TOPICS IN EXERCISE SCIENCE AND KINESIOLOGY

Process of Science

Comparison of Vascular Dopplers in Measuring Limb Occlusion Pressure for Blood Flow Restriction Therapy

KIARA B. BARRETT[1*], LOGAN B. PAGE[2*], MARCIN K. SZCZYGLOWSKI[3], TYLER D. MARTIN[4], and J. GRANT MOUSER[4]

[1]Neuromechanics Laboratory, Old Dominion University, Norfolk, VA, USA; [2]Physician Assistant Department, Augusta University, Savannah, GA, USA; [3]Department of Athletics, Colorado College, Colorado Springs, CO, USA; [4]Applied Physiology Laboratory, Troy University, Troy, AL, USA

[*]Kiara Barrett and Logan Page have shared first authorship with equal contribution

ABSTRACT

Topics in Exercise Science and Kinesiology Volume 4: Issue 1, Article 7, 2023. The use of blood flow restriction is becoming more common and requires the use of individualized pressures in order to remain a safe and effective rehabilitation modality. Measuring limb occlusion pressure (LOP) allows the practitioner to set the restriction pressure so that full occlusion does not occur. Objective: Compare a research-grade clinical vascular doppler and a consumer-grade vascular doppler in the measurement of LOP. Design: A randomized crossover design measuring LOP in the upper and lower body. Methods: 20 participants (men=10) visited the laboratory on one occasion. Limb circumference in the arm and thigh was measured. Following 10 min of supine rest, LOP was measured either in the arm, using a 5 cm wide inelastic cuff, or in the leg, using a 10 cm wide inelastic cuff. Measurements were repeated at 5 min intervals until LOP had been measured in both limbs with both dopplers. Results: Bland-Altman analysis showed agreement between the two dopplers in both the upper body (mean bias: 0.6 (-1.3 – 2.4) mmHg) and lower body (mean bias: -1.5 (-4.4 – 1.4) mmHg). Two one-sided tests of equivalence determined that both dopplers measured a statistically equivalent LOP in the upper body (p = .547) and lower body (p = .288). Conclusions: In a healthy, young population, the consumer-grade vascular doppler measured LOP equally as well as the research-grade clinical doppler.

KEY WORDS: Blood flow restriction, vascular dopplers, limb occlusion pressure, arterial occlusion pressure, occlusion training

INTRODUCTION

Physical Therapy is intended to improve functional capacity and quality of life following injury, surgery, or disease[1]. By addressing physical impairments in combination with psychosocial

notions, the aim is to improve independence, as well as reduce risk of further injury. The nature of an injury may limit the types of exercises and loading parameters that can be performed during therapy. Patients may not be able to bear the amount of load recommended to increase muscle strength, or may have post-operative restrictions which limit interventions. A technique that has recently entered the physical therapy domain, blood flow restriction (BFR), is proving efficacious in building muscle size and strength in the absence of high load training[2,3]. BFR is the artificial restriction of blood flow by either pneumatic cuff, nylon band, or elastic strap placed on an arm or leg at its most proximal region. A pneumatic cuff is most often used in research and clinical settings because it allows the easiest and safest management of pressure application. Once the cuff is in place, it is inflated to a percentage of the limb occlusion pressure (LOP), the minimum pressure at which all blood flow into a limb is halted[4]. Inflating the cuff to a sub-occlusive pressure allows the patient to exercise with a lighter load while maintaining some degree of blood flow, which may be more appropriate for a patient's status.

The American College of Sports Medicine recommends strength training with a resistance of at least 70% of one's one-repetition maximum (1RM) to induce muscular growth[5]. However, it has been demonstrated that exercises performed to volitional fatigue display similar hypertrophy when utilizing high loads and low loads[6,7]. Utilizing low loads to fatigue may become tedious for patients to complete due to the high number of repetitions required. Studies using BFR combined with low-load resistance training have shown muscle hypertrophy to occur with a training intensity as low as 20% of the 1RM[8–10]. Compared to traditional resistance training, the addition of BFR to training with low loads results in a quicker onset of muscular fatigue[11]. This supports the application of BFR in a physical therapy setting, allowing patients to achieve similar adaptations to traditional strength training while reducing joint stress and total workload[7,12].

For BFR isolation exercises in physical therapy settings, 80% and 50% of LOP are generally used for the lower and upper limbs, respectively. A common exercise protocol consists of a load of 30% 1RM combined with four sets of exercise comprising 75 goal repetitions (30 repetitions during the first set, and 15 repetitions during each subsequent set) separated by 30 sec rest periods between each set[4]. The cornerstone of these exercise prescriptions is the 1RM, yet the determination of this measurement can be difficult in the clinical setting; high loads may not be an option due to injury or other physical constraints. As an alternative, performing exercises to volitional failure (i.e., 4 sets to failure) has been shown to induce similar levels of hypertrophy, correcting for the absence of a true 1RM calculation. While effective in promoting muscular hypertrophy at lower loads, the application of BFR during exercise protocols can be unpleasant for patients. In addition to modifying the load of the exercise, varied occlusion pressures have been employed with similar reductions in blood flow[13], which may improve patient comfort.

The application of BFR has also been shown efficacious with aerobic training. Low load cardiorespiratory activity with BFR has demonstrated increases in peak oxygen uptake[14], and carotid arterial compliance[15]. Furthermore, in conditions where it may be inappropriate for

patients to begin low load exercise (i.e. bedrest), research has demonstrated attenuation of muscle atrophy[16] and strength loss[17] with the application of BFR in the absence of exercise.
In prior BFR research, a single arbitrary pressure has been applied to each participant (e.g., a pressure of 220 mmHg in the cuffs)[18–20]. This is problematic because each patient has individual characteristics that will affect their LOP. Limb circumference, cuff width, and systolic blood pressure are the most significant determinants of LOP[21,22], making it impossible to set a single pressure that will deliver the same restrictive stimulus to everyone. Therefore, ascertaining LOP for each patient is necessary before the application of BFR. Determination of LOP is achieved by placing the cuff on the proximal portion of the arm or leg. A vascular doppler is then applied to an artery distal to the cuff. The cuff is inflated until cessation of the auditory pulse, indicating the minimum pressure required to halt blood flow, the LOP.

The Hokanson MD6 vascular doppler is very common in BFR research and has been validated against doppler ultrasound measures of blood flow[23], but this doppler can be cost-prohibitive (~$1000 - $1300). Inexpensive consumer-grade dopplers are available but have not been validated against the MD6. The purpose of this study was to examine one consumer-grade doppler, the Edan SonoTrax (~$125 - $150), and compare it to the MD6 in measurements of LOP.

METHODS

Participants
Twenty healthy individuals (women=10, men=10) between 19 and 30 years old volunteered for this study. All data collection sessions occurred in the Applied Physiology Laboratory in at Troy University, Troy, AL. Anthropometric measurements were taken, and then inelastic pneumatic cuffs were placed at the proximal-most portion of each participant's left arm and leg. Following 10 min of supine rest and in a randomized crossover fashion, the LOP of each limb was measured using one of two vascular dopplers. That is, both arm and leg measurements were randomized, and the doppler that was performing the measurement was randomized. This was repeated at 5-minute intervals until LOP measurements were conducted with both vascular dopplers on both limbs.

Pre-Screening and Anthropometric Measures
Prior to participation, participants were informed of the purpose of the study. If participants did not meet any criteria for thromboembolism (past fracture of the hip, pelvis, or femur, major surgery within the six months prior to their visit, a diagnosis of either Crohn's disease or varicose veins, a personal or family history of either thromboembolism or pulmonary embolism, or a BMI of > 30.0)[24], and if they still wished to take part in the study, participants provided written informed consent. This study complied with all edicts of the Declaration of Helsinki and was approved by the University's Institutional Review Board. After providing written informed consent, participants' height and body mass were measured. Arm and thigh circumference were measured as follows: while standing, a mark half the distance from the acromion process to the lateral epicondyle of the humerus was made on the participant's arm, and an inelastic tape measure was used to measure the circumference of their arm at this location. The participant then reclined on an exam table with legs extended while supporting their upper body with their arms. A mark one-third of the distance between the anterior superior iliac spine and the superior

border of the patella was made on the participant's leg, and thigh circumference was measured at this point. These locations were chosen as they best represent the location of the inflatable cuffs.

Vascular Dopplers

Two vascular dopplers were employed for this study, the Hokanson MD6 (Hokanson, Inc., Belleview, WA, USA) and the Edan SonoTrax STV.08 (Edan Instruments, Inc., Shenzhen, Guangdong, China). The MD6 includes a pencil-style 5MHz ultrasound probe and is widely used in the determination of LOP in BFR research[8,21,25]. The SonoTrax includes an ergonomic 8MHz probe, with the additional availability of 4MHz and 5MHz probes.

Inflatable Cuffs and Limb Occlusion Pressure

A nylon, pneumatic cuff, 5 cm in width (SC5, Hokanson, Inc.) was placed on the proximal-most portion of the left arm, while a 10 cm wide cuff (SC10, Hokanson, Inc.) was placed on the proximal-most portion of the left thigh. With the cuffs in place, the participant rested supine for 10 min. The order of limb and doppler were randomized and counter-balanced using an online randomization tool (www.random.org). Following rest, one of the vascular dopplers, coated with ultrasound transmission gel, was placed over the artery (the radial artery at the wrist for the arm measurement, or the posterior tibial artery at the ankle for the thigh measurement) until an audible pulse was detected. Once the pulse was found, the cuff was inflated to 50 mmHg initially using a rapid cuff inflator (EC20, Hokanson, Inc.), and then the pressure in the cuff was slowly increased until cessation of the auscultatory signal. The researcher measuring the pulse with the doppler was blinded to the pressure being applied to the cuff for each measurement. The minimum pressure required to completely halt the pulse was recorded as the LOP as recorded by that specific vascular doppler. The cuff was then deflated, and the participant rested for five minutes. This process was repeated until LOP in both limbs had been measured with each of the two vascular dopplers.

Statistical Analysis

A Bland-Altman comparison of LOP measurements taken using the two vascular dopplers was completed. Mean bias, upper and lower limits of agreement, and 95% confidence intervals (CI) of each were calculated. Plots of the difference between the SonoTrax and the MD6 against the mean measurement of each were created for both the arm and thigh measurement. Two one-sided tests of equivalence using 90% CI, with upper and lower equivalence bounds of 5 mmHg and -5 mmHg, respectively, were calculated to determine equivalence between the methods. All statistical analyses were performed using Jamovi statistical software (version 0.9.5.12). Statistical significance was set at $\alpha = .05$. Unless noted, all results are reported as mean (95% CI).

RESULTS

All 20 participants completed the study, the characteristics for whom can be found in Table 1. For the LOP measured in the arm, Bland-Altman analysis revealed a mean bias of 0.6 (-1.3 – 2.4) mmHg, with upper and lower limits of agreement at 8.4 (5.1 – 11.7) mmHg and -7.3 (-10.6 – -4.0)

mmHg, respectively. Individual responses within this analysis can be found in Figure 1. Two one-sided tests of equivalence determined that the mean difference between dopplers was statistically insignificant (p = .547), and that the 90% CI of the difference (-1.0 – 2.1) mmHg fell within the upper and lower equivalence bounds.

Table 1. Participant Characteristics

	Women (n=10)	Men (n=10)	Combined (n=20)
Age (yr)	20.5 (1.8)	22.7 (2.7)	21.6 (2.5)
Height (m)	1.75 (.08)	1.82 (.08)	1.78 (.09)
Body Mass (kg)	68.7 (5.7)	81.5 (15.9)	75.1 (13.3)
Arm Circumference (cm)	29.5 (2.1)	32.9 (3.9)	31.2 (3.5)
Leg Circumference (cm)	61.4 (2.3)	60.7 (5.1)	61.1 (3.9)
Arm LOP (mmHg) **– Hokanson**	139.7 (12.2)	150.9 (12.1)	145.3 (13.1)
Arm LOP (mmHg) **– SonoTrax**	138.3 (12.4)	151.2 (11.9)	144.8 (13.6)
Leg LOP (mmHg) **– Hokanson**	142.7 (9.3)	159.6 (19.6)	151.2 (17.3)
Leg LOP (mmHg) **- SonoTrax**	144.5 (9.7)	160.8 (22.1)	152.7 (18.6)

Results presented as mean (SD); LOP: Limb Occlusion Pressure

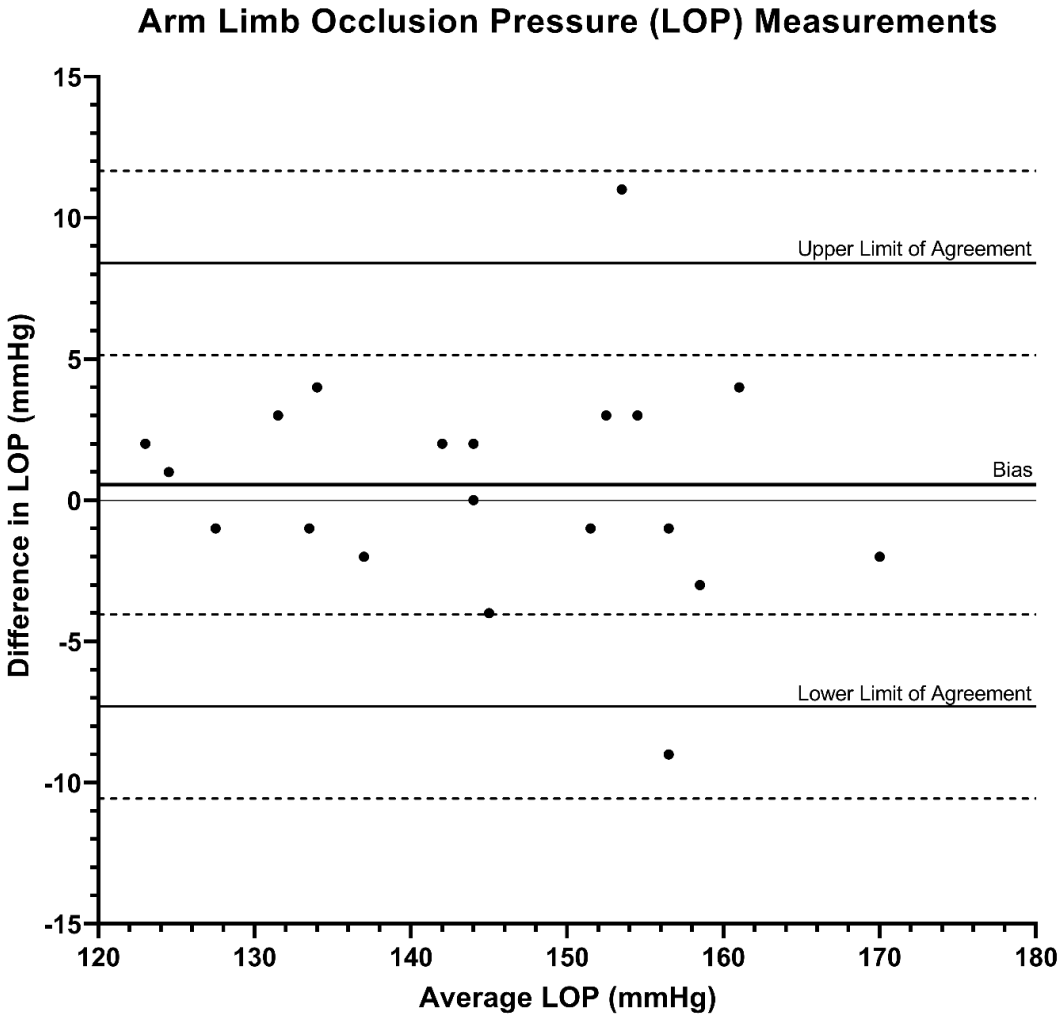

Figure 1. Bland-Altman comparison showing the differences in LOP measured in the arm. Dashed lines represent the 95% CI of each measure.

For the LOP measured in the leg, Bland-Altman analysis showed a mean bias of -1.5 (-4.4 – 1.4) mmHg, with upper and lower limits of agreement at 10.5 (5.5 – 15.5) mmHg and -13.5 (-18.5 - -8.5) mmHg, respectively. Individual responses within this analysis can be found in Figure 2. Two one-sided tests of equivalence determined that the mean difference between dopplers was insignificant (p = .288), and that the 90% CI of the difference (-3.9 – 0.9 mmHg) fell within the upper and lower equivalence bounds.

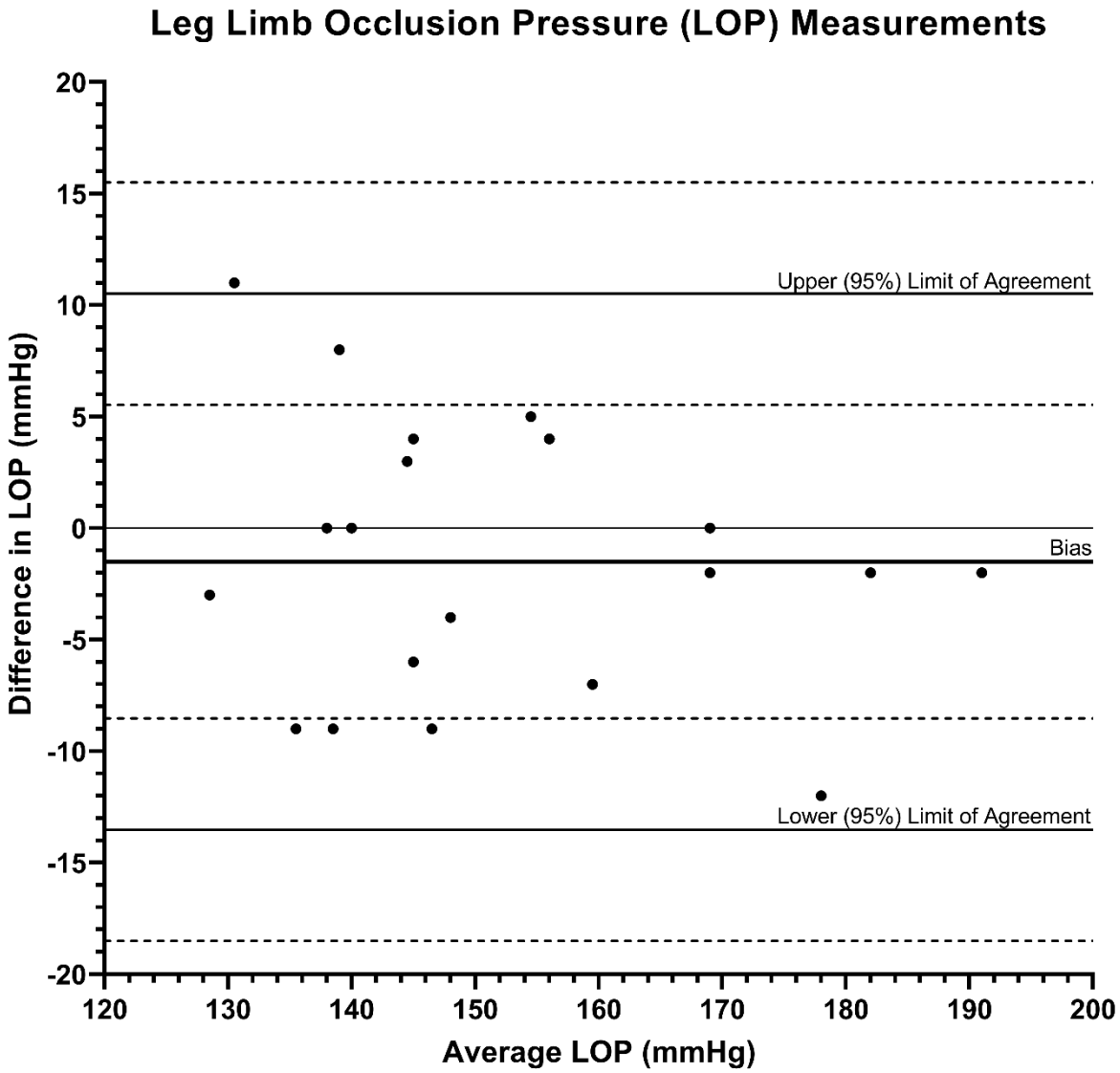

Figure 2. Bland-Altman comparison showing the differences in LOP measures in the leg. Dashed lines represent the 95% CI of each measure.

DISCUSSION

This study compared a clinical-grade vascular doppler with a consumer-grade vascular doppler in the measurement of LOP for use with BFR therapy. It was determined that the two dopplers measure LOP to a similar degree, and this similarity is statistically equivalent for this population.

When employing BFR based on LOP, it is typically applied in steps of 10%; the most common prescriptions are 40-60% of the LOP in the upper body and 80% in the lower body[4]. The equivalence bounds were set between -5 and +5 mmHg because this allowed, at most, a difference from the actual LOP of 10 mmHg. Applied on a relative basis, the difference between measured and actual limb occlusion thus becomes very small, and the authors do not believe such a small difference is clinically significant in the application of BFR.

This study adds to a past study that compared a similar vascular doppler to doppler ultrasound measures of blood flow[23]. The present study provides evidence that cost-efficient, consumer-grade vascular dopplers can be just as effective in measuring the LOP, although further comparisons are warranted. Therapists and clinicians wishing to test blood flow restriction in their practices while avoiding an initial high monetary investment could benefit from using this device as such.

This study was performed on a healthy, college-aged population. Since it is known that limb circumference and blood pressure play a determinant role in the LOP[21], it is feasible that in populations with higher blood pressure or larger individuals with larger limb circumferences, these results might not hold. This could be due to the operating frequencies of the dopplers, or the shape of the tip of the probe: the SonoTrax probe has a flat probe tip, while the Hokanson has a cupped head, which may increase its ability to attain a clear signal in larger limbs with more adiposity. Further examination of these methods in different populations is warranted. Similarly, this study compared the MD6 clinical-grade vascular doppler to a single consumer-grade vascular doppler. Future research should examine multiple consumer-grade dopplers against widely used clinical dopplers in the measurement of LOP for the application of BFR.

A consumer-grade vascular doppler (~$125 - $150) performed equally as well as a research-grade clinical vascular doppler (~$1000 - $1300) in the measurement of LOP in both the arms as well as the legs. Physical therapists and clinicians wishing to integrate BFR into their practice should feel confident in using this consumer-grade device.

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