse warrior / Side angle (Left, Right side), Plank, Four-limbed staff, Upward-facing dog, Downward-facing dog, Half standing forward bend, Standing forward bend, Chair, Prayer poses) including jumping was performed during the last 4 months. We progressively increased the session intensity by adding the number of SS and jumping during the 8-month intervention (Table 1).

The postures were static and held for approximately five to ten breaths each. All Yoga postures were followed by the English name and instructions for the postures were obtained from Hatha Yoga Illustrated (Kirk et al., 2004).
On the first day of the Yoga intervention, participants were informed about proper Yoga attire and safety consideration for performing Yoga postures. Participants were encouraged to inform the Yoga instructor prior to class if they had any medical or other conditions such as muscle soreness that could affect their performance. Participants self-monitored their exercise intensity by measuring their HR using the palpation method (radial artery) and by recording their Ratings of Perceived Exertion (RPE) after the SS exercises. During the training program, the average RPE ranged from 12 (light exertion) to 14 (somewhat hard) and about half of the women had exercise HR between 60-80% of their estimated maximum HR (HR_{max} = 220 – age) (data not shown).

Table 1. Yoga postures and sun salutations monthly progression.

Months	Mondays	Wednesdays
1	Sitting warm-up	Sitting warm-up
	SS I (3)*	SS I (3)
	Triangle pose	Triangle pose
	Warrior II / Reverse warrior pose	Warrior II / Reverse warrior pose
	Side angle pose	Side angle pose
	Wide legged forward bend pose	Wide legged forward bend pose
	Single-leg balance pose	Single-leg balance pose
	Tree pose	Tree pose
	Side plank pose	Side plank pose
	Bridge pose	Bridge pose
	Double legs lift	Double legs lift
	Cool down	Cool down
2	Sitting warm-up	Standing warm-up
	SS I (4)	SS I (4)
	Triangle pose	Triangle pose
	Warrior II / Reverse warrior pose	Warrior II / Reverse warrior pose
	Side angle pose	Side angle pose
	Wide legged forward bend pose	Wide legged forward bend pose
	Tree pose	Tree pose
	Standing forward bend pose	Standing forward bend pose
	Cat & Cow pose	Cat & Cow pose
	Boat pose	Side plank pose
	Rolling like a ball / Double legs lift / Dynamic Bridge	Rolling like a ball / Double legs lift / Dynamic Bridge
	Cool down	Cool down
3	Sitting warm-up	Standing warm-up
	SS I (5)	SS I (5)
	Triangle pose	Triangle pose
	Warrior I / II / Reverse warrior pose	Warrior I / II / Reverse warrior pose
	Side angle pose	Side angle pose
	Extended / Revolved Extended side angle pose	Extended / Revolved Extended side angle pose
	Wide legged forward bend pose	Wide legged forward bend pose
	Tree pose	Tree pose
	Chair pose	Chair pose
	Side plank pose	Side plank pose
	Dolphin pose / Dolphin plank	Dolphin pose / Dolphin plank
	Rolling like a ball / Double legs lift / Dynamic Bridge	Rolling like a ball / Double legs lift / Dynamic Bridge
	Cool down	Cool down
4	Sitting warm-up	Standing warm-up
	SS I (6)	SS I (6)
	Triangle pose	Triangle pose
	Warrior II / Reverse warrior pose	Warrior II / Reverse warrior pose
	Side angle pose	Side angle pose
	Extended / Revolve Extended side angle pose	Extended / Revolve Extended side angle pose
	Wide legged forward bend pose	Wide legged forward bend pose
	Variation of tree pose	Gate pose
	Forward bending pose	Low lunge pose
	Seated forward bend pose	Rolling like a ball
	Boat pose	Plow pose
	Side plank pose	Sphinx pose
	Sphinx pose	Dolphin pose / Dolphin plank
	Dolphin pose / Dolphin plank	Bow pose
	Roll-up / Crisscross crunches / Dynamic bridge	Roll-up / Crisscross crunches / Dynamic bridge
	Cool down	Cool down

* SS: Sun Salutations (# of SS performed)

Table 1. Continued.

Months	Mondays	Wednesdays
5	Supine warm-up SS II (4) Triangle pose Wide legged forward bend pose Variation of tree pose Chair pose Mermaid pose Side plank pose Side reclining leg lift pose Dolphin pose / Dolphin plank Bow pose Roll-up / Crisscross crunches / Dynamic bridge Cool down	Sitting warm-up SS II (4) Triangle pose Wide legged forward bend pose Revolved side angle pose Standing forward bend pose Wide angle pose Rolling like a ball Plow pose Side plank pose Dolphin pose / Dolphin plank Roll-up / Crisscross crunches / Dynamic bridge Cool down
6	Supine warm-up routine SS II (5) Triangle pose / Revolved triangle pose Intense side stretch pose Eagle pose Standing forward bend pose Camel pose Side plank pose Bow pose Roll-up / Crisscross crunches / Dynamic bridge Cool down	Sitting & Standing warm-up SS II (5) Triangle pose / Revolved triangle pose Intense side stretch pose Eagle pose Rolling like a ball Fish pose Plow pose Shoulder stand pose Roll-up / Crisscross crunches / Dynamic bridge Cool down
7	Supine warm-up SS II (6) Triangle pose / Revolved triangle pose Half moon pose Warrior III Tree pose Standing forward bend pose Camel pose Side plank pose Bow pose Roll-up / Crisscross crunches / Dynamic bridge Cool down	Sitting & Standing warm-up SS II (6) Triangle pose / Revolved triangle pose Half moon pose Warrior III Eagle pose Cow face pose Fish pose Plow pose Shoulder stand pose Roll-up / Crisscross crunches / Dynamic bridge Cool down
8	Supine warm-up SS II (7) Triangle pose / Revolved triangle pose Half moon pose Warrior III Eagle pose Standing forward bend pose Camel pose Side plank pose Dolphin pose / Dolphin plank Bow pose Roll-up / Crisscross crunches / Dynamic bridge Cool down	Standing warm-up SS II (7) Triangle pose / Revolved triangle pose Half moon pose Warrior III Eagle pose Gate pose Low lunge pose Fish pose Plow pose Shoulder stand pose Roll-up / Crisscross crunches / Dynamic bridge Cool down

*SS: Sun Salutations (# of SS performed)

Statistical analysis

All descriptive data for the dependent variables are presented as mean ± standard error (SE). Group differences in baseline values for the dependent variables were determined by independent t-tests. If there were significant group differences at baseline, ANCOVA was used to compare group differences in the post variables using the baseline variable as a covariate. If there were no group differences at baseline, two-way mixed factorial ANOVA [Group (YE vs. CON) × Time (pre vs. post)] with repeated measures was used to analyze groups responses to the intervention. If a significant group × time interaction occurred, paired t-tests were used as post-hoc tests to determine significant time differences within each group. The percent changes in dependent variables were calculated ($\%\Delta = [(\text{post} - \text{pre}) / \text{pre}] \times 100$). An independent t-test was used to examine significant group differences in the percent change variables. All statistical procedures were performed using SPSS for Windows 17.0 version (Chicago, IL). The level of significance was set at $p \leq 0.05$.

Results

Participant characteristics

Table 2 shows the means ± SE for the baseline physical characteristics and body composition variables for each group. There were no significant group differences for the physical characteristics or body composition variables at baseline ($p > 0.05$).

Table 2. Physical characteristics for YE and CON groups at the beginning of study. Values are means (± SE).

Variable	YE (n = 16)	CON (n = 18)
Age (years)	45.7 (1.0)	43.2 (1.0)
Height (m)	1.63 (.01)	1.61 (.01)
Weight (kg)	69.7 (3.3)	70.0 (2.2)
BMI (kg·m^{-2})	26.0 (1.0)	27.0 (1.0)
FM (kg)	27.8 (2.2)	28.2 (2.0)
Body fat (%)	39.4 (1.6)	39.8 (1.9)

YE: Yoga Exercise, CON: Control, BMI: Body Mass Index, FM: Fat Mass

Arterial compliance and cardiovascular variables

Baseline mean values for AC and cardiovascular variables did not differ between groups ($p > 0.05$). The large artery and small artery compliance responses to training are depicted in Figures 2 and 3, respectively. There were no significant ($p > 0.05$) group, time, or group × time interaction effects for either AC variables. Table 3 shows the pre and post training means for the blood pressure variables, RHR, SVR, and TVI. There were no significant ($p > 0.05$) group, time, or group × time interactions for any of the cardiovascular variables.

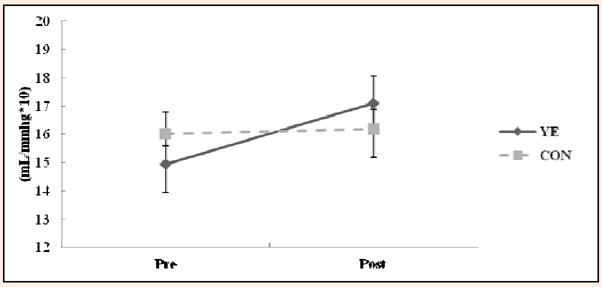

Figure 2. Large artery compliance responses to 32 weeks of training. Values are means ± SE. YE: Yoga Exercise, CON: Control, No significant group, time, or group × time interaction effects ($p > 0.05$).

Muscle strength

Table 4 shows the baseline and post testing muscle strength 1RM values. At baseline, there were significant group differences in lat pull down, shoulder press, and leg press ($p < 0.05$). After adjusting baseline mean differences using ANCOVA, there were no group difference for lat pull down and shoulder press after the 8 months of training ($p > 0.05$). However, there was significant main effect for leg press ($p < 0.01$). There were no time or group × time interaction effects observed for bicep curl, knee extension, and knee flexion ($p > 0.05$). There were significant group differences ($p < 0.01$) in percent changes for leg press as the YE group had a significantly greater relative increase compared to the CON group (11.4 ± 4.2 % vs. -6.5 ± 2.7%). There were no significant differences in percent changes in lat pull down, shoulder press, bicep curl, knee extension, and knee flexion from baseline ($p > 0.05$) (Figure 4).

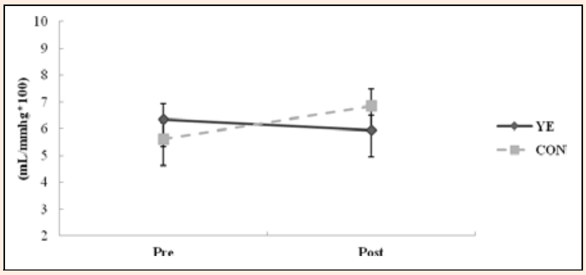

Figure 3. Small artery compliance responses to 32 weeks of training. Values are means ± SE. YE: Yoga Exercise, CON: Control, No significant group, time, or group × time interaction effects ($p > 0.05$).

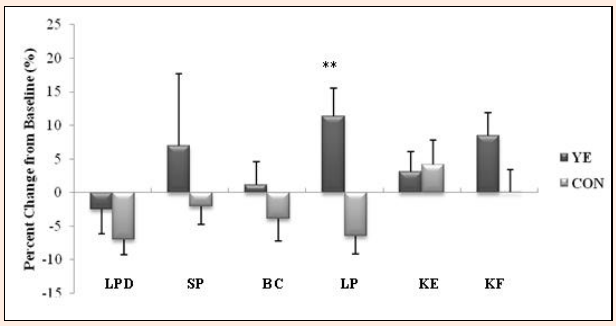

Figure 4. Percent changes in muscle strength for each group. Values are means ± SE. YE: Yoga Exercise, CON: Control, LPD: Lat Pull Down, SP: Shoulder Press, BC: Bicep curl, LP: Leg Press, KE: Knee Extension, KF: Knee Flexion. ** $p < 0.01$ Significant group difference.

Discussion

To our knowledge, our study is the first randomized controlled trial to investigate the effects of Yoga exercise on

Table 3. Cardiovascular variables before and after training. Values are means (± SE).

Variable	YE (n=16)		CON (n=18)	
	Baseline	Post	Baseline	Post
SBP (mmHg)	121.6 (3.4)	121.2 (3.8)	119.3 (2.4)	116.7 (2.0)
DBP (mmHg)	71.4 (2.0)	71.4 (2.5)	70.6 (1.6)	69.6 (7.1)
PP (mmHg)	49.9 (2.0)	49.8 (1.8)	48.8 (1.7)	47.3 (1.2)
RHR (beats/min)	65.9 (2.0)	65.9 (2.3)	65.8 (2.5)	66.1 (2.4)
SVR (dyne·sec·cm^{-5})	1341.4 (44.1)	1311.7 (47.8)	1349.2 (37.8)	1325.5 (44.9)
TVI (dyne·sec·cm^{-5})	130.2 (6.7)	119.1 (6.2)	125.1 (7.0)	121.0 (4.1)

YE: Yoga Exercise, CON: Control, SBP: Systolic Blood Pressure, DBP: Diastolic Blood Pressure, PP: Pulse Pressure, RHR: Resting Heart Rate, SVR: Systemic Vascular Resistance, TVI: Total Vascular Impedance. No significant group, time, or group × time interaction effects ($p > 0.05$).

Table 4. Muscle strength before and after 8 months of training. Values are means (± SE).

Variable		YE (n=16)		CON (n=18)	
		Baseline	Post	Baseline	Post
Upper Body	**Lat Pull Down***	34.7 (2.1)	33.7 (2.1)	40.7 (1.6)	37.7 (1.5)
	Shoulder Press*	31.2 (2.6)	30.3 (2.7)	37.8 (1.3)	36.9 (1.5)
	Biceps Curl	16.3 (1.2)	16.5 (1.4)	17.6 (1.1)	16.6 (1.0)
Lower Body	**Leg Press****	89.4 (5.7)	98.5 (6.3)	106.4 (4.9)	98.1 (3.8)
	Knee Extension	42.9 (3.4)	43.8 (3.4)	44.9 (2.4)	45.7 (1.8)
	Knee Flexion	44.1 (2.4)	47.0 (2.1)	48.0 (1.7)	47.5 (1.6)

All values expressed in kg. YE: Yoga Exercise, CON: Control. * $p < 0.05$ Baseline group differences. ** $p < 0.01$ Significant time effect.

AC in healthy premenopausal women. We did not find any significant changes in either large or small artery-compliance or in cardiovascular variables after 32 weeks of supervised Yoga training. There is only one report on the effect of Yoga on central arterial stiffness measured by PWV (Duren et al., 2008) that found no differences in carotid artery distensibility , PWV, and PP between Yoga (n = 8) and aerobic (n=8) groups compared to the sedentary (n = 10) group. In our study, the 8 month Yoga intervention did not alter HR or systolic/diastolic blood pressure.

In spite of its growing popularity, there have been limited intervention studies on physiological responses related to Yoga exercise. Our findings contradict previous studies reporting that Yoga exercise had a positive cardiovascular effects by reducing BP and HR (Innes et al., 2005; Madanmohan et al., 2008; Yogendra et al., 2004). Madanmohan et al. (2008) found that Yoga training 6 times per week for 6 weeks decreased diastolic pressure and increased pulse pressure in both young males and females. Damodaran et al. (2002) reported daily Yoga practice one hour for three months significantly decreased BP in middle aged men and women with mild to moderate essential hypertension. McCaffrey et al. (2005) also found Yoga exercise, 3 times a week for 8 weeks showed reductions in BP and HR in hypertensive participants. One possible explanation for the lack of agreement of our results with those studies is that they focused on clinical populations, whereas our target population was healthy premenopausal women who did not have any cardiovascular diseases. In addition, since there are many different types of Yoga, it is difficult to compare the results of these studies to our findings.

Another issue to consider is whether the intensity of Yoga exercise is sufficient to increase AC. Previous studies have shown positive effects on AC when subjects performed at approximately 50-70% of maximal oxygen consumption or HR reserve (Cameron and Dart, 1994; Tanaka et al., 1998; 2000). In a study by Hagins et al. (2007), a typical Hatha Yoga session did not meet the ACSM recommendations for levels of physical activity to improve or maintain health or cardiorespiratory fitness that was inversely associated with arterial stiffness (Boreham et al., 2004; Cameron and Dart, 1994). They suggested that increasing the number of Sun Salutations may be a way to increase the intensity high enough to improve cardiorespiratory fitness. Sun Salutations are used as a warm-up routine for most Yoga practices and it consists of more than 10 dynamic postures. In contrast, two Yoga classes per week for 8 weeks significantly increased cardiorespiratory endurance determined by a maximal treadmill exercise test in healthy young subjects (Tran et al., 2001). Only two to three cycles of SS were performed with various postures for 8 weeks. In our study, the 8 month Yoga program was designed to elicit an exercise intensity sufficient to increase AC, and the progression of the intensity was implemented by increasing the number of SS performed during the sessions. Our 8 month Yoga program followed the most common Yoga class routines consisting of sitting, standing, and lying postures. SS I was performed with relatively easy postures for the first 4 months. Subjects performed SS II with advanced postures during the last 4 months. Although we increased the session intensity by adding to the number of SS each month, it still may not have been sufficient intensity or duration to elicit improvements in AC.

In the present study, subjects in the YE and CON groups performed 1RM testing to determine their upper and lower body muscle strength using isotonic exercises. Yoga exercises are mostly associated with isometric movements including both eccentric and concentric muscle contractions. The Yoga sequences can be dynamic movements depending on different types of Yoga. Many Yoga exercises include weight-bearing balance and static postures such as Triangle, Tree and Warrior series as well as non-weight-bearing postures. These movements, therefore, incorporate both open (a single joint/muscle group) and closed (multiple joints/muscle groups) chain exercises for upper and lower body. In the current study, we used isotonic resistance exercises (leg press, knee extension, knee flexion) for lower body to measure multiple muscle groups related to closed chain exercises. We did not find any significant improvements except for leg press strength that increased in YE group and decreased in the CON group. Although subjects performed dynamic sun salutation series including plank and downward facing dog postures, those static postures did not increase any of upper body strength. Tran et al. (2001) examined the effects of the 8 week Hatha Yoga training on muscular strength. They found isokinetic muscular strength for elbow extension, elbow flexion, and knee extension increased by 31%, 19%, and 28%, respectively, whereas isometric muscular endurance for knee flexion increased 57%. In contrast to our study, their participants were much younger (18-27 years) and Yoga sessions were offered four times per week for 8 weeks, instead of twice a week. Also, we were only able to assess isotonic strength, thus, the lack of agreement between these findings may be explained in part by the older age of our participants, the different mode of muscle strength measurements and lower frequency of training.

Several limitations of this study should be noted. A major limitation of the present study is that we had a large dropout rate in the YE group (41%), whereas the CON group only had a 10% dropout rate during the intervention. The reasons for participant dropout, however, were not related to the Yoga exercise intervention itself. Although we chose the most powerful type of Yoga, Ashtanga, with increased number of SS during the intervention period, individual participants may have experienced varying intensities because some of participants performed the modified postures. In Yoga, variations of Yoga postures, sequences, and duration of each movement are dependent on individual's flexibility and muscle strength. Most Yoga postures are predominately associated with isometric movements, but we measured muscle strength using isotonic exercises. Thus, future Yoga studies should assess isometric strength, such as hand grip, elbow flexion, isometric knee extension, isometric trunk extension or flexion.

Conclusion

Arterial compliance of the large and small arteries was not affected by the 8 month Yoga training in healthy premenopausal women. However, leg press muscular strength improved in the Yoga participants.

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References

Arnett, D.K., Evans, G.W. and Riley, W.A. (1994) Arterial stiffness: a new cardiovascular risk factor? *American Journal of Epidemiology* **140,** 669-682.

Boreham, C.A., Ferreira, I., Twisk, J.W., Gallagher, A.M., Savage, M.J. and Murray, L.J. (2004) Cardiorespiratory fitness, physical activity, and arterial stiffness: the Northern Ireland Young Hearts Project. *Hypertension* **44,** 721-726.

Cade, W.T., Reeds, D.N., Mondy, K.E., Overton, E.T., Grassino, J., Tucker, S., Bopp, C., Laciny, E., Hubert, S., Lassa-Claxton, S. and Yarasheski, K.E. (2010) Yoga lifestyle intervention reduces blood pressure in HIV-infected adults with cardiovascular disease risk factors. *HIV Medicine* **11,** 379-388.

Cameron, J.D. and Dart, A.M. (1994) Exercise training increases total systemic arterial comliance in humans. *The American Journal of Physiology* **266,** 693-701.

Cohn, J.N. (1999) Vascular wall function as a risk marker for cardiovascular disease. *Journal of Hypertension. Supplement* **17,** S41-44.

Cohn, J.N., Finkelstein, S., Mcveigh, G., Morgan, D., Lemay, L., Robinson, J. and Mock, J. (1995) Noninvasive pulse wave analysis for the early detection of vascular disease. *Hypertension* **26,** 503-508.

Cortez-Cooper, M.Y., Devan, A.E., Anton, M.M., Farrar, R.P., Beckwith, K.A., Todd, J.S. and Tanaka, H. (2005) Effects of high intensity resistance training on arterial stiffness and wave reflection in women. *American Journal of Hypertension* **18,** 930-934.

Cowen, V.S. and Adams, T.B. (2007) Heart rate in yoga asana practice: A comparison of styles. *Journal of Bodywork &Movement Therapies* **11,** 91-95.

Damodaran, A., Malathi, A., Patil, N., Shah, N., Suryavansihi and Marathe, S. (2002) Therapeutic potential of yoga practices in modifying cardiovascular risk profile in middle aged men and women. *Journal of the Association of Physicians of India* **50,** 633-640.

Duren, C.M., Cress, M.E. and Mccully, K.K. (2008) The influence of physical activity and yoga on central arterial stiffness. *Dynamic Medicine* **7,** 2.

Field, T. (2011) Yoga clinical research review. *Complementary Therapies in Clinical Practice* **17,** 1-8.

Finkelstein, S.M. and Cohn, J.N. (1992) First- and third-order models for determining arterial compliance. *Journal of Hypertension Supplement* **10,** S11-14.

Gates, P.E. and Seals, D.R. (2006) Decline in large elastic artery compliance with age: a therapeutic target for habitual exercise. *British Journal of Sports Medicine* **40,** 897-899.

Ge, J.Y., Li, X.L., Zhang, H.F., Xu, Q., Tong, M. and Wang, J.G. (2008) Elasticity indices of large and small arteries in relation to the metabolic syndrome in Chinese. *American Journal of Hypertension* **21,** 143-147.

Hagins, M., Moore, W. and Rundle, A. (2007) Does practicing hatha yoga satisfy recommendations for intensity of physical activity which improves and maintains health and cardiovascular fitness? *BMC Complementary and Alternative Medicine* **7,** 40-49.

Hayes, M. and Chase, S. (2010) Prescribing yoga. *Primary Care* **37,** 31-47.

Hodes, R.J., Lakatta, E.G. and Mcneil, C.T. (1995) Another modifiable risk factor for cardiovascular disease? Some evidence points to arterial stiffness. *Journal of the American Geriatric Society* **43,** 581-582.

Innes, K.E., Bourguignon, C. and Taylor, A.G. (2005) Risk indices associated with the insulin resistance syndrome, cardiovascular disease, and possible protection with yoga: a systematic review. *The Journal of The American Board of Family Medicine* **18,** 491-519.

Kirk, M., Boon, B. and Daniel, D. (2004) *Hatha Yoga Illustrated: For Greater Strength, Flexibility, and Focus*: Human Kinetics

Lehmann, E.D., Hopkins, K.D., Rawesh, A., Joseph, R.C., Kongola, K., Coppack, S.W. and Gosling, R.G. (1998) Relation between number of cardiovascular risk factors/events and noninvasive Doppler ultrasound assessments of aortic compliance. *Hypertension* **32,** 565-569.

Madanmohan, Mahadevan, S.K., Balakrishnan, S., Gopalakrishnan, M. and Prakash, E.S. (2008) Effect of six weeks yoga training on weight loss following step test, respiratory pressures, handgrip strength and handgrip endurance in young healthy subjects. *Indian Journal of Physiology & Pharmacology* **52,** 164-170.

Mccaffrey, R., Ruknui, P., Hatthakit, U. and Kasetsomboon, P. (2005) The effects of yoga on hypertensive persons in Thailand. *Holistic Nursing Practice* **19,** 173-180.

Miyachi, M., Kawano, H., Sugawara, J., Takahashi, K., Hayashi, K., Yamazaki, K., Tabata, I. and Tanaka, H. (2004) Unfavorable effects of resistance training on central arterial compliance: a randomized intervention study. *Circulation* **110,** 2858-2863.

O'Rourke, M. (1990) Arterial stiffness, systolic blood pressure, and logical treatment of arterial hypertension. *Hypertension* **15,** 339-347.

Oliver, J.J. and Webb, D.J. (2003) Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. *Arteriosclerosis, Thrombosis, and Vascular Biology* **23,** 554-566.

Resnick, L.M., Militianu, D., Cunnings, A.J., Pipe, J.G., Evelhoch, J.L., Soulen, R.L. and Lester, M.A. (2000) Pulse waveform analysis of arterial compliance: relation to other techniques, age, and metabolic variables. *American Journal of Hypertension* **13,** 1243-1249.

Rietzschel, E.R., Boeykens, E., De Buyzere, M.L., Duprez, D.A. and Clement, D.L. (2001) A comparison between systolic and diastolic pulse contour analysis in the evaluation of arterial stiffness. *Hypertension* **37,** E15-22.

Rowe, J.W. (1987) Clinical consequences of age-related impairments in vascular compliance. *American Journal of Cardiology* **60,** 68G-71G.

Seals, D.R., Desouza, C.A., Donato, A.J. and Tanaka, H. (2008) Habitual exercise and arterial aging. *Journal of Applied Physiology* **105,** 1323-1332.

Seo, D.-I., Kim, E., Fahs, C.A., Rossow, L., Young, K., Ferguson, S.L., Thiebaud, R., Sherk, V.D., Loenneke, J.P., Kim, D., Lee, M.-K., Choi, K.-H., Bemben, D.A., Bemben, M.G. and So, W.-Y. (2012) Reliability of the one-repetition maximum test based on

muscle group and gender. *Journal of Sports Science and Medicine* **11 (in press)**.
Tanaka, H., Desouza, C.A. and Seals, D.R. (1998) Absence of age-related increase in central arterial stiffness in physically active women. *Arteriosclerosis, Thrombosis, and Vascular Biology* **18,** 127-132.
Tanaka, H., Dinenno, F.A., Monahan, K.D., Clevenger, C.M., Desouza, C.A. and Seals, D.R. (2000) Aging, habitual exercise, and dynamic arterial compliance. *Circulation* **102,** 1270-1275.
Tran, M.D., Holly, R.G., Lashbrook, J. and Amsterdam, E.A. (2001) Effects of Hatha Yoga Practice on the Health-Related Aspects of Physical Fitness. *Preventive Cardiology* **4,** 165-170.
Weeks, B.K. and Beck, B.R. (2008) The BPAQ: a bone-specific physical activity assessment instrument. *Osteoporosis International* **19,** 1567-1577.
Winer, N., Sowers, J.R. and Weber, M.A. (2001) Gender differences in vascular compliance in young, healthy subjects assessed by pulse contour analysis. *Journal of Clinical Hypertension* **3,** 145-152.
Yang, K. (2007) A review of yoga programs for four leading risk factors of chronic diseases. *Evidence-based Complementary and Alternative Medicine* **4,** 487-491.
Yoga Journal. (2008) *2008 "Yoga in America" Market Study* [Online]. Available from URL: http://www.yogajournal.com/advertise/press_releases/10 [Accessed November 21, 2011].
Yogendra, J., Yogendra, H.J., Ambardekar, S., Lele, R.D., Shetty, S., Dave, M. and Husein, N. (2004) Beneficial effects of yoga lifestyle on reversibility of ischaemic heart disease: caring heart project of International Board of Yoga. *Journal of the Association of Physicians of India* **52,** 283-289.
Zimlichman, R., Shargorodsky, M., Boaz, M., Duprez, D., Rahn, K.H., Rizzoni, D., Payeras, A.C., Hamm, C. and Mcveigh, G. (2005) Determination of arterial compliance using blood pressure waveform analysis with the CR-2000 system: Reliability, repeatability, and establishment of normal values for healthy European population--the seven European sites study (SESS). *American Journal of Hypertension* **18,** 65-71.

Key points

- The 8 month Yoga training did not affect arterial compliance of the large and small arteries.
- None of the cardiovascular variables were changed by the Yoga intervention.
- Isotonic muscle strength was not altered by the Yoga intervention, with the exception of leg press.

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