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Can Blood Flow Restricted Exercise Improve Ham:Quad Ratios Better Than Traditional Training?

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ABSTRACT

International Journal of Exercise Science 12(4): 1080-1093, 2019. Muscular deficiencies between the quadriceps and hamstrings are prevalent among women and often lead to knee injury and ACL tears. The purpose of this study was to examine whether short term resistance training with or without blood flow restriction (BFR) could improve hamstring:quadricep ratios (H:Q) and reduce the chance for injury. Women (n = 14; 18-25 yrs) were randomly assigned to either a traditional resistance training (RT: n = 8) or BFR resistance training in combination with traditional RT (RT+BFR: n = 6) group. Subjects trained 3 days/week for 6 weeks. The RT group completed 3 sets of 10 reps at 70% of their one-repetition maximum (1RM) with 1-minute rest between sets. The RT+BFR group completed the first 5 exercises similar to the RT group but performed the two-leg hamstring curl under blood flow restriction at 50% of occlusive pressure and 30% 1RM, completing 4 sets (30, 15, 15, 15) with 30 seconds rest between sets. Training effects were assessed using a two-way repeated measures ANOVA. Statistical significance was set at p≤0.05. There were significant ($p < 0.05$) main effects for time, with all muscle groups increasing strength but no significant main effects or interaction for the H:Q ratios at four testing speeds (60°/s, 180°/s, 240°/s, and 300°/s). This study found that hamstring strength with low load (30% 1RM) BFR training was improved to a similar extent as the hamstrings trained with the traditional high load (75% 1RM) program even though less external weight was used during training. H:Q ratios showed small non-significant increases post-training for both groups.

KEY WORDS: muscle imbalance; rehabilitation; alternative training techniques

INTRODUCTION

The American College of Sports Medicine recommends resistance training at intensities of at least 70% of one repetition maximum (1RM) with 1 to 3 sets of 8 to 12 repetitions, minimally on 2 non-consecutive days per week to produce skeletal muscle hypertrophy (2). Since the early 2000's, alternative training programs like resistance training with the addition of blood flow restriction (BFR), which utilizes low percentages (20-30%) of an individual's 1RM while restricting blood flow to the exercising muscle (patented in 1998), have also produced positive muscle adaptations with no significant evidence of muscle damage (12, 25, 28). In one of the earliest blood flow restricted studies published, Takarada et al. (28) documented that low intensity blood flow restricted resistance exercise (50% 1RM) of the elbow flexor muscles produced similar gains in muscle cross-sectional area and isokinetic strength as the traditional high intensity resistance exercise protocol in postmenopausal women. In addition, the use of BFR without exercise has attenuated muscle atrophy and strength decrements proceeding anterior cruciate ligament reconstructive surgeries (29) and in patients in casts over long periods of time (10).

Isokinetic testing can evaluate quadriceps and hamstring muscle strength at different contraction speeds to develop hamstring to quadriceps strength ratios (H:Q) (7) that could be used as an indicator for possible knee injury (3). Since the H:Q ratio is recorded as a percent, a normal range is considered to be between 50-80% depending on testing speed, with ratios increasing closer to 1.0 as speed increases. Individuals falling below 50% are thought to be more susceptible to knee ligament injury (24), especially for women since they tend to have lower ratios primarily due to wider hips causing a higher hip-to-knee angle (Q-angle) and higher knee hyperextension angles (genu recurvatum) (6). If the H:Q ratio can be increased by increasing the strength of the hamstrings more than the quadriceps, then the risk for future knee injury might be reduced. There have been no previous studies that examined BFR resistance training and its effect on H:Q ratios in women. Since 2000, most blood flow restricted studies included males only or combined both males and females in the study sample but analyzed results with both sexes combined, with no effort to differentiate the sex related responses. In fact, a systematic review completed in 2016 (27) designed to report on the effectiveness of BFR exercise on strength and muscle hypertrophy identified 916 possible articles and eventually 47 that fit the review criteria. Of these 47 papers, 26 were male only studies, 14 included both sexes with all subjects analyzed together, and only 7 were female only.

Therefore, since BFR training has been shown to be as effective or more effective than traditional high load resistance training programs, the primary purpose of the study was to utilize BFR training principles in combination with traditional resistance exercises to determine if hamstring strength could be better improved with low load (30% 1RM) BFR exercise compared to traditional high load (70% 1RM), which would then decrease strength deficiencies between the hamstring and quadriceps muscle groups and increase the H:Q ratio. The rationale to train only the hamstrings with BFR was based on previous studies that have reported equal of greater strength and hypertrophy benefits with BFR training. We assumed that training the hamstrings with BFR would provide a greater potential increase in strength compared to the quads that were to be trained with the traditional resistance training program (70% 1RM) and therefore this design would be the best way to affect the H:Q ratio while still increasing the strength in both muscle groups. The secondary purpose of the study was to determine the responses of the H:Q ratios of female subjects by isokinetic strength testing as the speed of contractions increased from 60°/s to 180°/s, 240°/s, and 300º/s. It was hypothesized that the low-load (30%1RM) blood flow restricted exercise group would exhibit similar or greater improvements in 1RM strength and peak torque for the hamstring muscle group as the high load (70%) resistance exercise group but with much less mechanical stress to the knee joint because of the significantly lower external load being lifted. It was also expected that the H:Q ratios would increase (greater increases in hamstring strength gains compared to quadriceps strength gains) more for the BFR group compared to the traditional resistance training group. Finally, it was hypothesized that even through peak torques for both the quadriceps and hamstring muscle groups were expected to decline with increasing speeds of contraction at baseline and following training (from 60°/s to 300°/s), the H:Q ratios would increase closer to 1.0 following the training stimulus for both groups.

METHODS

Participants

An a priori power analysis was performed using G*Power 3.1.9.2 using effect sizes estimated from a BFR training study by Martin-Hernandez et al. (15) and a resistance training study by Holcomb et al. (8). Based on these studies, H:Q ratio effect sizes ranged from small (−0.56) to moderate (1.31) requiring total samples sizes of 7 to 28 for 80% power. Twenty-eight subjects were screened for the study; however, only fourteen subjects (RT, n = 8; RT+BFR, n = 6) completed the study and all training sessions within their assigned protocols. "This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science" (20).

Healthy females aged 18 to 24 years were recruited for this study. All consenting procedures and experimental testing were approved by the Institutional Review Board at the University of Oklahoma Health Sciences Center. Subjects were included if they participated in less than 2 days/week of resistance training or less than 30 minutes/day of aerobic activities. Exclusion criteria were the following: tobacco users; a BMI greater than 30 kg/m^2; previous orthopedic knee injury; risk factors for thromboembolism (Crohn's disease, previous hip, pelvis, or femur fracture, major surgery within the last six months, varicose veins, a family history of deep vein thrombosis or pulmonary embolism); hypertension (resting blood pressure > 140/90 mmHg); and an ankle brachial index less than 0.9.

Protocol

This study utilized a mixed factorial (group × time) repeated measures design for the 6-week training program. Subjects came to the laboratory for the first visit to provide written informed consent and complete screening questionnaires. Upon inclusion in the study, subjects visited the laboratory for two pre-test days that were spaced two weeks apart. They were asked to continue normal activity for this period of time as well as for the entire length of the training period (six weeks). This two-week period allowed each subject to act as their own control for the study and allowed for reliability to be established for our outcome measures. After the conclusion of the two pre-test sessions, subjects were randomly assigned to either six weeks of a traditional resistance training program (RT: n = 8) consisting of six exercises (three upper body: chest press, lat pull down, and biceps curl; and three lower body: two-leg press, quadriceps extension, and hamstring curls) with three sets of 10 repetitions at 70% of each subjects 1RM or to a similar resistance training program as the RT group with the exception of the hamstring exercise that was performed with blood flow restriction utilizing four sets of 30, 15, 15, 15 repetitions at 30% hamstrings 1RM (RT+BFR: n = 6). At the mid-point of training, 1RM was reassessed for each muscle group, including the hamstrings, and the training resistances were increased accordingly to maintain the appropriate intensities. At the conclusion of training, subjects performed the same test measures conducted at baseline, 2-4 days after the last training visit. The subjects were informed to rest at least 24 hours prior to the post-test with no caffeine or alcohol consumption during that time period.

At the first visit, height and weight were measured using a stadiometer (Stadi-O-Meter) and electric floor scale (Tanita digital scale) to calculate BMI. Each subject also had their quadriceps angle (Q angle) and genu recurvatum (knee hyperextension) assessed using a goniometer (Lafayette Instruments, Lafayette, IN). To assess Q angle, subjects stood upright, feet shoulder width apart. The apex of the goniometer was placed at the center of the patella with one arm of the goniometer centered in the tibial tuberosity and the other arm centered and pointed to the ASIS (front portion of the iliac crest or hip bone). The Q angle was compared to normative ranges that are specific to females with values below 20% considered normal. To measure genu recurvatum (knee hyperextension), subjects were supine with their ankles elevated on a small cylinder bolster and knee extended downward. The apex of the goniometer was placed at the center axis of rotation of the knee while one arm of the goniometer was centered towards the outer anklebone and the other arm centered towards the outer portion of the hip joint.

After 10 minutes of supine rest, blood pressure was measured using an electric automatic blood pressure cuff (OMRON Healthcare) and ankle brachial index was measured using a bi-directional Doppler probe (MD6, D E Hokanson) and a hand-held pressure cuff to test for peripheral vascular disease. Then, in order to determine arterial occlusion pressures for the BFR exercise (50% of total occlusion pressure), a wide (13.5 cm) pressure cuff was placed on the proximal portion of the subject's thigh and connected to the Hokanson (E20 Rapid Cuff Inflator with AG101 Cuff Inflator Air Source), and a bi-directional Doppler probe was placed on the posterior tibial artery to detect pulse at the ankle. The cuff was first inflated to 50mm Hg for 30 seconds, then deflated for 10 seconds. The cuff pressure was then inflated to the subject's systolic pressure for 30 seconds, then deflated for 10 seconds. The next steps in the procedure were to inflate the cuff by 40 mm Hg for 30 seconds, deflate for 10 seconds incrementally until arterial flow (pulse at the ankle) was no longer detected by the Doppler probe. The cuff pressure was then decreased by 10mm Hg to regain arterial flow and then increased by 1 mm Hg until flow was once again occluded. Arterial occlusion pressure was recorded as the lowest cuff pressure at which the pulse was not present. This procedure typically takes 3-5 minutes to complete in our laboratory. It was conducted for both thighs with a 5-minute rest period in between measures. There was no significant difference in mean occlusion pressures between legs (right: 279 ± 40 mmHg vs. left: 269 ± 45 mmHg, $p = 0.14$).

Subjects then completed five different questionnaires. The first was the International Physical Activity Questionnaire (IPAQ) (5) which quantified physical activity levels during normal daily living. Subjects were included in the study if they were classified as "low activity" (below 600 met-minutes per week). Subjects also completed a Health History Questionnaire (developed in the Neuromuscular and Bone Density labs in the Department of Health and Exercise Science at the University of Oklahoma) to determine past health issues that would hinder a subject's inclusion in the study and the Physical Activity Readiness Questionnaire (PAR-Q) (32) to screen subjects for any health issues they experience during physical activity that would require physician clearance before participating in the study. The Lysholm knee scoring scale (13) was used to assess whether the subjects' had any knee pain or discomfort during physical activity and finally, a Menstrual History Questions (developed in the Bone Density lab in the Department of Health and Exercise Science at the University of Oklahoma) was completed.

Subjects performed 3 seated maximal quadriceps and hamstring isokinetic strength trials at 4 speeds (60°/s, 180°/s, 240°/s, and 300º/s) on the Biodex System 3 (Biodex Medical Systems, Shirley, NY) with 3 minutes of rest separating speeds. Then following 10 minutes of rest, 1RM testing for each of the 6 isotonic training exercises, utilizing individual Cybex plate-loaded machines, was completed in the following order: chest press, two-leg press, lat pull down, quadriceps extension, biceps curl, and hamstring curl. Each 1RM was completed within 5 attempts and 5 minutes of rest separated each muscle group. These same protocols were used for the second pre-test visit, at the mid-point of training (after week 3), and at the end of the training programs.

The 2 progressive overload training programs lasted 6 weeks (18 training sessions). Subjects trained 3 times/ week with at least 1 day between training days. Subjects in both groups (RT and RT+BFR) performed the same 6 resistance exercises in the same order (chest press, two-leg press, lat pull down, quadriceps extension, bicep curl, and hamstring curl) to a cadence of 1 second concentric and 1 second eccentric. Recruitment efforts from previous studies were very difficult when the study design only included 1 or 2 muscle groups that were to be trained. Since the entire protocol would only take 10 to 15 minutes to complete, subjects felt that it was too inconvenient to go to the lab for a 15-minute visit. Therefore, the upper body exercises were included in the current design to help ensure successful recruitment and training adherence since the upper body exercises allowed for a whole body workout for the subjects enrolling in the study, even though we were only interested in attempting to affect the H:Q ratio with BFR training. Therefore, the only difference between the 2 groups training sessions was the addition of BFR to the hamstring curl exercise (instead of the high intensity (70% 1RM) for the RT+BFR group. For the RT group, 70% 1RM was used for each of the 6 exercises with subjects completing 3 sets of 10 repetitions with 1-minute rest between sets. The RT+BFR group followed the same protocol for the first 5 exercises, then, prior to the hamstring exercises, pneumatic cuffs used for blood flow restriction were placed at the most proximal location of both thighs, inflated to 50% of the occlusion pressure, and 4 sets at 30% 1RM (30, 15, 15, 15 with 30 seconds rest between sets) of hamstring curl exercises were completed. The 50% total occlusion pressure was chosen based on several studies from our lab investigating the neuromuscular responses to BFR pressures ranging from 20% to 80% of total occlusion pressure (11, 18, 26). Maximal strength values (1RM) were re-assessed for each muscle group and for both training groups at the midpoint of training (week 3) to ensure progressive overload, however, there was no progression for occlusion pressures during the 6-week training programs.

Statistical Analysis

Descriptive statistics (mean ± SD) were computed for age, height, weight, body mass index

(BMI), blood pressure, peak torques and H:Q ratios at 60°/s, 180°/s, 240°/s, and 300°/s, and 1RM values for all exercises. Paired t-tests, Pearson Correlation Coefficients, and Intraclass Correlation Coefficients (ICC) were used to determine reliability and consistency between the two pre-test measurements. Standard error of measurement (SEM) was calculated using the formula (SD√1-ICC). Minimal difference (MD) was calculated to determine the change required to be considered a real change (MD = SEM × 1.96 × √2).

If there were no significant differences between strength measures for pre-test 1 and 2 days, the values for the 2 pre-test days were averaged and used as the new pre-test value for subsequent data analyses. If the two pre-test measurements were significantly different, then the pre-test 2 data were used for the further analyses. Independent t-tests were used to compare group differences in physical characteristics for the pre-test time point to determine the need to adjust for possible covariates. Since the only variable that was significantly (p = 0.016) different between the two groups was BMI, we did not perform ANCOVA. Two-way repeated measures ANOVA (group × time) was used to determine the training program effects on muscular strength variables. If there was a significant interaction effect, the model was decomposed by performing paired t-tests (pre vs. post training) within each group. Cohen's d effect sizes were calculated for pre-post training comparisons within each group, and the magnitude of effect sizes was determined using the untrained individuals' scale for strength training research (trivial < 0.50, small 0.50-1.25, moderate 1.25-1.9, large > 2.0) proposed by Rhea (23). All analyses were run using Statistical Package for Social Sciences version 19 (SPSS Inc., IL, USA). Statistical significance was set at $p \leq 0.05$.

RESULTS

Table 1 shows the physical characteristics for each group. BMI was significantly ($p \leq 0.05$) higher for the RT+BFR group.

Table 1. Pre-Test Physical Characteristics (Mean ± SD)

Variable	RT (n = 8)	RT + BFR (n = 6)
Age (yrs)	21.63 ± 0.74	21.67 ± 0.82
Height (m)	1.67 ± 0.08	1.64 ± 0.07
Body Mass (kg)	59.03 ± 4.17	66.03 ± 9.66
BMI (kg/m^2)	21.39 ± 2.10	24.32 ± 1.70*
SBP (mmHg)	105.4 ± 3.7	106.8 ± 6.8
DBP (mmHg)	66.8 ± 5.0	69.6 ± 2.8
Q-Angle		
Right (°)	11.13 ± 5.06	7.83 ± 2.71
Left (°)	11.38 ± 4.41	10.83 ± 2.64
Genu Recurvatum		
Right (°)	5.75 ± 1.83	4.83 ± 1.60
Left (°)	5.13 ± 1.36	6.00 ± 1.10

Note: *p < 0.05 significant group difference; RT: Resistance Training Group; RT + BFR: Resistance Training with Blood Flow Restriction Group

Pre-Test Isokinetic Strength and 1RM Measures: There were 5 out of 16 isokinetic strength comparisons that were significantly different from pre 1 to pre 2 (Table 2). There was a significant difference between days for the right hamstring (300°/s; p = 0 .046), right quadriceps (60°/s; p = 0.005 and 240°/s; p = 0.048), and for the left quadriceps (60°/s; p = 0.016 and 300°/s; p = 0.012), thus, pre-test 2 values were used in subsequent analyses. ICCs for the 1RM strength and peak torque values at each speed were moderate to strong for most variables, with the exception of the right hamstring peak torque at 240°/s.

Table 2. Pre-Test 1 and 2 Measures for Peak Torque Variables (Mean ± SD)

Peak Torque (Nm)		Pre 1 (n = 14) Mean ± SD	Pre 2 (n = 14) Mean ± SD	p	ICC	SEM	MD
Hamstring							
Right	60°/s	68.7 ± 11.8	68.2 ± 10.4	.832	0.70	8.21	22.1
	180°/s	51.4 ± 18.3	50.9 ± 9.8	.886	0.41	12.1	33.5
	240°/s	52.2 ± 12.1	50.1 ± 7.6	.576	0.07	12.9	35.8
	300°/s	51.4 ± 9.3	45.7 ± 9.1	.046*	0.46	9.1	25.2
Left	60°/s	63.2 ± 11.0	61.0 ± 13.6	.425	0.68	9.5	26.3
	180°/s	48.2 ± 8.8	50.1 ± 11.8	.321	0.79	6.4	17.7
	240°/s	48.7 ± 11.3	46.8 ± 12.2	.493	0.63	9.7	22.0
	300°/s	45.2 ± 11.3	45.3 ± 8.7	.977	0.58	9.1	25.2
Quadriceps							
Right	60°/s	147.3 ± 30.0	129.6 ± 16.9	.005**	0.68	18.0	40.7
	180°/s	94.8 ± 19.6	87.2 ± 16.4	.082	0.64	13.3	36.9
	240°/s	85.9 ± 19.2	75.8 ± 12.7	.048*	0.44	16.2	44.9
	300°/s	83.4 ± 16.0	75.3 ± 13.2	.067	0.47	14.9	41.3
Left	60°/s	134.6 ± 20.2	120.6 ± 18.3	.016*	0.52	18.1	50.2
	180°/s	88.2 ± 15.5	85.0 ± 10.5	0.373	0.54	11.9	33.0
	240°/s	80.3 ± 16.7	76.4 ± 15.4	0.116	0.86	8.2	22.7
	300°/s	75.8 ± 14.9	69.1 ± 10.8	0.012*	0.78	8.2	22.7
H/Q Ratios							
Right	60°/s	.482 ± .052	.529 ± .066	0.069	-0.093	.054	.15
	180°/s	.547 ± .105	.595 ± .112	0.213	0.226	.096	.27
	240°/s	.618 ± .100	.675 ± .131	0.216	0.019	.115	.32
	300°/s	.661 ± .137	.619 ± .127	0.259	0.492	.112	.31
Left	60°/s	.472 ± .070	.505 ± .080	0.085	0.606	.047	.13
	180°/s	.552 ± .086	.585 ± .103	0.108	0.721	.050	.14
	240°/s	.617 ± .134	.617 ± .126	0.995	0.483	.094	.26
	300°/s	.618 ± .149	.661 ± .102	0.357	0.149	.115	.32

Notes: °/s: degrees per second; r: Pearson Correlation Coefficient; ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MD: Minimal Difference; H/Q: Hamstring to Quadriceps isokinetic strength ratio; *$p \le 0.05$; **$p \le 0.01$ significant difference between pre-test days

H:Q ratios for right and left legs increased as speed increased (60°/s, 180°/s, 240°/s, and 300°/s) and were not significantly different between the two pre-test measures (all $p \ge 0.085$). As might be expected when calculating a ratio based on two different muscle groups at 4 different speeds, the ICCs were low to moderate, with the right leg showing poorer reproducibility than the left leg (Table 2).

1RM values (Table 3) for the chest press and hamstring exercises were similar between the 2 pre-test days (p = 0.189 and p = 0.312, respectively). There were, however, significant mean differences between days for leg press (p = 0.008), lat pulldown (p = 0.006), quadriceps extension (p = 0.043), and bicep curl exercises (p = 0.007), therefore, pre-test 2 values were used in further analyses. The ICC's for the 1RM strength measures were generally good (above 0.8 with the exception of the hamstring curl; ICC = 0.61).

There were no significant group differences for muscle performance variables at baseline with the exception of lat pull down 1RM strength (RT: 36.6 ± 3.9 kg; RT + BFR: 44.9 ± 9.4 kg; p = 0.040).

Table 3. Pre-Test 1 and 2 Measures for 1RM (Means ± SD)

1RM Values (kg)	Pre 1 (n = 14) Mean ± SD	Pre 2 (n = 14) Mean ± SD	p	ICC	SEM	MD
Chest Press	34.3 ± 7.4	35.7 ± 7.4	0.189	0.858	2.8	7.5
Leg Press	111.7 ± 23.4	102.3 ± 20.1	0.008**	0.868	7.9	21.9
Lat Pulldown	36.7 ± 6.5	40.2 ± 7.8	0.006**	0.854	2.3	6.4
Bicep Curl	21.7 ± 5.8	23.7 ± 5.2	0.007**	0.816	2.3	6.4
Quad Extension	55.9 ± 12.5	60.1 ± 10.6	0.043*	0.908	3.5	9.7
Hamstring Curl	58.5 ± 9.5	56.0 ± 10.6	0.312	0.611	6.2	17.2

Note: 1RM: One repetition maximum (kg); ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MD: Minimal Difference; *: $p \leq 0.05$; **: $p \leq 0.01$ significant difference between pre-test days

One-Repetition Maximum Testing: Based on the 2 way repeated measures ANOVA, there were significant time effects (all $p \leq 0.001$), but no significant group or group × time interaction effects for each muscle group, indicating significant strength increases (all $p \leq 0.001$) from pre to post-training regardless of the training group (Table 4). The percent change scores for all 6 exercises were calculated to assess differences in the magnitude of the training responses between the two training groups. There were no significant differences between RT and RT + BFR for percent increases in 1RM strength for any muscle group (Table 4).

Table 4. 1RM Strength Changes Pre- to Post-Training by Group (Mean ± SD)

	RT (n = 8)			RT + BFR (n = 6)			
1RM Strength (kg)	Pre	Post	%Δ	Pre	Post	%Δ	%Δ p^{a}
Chest Press**	31.8 ± 4.8	39.5 ± 5.7	24.4 ± 4.3	39.1 ± 7.9	45.5 ± 9.7	16.4 ± 11.4	.157
Lat Pull Down**	36.9 ± 4.0	47.2 ± 6.3	28.1 ± 11.9	45.0 ± 9.4	54.5 ± 6.4	23.8 ± 16.2	.580
Biceps Curl**	24.8 ± 4.5	31.6 ± 4.4	29.3 ± 19.1	25.1 ± 5.5	34.1 ± 6.2	37.2 ± 11.4	.384
Two-Leg Press**	104.6 ± 25.7	123.3 ± 29.7	18.2 ± 8.7	99.3 ± 10.5	118.2 ± 13.8	19.0 ± 5.9	.844
Quad Extension**	62.5 ± 11.1	73.1 ± 13.8	17.0 ± 6.3	56.9 ± 9.6	72.0 ± 11.2	27.2 ± 12.5	.067
Hamstring Curl**	59.9 ± 8.5	74.2 ± 13.0	23.7 ± 8.8	53.7 ± 9.3	68.2 ± 12.0	27.5 ± 11.6	.496

Note: ** $p \leq 0.001$ significant time effect; ^{a} p value for %Δ comparison between groups

Peak Torque and H:Q Ratios: Peak torque significantly increased (all $p \leq 0.009$ significant time effect) after training for both right and left hamstring and quadriceps muscle groups at all four speeds (60°/s, 180°/s, 240°/s, and 300º/s). Although there were no significant group or group × time interaction effects, the RT group had small to moderate effect sizes while RT+BFR had trivial to small effect sizes for peak torque variables (Table 5). Right and left leg H:Q ratios did not significantly change after training at any of the testing speeds or for either group, and effect sizes were trivial (< 0.50) to small (0.50 to 1.25; Table 6).

Table 5. Peak Torque Values Pre- and Post-Training (Mean ± SD)

	RT (*n* = 8)			RT + BFR (*n* = 6)		
Peak Torque (Nm)	Pre	Post	ES	Pre	Post	ES
Hamstring						
Right**						
60°/s	68.64 ± 10.98	79.65 ± 16.98	0.79	68.29 ± 10.20	77.83 ± 15.56	.74
180°/s	50.80 ± 7.15	67.75 ±13.40	1.65	51.62 ± 13.53	62.95 ± 17.65	.73
240°/s	49.40 ± 5.50	64.36 ± 11.94	1.72	53.47 ± 9.36	57.42 ± 15.13	.32
300°/s	46.22 ± 5.35	59.23 ± 12.15	1.49	51.65 ± 10.02	54.20 ±15.98	.20
Left**						
60°/s	61.68 ± 8.18	76.10 ± 15.09	1.24	71.03 ± 33.57	74.93 ± 16.62	.15
180°/s	48.17 ± 7.26	63.49 ± 12.21	1.57	50.48 ± 13.25	56.88 ± 11.34	.52
240°/s	48.34 ±10.41	59.45 ± 8.89	1.15	47.09 ± 11.92	56.67 ± 7.96	.96
300°/s	45.00 ± 8.77	60.48 ± 10.54	1.60	45.57 ± 10.03	52.85 ±10.91	.70
Quadriceps						
Right**						
60°/s	138.83 ± 22.29	151.84 ± 35.47	0.45	140.45 ± 24.81	155.87 ± 15.74	.76
180°/s	87.83 ± 13.94	107.49 ± 16.71	1.28	95.21 ± 19.70	104.35 ± 13.43	.55
240°/s	78.65 ± 12.54	95.55 ± 14.55	1.25	83.79 ± 14.96	97.90 ± 15.41	.93
300°/s	80.18 ± 12.49	91.24 ± 14.70	0.81	78.21 ± 13.85	88.43 ± 15.48	.70
Left**						
60°/s	125.28 ± 17.33	150.96 ± 36.57	0.96	130.63 ± 17.07	155.50 ± 37.01	.92
180°/s	82.83 ± 8.30	100.23 ± 20.45	1.21	91.99 ± 14.44	104.28 ± 20.13	.72
240°/s	74.56 ± 12.38	89.29 ± 13.98	1.12	83.44 ± 18.84	93.630 ± 22.73	.49
300°/s	69.88 ± 11.77	85.79 ± 11.64	1.36	75.82 ± 13.15	85.18 ± 17.01	.62

Note: **$p < 0.01$ significant time effect for all speeds; ES: Effect Size Cohen's d for pre vs. post comparison within group

Table 6. H:Q Strength Ratios Pre- and Post-Training (Means ± SD)

	RT (*n* = 8)			RT + BFR (*n* = 6)		
H:Q ratio	Pre	Post	ES	Pre	Post	ES
Right						
60°/s	0.503 ± 0.034	0.530 ± 0.084	.47	0.504 ± 0.044	0.497 ± 0.070	.12
180°/s	0.590 ± 0.064	0.632 ± 0.103	.50	0.545 ± 0.108	0.596 ± 0.111	.47
240°/s	0.652 ± 0.101	0.676 ± 0.110	.23	0.639 ± 0.059	0.591 ± 0.142	.48
300°/s	0.621 ± 0.118	0.648 ± 0.085	.26	0.667 ± 0.115	0.613 ± 0.127	.49
Left						
60°/s	0.497 ± 0.048	0.511 ± 0.060	.26	0.478 ± 0.092	0.483 ± 0.045	.07
180°/s	0.582 ± 0.066	0.642 ± 0.101	.71	0.550 ± 0.115	0.549 ± 0.080	-.01
240°/s	0.649 ± 0.097	0.672 ± 0.098	.23	0.574 ± 0.125	0.615 ± 0.126	.33
300°/s	0.657 ± 0.053	0.709 ± 0.118	.61	0.616 ± 0.139	0.630 ± 0.116	.11

Note: ES: Effect Size, Cohen's d for pre to post comparison

DISCUSSION

In this study, we used BFR training for the hamstring curl as a novel approach to improve hamstring:quadriceps strength ratios in comparison to a traditional high intensity strength training in young untrained women. While both of our training protocols were effective for improving isotonic and isokinetic strength, overall, H:Q ratios showed small non-significant increases for both groups. This finding suggests that utilizing a low intensity (30% 1RM) BFR protocol for the hamstring muscle group offered no advantage over the high intensity protocol other than placing less stress at the knee joint because of the lower external load being lifted. The effect sizes for peak torques at each speed for hamstring and quadriceps muscle groups for the RT group were considerably larger (0.45 to 1.72) compared to the BFR group (0.15 to 0.96), even though both groups trained the quadriceps with the same high intensity load (70% 1RM). The same pattern was observed for H:Q ratio effect sizes for both groups (RT ranged from 0.23 to 0.71; RT+BFR ranged from -0.01 to 0.49).

Our findings support the previous literature that BFR resistance exercise is effective for inducing strength gains with less stress to the exercising joints (1, 14, 15, 25, 28-31, 34, 35). A recent meta-analysis by Schoenfeld et al. (25) reported that the magnitude of strength gains are larger for high intensity resistance training than for low load BFR training, which is similar to our results.

We found that H:Q ratios were not significantly different between groups or from pre to post-test periods; however, both groups tended to show increases in H:Q ratios after training. Also, the majority of our participants had H:Q ratios within the normal range for both time points. Although not statistically significant, the increases in H:Q ratios might be of clinical significance for individuals who are in rehabilitation after knee injury or ACL surgery (9). The H:Q ratio can serve as a baseline to determine imbalances and those who may be at risk for knee injury (7, 22, 24). The normal range for isokinetic H:Q ratios is between 50-80% (17), with values below this range being associated with increased risk for knee ligament injury, especially for the ACL. Devan et al. (6) found that H:Q ratios below the normal range at a test speed of 300°/s were positively correlated with overuse knee injuries in Division I female athletes. Furthermore, they determined that athletes with genu recurvatum also had significant associations with overuse knee injuries. We assessed Q-angle and genu recurvatum, however, none of our participants had abnormally high measures for either variable (severe Q-angle > 21º, genu recurvatum > 12º).

We found that H:Q ratios increased as the isokinetic contraction speed increased as hypothesized. Wyatt and Edwards (34) reported significant torque differences between different test speeds, and that the torque output of the hamstring and quadriceps at 300º/s should approach unity (1:1). Powell and Barber-Foss (22) examined H:Q ratios in high school athletes and found that H:Q ratios were significantly higher for 300º/s than for 60º/s speed for both legs.

There are several unique aspects to our study. Although blood flow restriction has been used during a post-operative stimulus for ACL tear patients, it has not been studied from a preventative perspective. In addition, the use of BFR resistance training focused on the hamstrings has not been previously examined. Martin-Hernandez et al. (15) conducted a 5-week training study in men comparing low and high volume BFR training to traditional high intensity training (85% 1RM 3 sets 8 reps) but they trained only the quadriceps muscle group. They found quadriceps 1RM and quadriceps and hamstrings isokinetic peak torque (60 and 180 º/s) all significantly increased post-training for both groups. The H:Q ratios significantly decreased about 5 to 7% after training, which is not surprising since they trained the quadriceps without training the hamstrings.

Another novel aspect of this study is the use of women as subjects for BFR training protocols. Women are often excluded from BFR studies due to greater risks of blood clotting and the complications associated with taking oral contraceptives. Holcomb et al. (8) evaluated the H:Q ratios at 60°/s, 180°/s, and 240 °/s following 6 weeks of resistance training that emphasized the hamstring muscle groups for female collegiate soccer players. They also reported a non-significant increase in the H:Q ratio, similar to our findings.

There were several limitations to this study that require consideration. Although strict exercise and diet guidelines for times outside of the training sessions were provided to the subjects, it cannot be guaranteed that they were followed. Another limitation was the small sample size for the RT+BFR group in particular. Finally, the statistical power of our study was affected by the poor ICCs observed for the H:Q ratios at each speed (0.019 to 0.721). Given the peak torque ICCs were moderate (0.40) to strong (0.80) for both muscle groups, this may be a function of the calculation of the H:Q ratios being influenced by the direction of small peak torque changes for the muscle groups. It should be noted that many training studies do not report reliability measures for peak torque or H:Q ratios (e.g., 8, 15, 28).

In our study, low load (30% 1RM) BFR training did not enhance hamstring muscle strength or improve H:Q ratios to a greater extent than traditional high load (70% 1RM) resistance training as both programs resulted in similar gains in hamstring strength. H:Q ratios for both groups did increase as a sign of positive training adaptations, but the improvements were not statistically significant. Additionally, the H:Q ratios increased as the speed of contractions increased from

60°/s to 300°/s in a similar fashion for both training programs. Low load BFR training might be more suitable for those in knee rehabilitation programs or elderly populations who are only capable of lifting low loads but still desiring improvements in strength.

From a clinical perspective, if there is no indication for an increased risk of venous thromboembolism (DVT-deep vein thrombosis or PE-pulmonary embolism), blood flow restricted resistance exercise has provided an alternative and promising method of rehabilitation for many different clinical settings. With this in mind, a study of almost 13,000 individuals utilizing BFR training reported the incidence of DVT was less than 00.06% and PE was less than 0.01% (19, 21). Promising results of BFR training have been reported following rehabilitation from knee osteoarthritis, osteochondral fracture, loss of muscle mass, anterior cruciate ligament reconstruction, Achilles tendon rupture, and non-reconstructive knee arthroscopy (4). A new area of rehabilitation utilizing BFR with low intensity cycling has been used to work with patients with peripheral arterial disease in the hope of improving walking distances with no pain (33). Additionally, BFR training has been used in the National Basketball Association and National Football League to help players stay mobile after injuries and reduce the time of missed play, and in the military, especially at the Center for the Intrepid at Brooke Army Medical Center, to help wounded warriors regain a high quality of life (16). Finally, new areas of research that have been suggested that could benefit from low intensity BFR resistance exercise include individuals with osteopenia or osteoporosis and those with neurological conditions like cerebral palsy and multiple sclerosis or those recovering from stroke (33).

REFERENCES

1. Abe T, Brechue W, Fujita S, Ogasawara R, Yasuda T, Sato Y. Muscle hypertrophy following multi-joint low intensity resistance training with single-joint blood flow restriction. Med Sci Sports Exerc 40: S257, 2008.

2. American College of Sports Medicine. Progression models in resistance training for health adults. Med Sci Sports Exerc 41: 687–708, 2009.

3. Baratta R, Solomonow M, Zhou B, Letson D, Chuinard R,D'Ambrosia R. Muscular coactivation: the role of the antagonist musculature in maintaining knee stability. Amer J Sports Med 16: 113–122, 1988.

4. Bond C, Hackney K, Brown S, Noonan B. Blood flow restriction exercise as a rehabilitation modality following orthopedic surgery: A review of venous thromboembolism risk. J Othoped Sports Phys Ther 49(1): 17-27, 2018.

5. Booth M. Assessment of physical activity: An international perspective. Res Quarterly Exerc Sport 71(Suppl 2): s114-120, 2000.

6. Devan M, Pescatello L, Faghri P, Anderson J. A prospective study of overuse knee injuries among female athletes with muscle imbalances and structural abnormalities. J Athlet Training 39: 263–267, 2004.

7. Grace T, Sweetser E, Nelson M, Ydens L, Skipper B. Isokinetic muscle imbalance and knee joint injuries: a prospective blind study. J Bone Joint Surg 66: 734–740, 1984.

8. Holcomb W, Rubley M, Lee H, Guadagnoli M. Effect of hamstring-emphasized resistance training on hamstring-quadriceps strength ratios. J Strength Con Res 21(1): 41-47, 2007.

9. Kannus P. Ratio of hamstring to quadriceps femoris muscles' strength in the anterior cruciate ligament insufficient knee. J Amer Phys Ther Assoc 68: 961–965, 1988.

10. Kubota A, Sakuraba K, Koh S, Orgura Y, Tamura Y. (2011) Blood flow restriction by low compressive force prevents disuse muscular weakness. J Sci Med Sport 14: 95–99, 2011.

11. Loenneke J, Kim D, Fahs C, Thiebaud R, Abe T, Larson R, Bemben D, Bemben M. The effects of resistance exercise with and without different degrees of blood-flow restriction on perceptual responses. J Sports Sci 33(14): 1472-1479, 2015.

12. Loenneke J, Wilson J, Wilson G, Pujol J, Bemben M. Potential safety issues with blood flow restriction training. Scan J Med Sci Sports 21(4): 510-518, 2011.

13. Lysholm J, Gillquist J. Evaluation of the knee ligament surgery results with special emphasis on use of a scoring scale. Am J Sports Med 10: 150-153, 1982.

14. Madarame H, Neya M, Ochi E, Nakazato K, Sato Y, Ishii N. Cross-transfer effects of resistance training with blood flow restriction. Med Sci Sports Exerc 40: 258–263, 2008.

15. Martin-Hernandez J, Marin P, Menendez H, Ferrero C, Loenneke J, Herrero A. Muscular adaptations after two different volumes of blood flow-restricted training. Scand J Med Sci Sports 23: e114-e120, 2013.

16. McEwan J. Personalized blood flow restriction (BFR) rehabilitation. Tourniquets.org 2019.

17. Mofford M, Whipple R, Hofkosh J. A study of isokinetic exercise. Phys Ther 49: 735–747, 1969.

18. Mouser J, Ade C, Black C, Bemben D, Bemben M. Brachial blood flow under relative levels of blood flow restriction is decreased in a nonlinear fashion. Clin Physiol Funct Imaging 38: 425-430, 2018.

19. Nakajima T, Kurano M, Iida H, Takano H, Oonuma H, Morita T, Meguro K, Sato Y, Nagata T. Use and safety of KAATSU training: Results of a national survey. Int J KAATSU Training Res 2: 5-13, 2006.

20. Navalta JW, Stone WJ, Lyons TS. Ethical Issues Relating to Scientific Discovery in Exercise Science. Int J Exerc Sci 12(1): 1-8, 2019.

21. Patterson S, Brandner C. The role of blood flow restriction training for applied practitioners: A questionnaire-based survey. J Sports Sci 36(2): 5-13, 2017.

22. Powell J, Barber-Foss D. Sex-related injury patterns among selected high school sports. Amer J Sports Med 28: 385–391, 2000.

23. Rhea M. (2004). Determining the magnitude of treatment effects in strength training research through the use of effect size. J Strength Cond Res 18: 919-920, 2004.

24. Rosene J, Fogarty T, Mahaffrey B. Isokinetic Hamstrings:Quadriceps ratios in intercollegiate athletes. J Athlet Training 36: 378-383, 2001.

25. Schoenfeld B, Grgic J, Ogborn D, Krieger J. Strength and hypertrophy adaptations between low- vs high-load resistance training: A systematic review and meta-analysis. J Strength Cond Res 31(12): 3508-3523, 2017.

26. Scott B, Loenneke J, Slattery K, Dascombe B. Exercise with blood flow restriction: An updated evidence-based approach for enhanced muscular development. Sports Med 45(3): 313-325, 2015.

27. Slysz J, Stultz J, Burr J. The efficacy of blood flow restricted exercise: A systematic review and meta-analysis. J Sci Med Sports 19: 669-675, 2016.

28. Takarada Y, Sato Y, Ishii N. Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. Eur J Appl Physiol 86: 308–314, 2002.

29. Takarada Y, Takazawa H, Ishii N. Applications of vascular occlusion diminish disuse atrophy of knee extensor muscles. Med Sci Sports Exerc 32: 2035–2039, 2000b.

30. Takarada Y, Takazawa H, Sato Y, Takebayashi S, Tanaka Y, Ishii N. Effects of resistance exercise combined with moderate vascular occlusion on muscle function in humans. J Appl Physiol 88: 2097–2106, 2000a.

31. Takarada Y, Tsuruta T, Ishii N. Cooperative effects of exercise and occlusive stimuli on muscular function in low-intensity resistance exercise with moderate vascular occlusion. Jap J Physiol 54: 585–592, 2004.

32. Thomas S, Reading J, Shephard R. Revision of the physical activity readiness questionnaire (PAR-Q). Can J Sport Sci 14(4): 338-345, 1992.

33. Vanwye W, Weatherholt A, Mikesky A. Blood flow restriction training: Implementation into clinical practice. Int J Exerc Sci 10(5): 649-654, 2017.

34. Wyatt M, Edwards A. Comparison of quadriceps and hamstring torque values during isokinetic exercise. J Orthoped Sport Phys Ther 3: 48–56, 1981.

35. Yasuda T, Abe T, Sato Y, Midorikawa T, Kearns C, Inoue K, Ryushi T, Ishii N. Muscle fiber cross-sectional area is increased after two weeks of twice daily KAATSU-resistance training. Internat J Kaatsu Training Res 1: 65–70, 2005.