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Lower Body Positive Pressure to Improve Transition from Seated to Standing Postures

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Lower Body Positive Pressure to Improve Transition from Seated to Standing Postures

A Thesis submitted in partial satisfaction of the requirements
for the degree Master of Science

in

Biology

by

Meenakshi Pandiarajan

Committee in charge:

Professor Jan Hughes-Austin, Chair
Professor Randolph Hampton, Co-Chair
Professor Kimberly Cooper

2022

The Thesis of Meenakshi Pandiarajan is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

University of California San Diego

2022

DEDICATION

For my dear friends: thank you for all your “study sessions”, your care packages, your editors’ eyes, and your late-night quizzes. Pooja, Nanki, Leah, Nancy, and Devin – when I think of joy, I think of you. You make even the most unbearable of days worth celebrating.

For my parents, who have had to catch my life of the past two years in very short bursts shouted through a locked door and distracted phone calls: yes, I am *finally* done writing. Thank you for everything you do, big and small, and for trusting me to do my best.

For my brother, who has, by some inexplicable circumstance, gone and become a man: I don’t say it nearly as often as I should, but you mean the world to me. I’m always in your corner too.

And finally, for my grandfather and grandmother, who believed in me far more than I have ever believed in myself: I love you so much. I hope you knew that.

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LIST OF ABBREVIATIONS

LBPP	Lower Body Positive Pressure
FTSTS	Five Times Sit to Stand
TKA	Total Knee Arthroplasty
THA	Total Hip Arthroplasty
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
ADL	Activities of Daily Living
ACL	Anterior Cruciate Ligament

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ABSTRACT OF THE THESIS

Lower Body Positive Pressure to Improve Transition from Seated to Standing Postures

by

Meenakshi Pandiarajan

Master of Science in Biology

University of California San Diego, 2022

Professor Jan Hughes-Austin, Chair
Professor Randolph Hampton, Co-Chair

This thesis consists of a literature review describing the current standard of care and challenges in Total Knee Arthroplasty (TKA) and Total Hip Arthroplasty (THA), the potential application of lower body positive pressure (LBPP) in post-knee and hip surgery rehabilitation, and a feasibility study evaluating the ability of LBPP to ease the transition from seated to standing postures. LBPP is a method of simulating microgravity, causing a decrease in bodyweight by using positive chamber pressures to lessen body weight and load bearing. A study using the Five Times Sit to Stand (FTSTS) test to measure ease of movement and the Borg scale to determine physical exertion was conducted among 8 healthy participants (22.63

± 1.06 years of age, 50% women). Subjects were placed within a LBPP machine, asked to perform the FTSTS test at baseline, report their exertion levels, then repeat the test at 6 chamber pressures (-25 mmHg, -20mmHg, -10mmHg, 10mmHg, 20mmHg, 25mmHg) in an alternating negative-positive pattern, beginning with a negative chamber pressure. Blood pressure, heart rate, and body weight were measured at all chamber pressures. Borg values were significantly lower at positive chamber pressures compared to negative chamber pressures. FTSTS times were faster at positive chamber pressures than at negative chamber pressures. Heart rate and blood pressure did not differ at positive chamber pressures from baseline measurements. LBPP could be a potential supplement to rehabilitative therapy for post-knee and hip surgery patients by lessening load bearing and exertion while not increasing heart rate and blood pressure, markers of cardiovascular stress.

INTRODUCTION

Osteoarthritis is a highly prevalent form of arthritis, with 10% of men and 13% of women over the age of 60 affected (Zhang & Jordan, 2010). Total joint replacement is a treatment for particularly debilitating cases of osteoarthritis, with one study finding 1.4% of osteoarthritis patients undergoing total joint replacement annually (Jonsson et al., 2016). Total Hip Arthroplasty (THA) and Total Knee Arthroplasty (TKA) are two specific types of joint replacements and can provide significant benefits in improving quality of life and function as well as reducing pain (Blaha, 2014; Brooks et al., 1999; W. H. Harris & Sledge, 1990; Ritter et al., 1995; Skou et al., 2015).

In 2010 in the United States, 1.52% of the population had undergone TKA and 0.83% of the population had undergone THA at some point in their lives (Maradit Kremers et al., 2015). The prevalence of joint replacement is higher in women than men – with women accounting for 56% of THA and 64% of TKA - and rises drastically with age in both men and women – with THA going from 0.58% at 50 years to 5.26% at 80 years and TKA going from 0.68% at 50 years to 10.38% at 80 years (Maradit Kremers et al., 2015). Ninety-five percent of THA patients are over 45 years of age (Wolford et al., 2015). From 2000 to 2004, hypertension was the predominant comorbidity with THA, occurring in 45% of patients. Other common comorbidities include diabetes mellitus, hypercholesteremia, and obesity (Liu et al., 2009). A notable portion of the population undergoes THA or TKA at some point in their lives, with women and adults over 80 being at increased risk.

The incidence of joint replacement surgery continues to increase (Kurtz et al., 2007; Maradit Kremers et al., 2015; Wolford et al., 2015). Compared to 2005 rates of THA and TKA, the incidence of joint replacement surgery is expected to rise by 137% for THA and 601% for

TKA by 2030 (Kurtz et al., 2007). From 1980, the demographics for THA and TKA seem to be shifting younger – with this trend carrying on to today (Wolford ML et al, 2015, Maradit Kremers et al., 2015). Approximately 70% of TKA and THA patients from the last 40 years are estimated to be alive – indicating a need for optimized rehabilitation methods to ensure a high quality of life (Maradit Kremers et al., 2015). Increased joint replacement surgery, increase in life expectancy with joint replacement surgery, and increased prevalence in younger patients indicate an increased demand for full return to function.

Length of hospital stays in THA patients continue to decrease, from 8.7 days in 1990 to 4 days in 2010 (Liu et al., 2009; Wolford et al., 2015). This decrease is linked to an increase the use of rapid rehabilitation as well as an in discharges to rehabilitative centers, decreasing financial costs for hospitals and overall costs for patients (Liu et al., 2009). Shorter lengths of hospital stays indicate advancements in care and increased reliance on out of hospital rehabilitative centers for post-surgical THA and TKA recovery.

As the length of hospital stay continues to shorten, rehabilitation plans and expectations for hip and knee surgery change. At present, there is no consensus on post-surgical care for TKA or THA (Bandholm et al., 2018; Umpierres et al., 2014). Recovery programs may include elements of pre-operative education, perioperative multimodal pain management, minimally invasive surgical techniques, continuous passive motion, and early rehabilitation. Studies often focus on length of hospital stay, readmission rates, and return to function. While the objectives of specific rehabilitation programs may differ, active range of motion, activities of daily living, pain management, and continued physiotherapy are common factors (Westby et al., 2014), which are described in more detail below.

Range of motion is a frequently used metric to evaluate rehabilitative success and is a common priority in post-surgical physical therapy (Westby et al., 2014). Increased knee range of motion influences functional ability and patient expectations, especially in those achieving greater than 130 ° range of motion (Devers et al., 2011). Range of knee motion during the acute stage of post-operative treatment, less than 1 month after surgery, was significantly linked to range of motion at 1 year. Achieving range of motion goals at acute stages was a reliable predictor of success at 1 year, indicating the importance of early rehabilitation (OKA et al., 2020). Post-operative range of hip motion is also associated with return to function, with high range of motion (exceeding 115° flexion) significantly linked to high functional outcome in the hips (Davis et al., 2007). Thus, the ability to achieve optimal range of motion in the hip and knee indicates a successful return to function.

The ability to complete activities of daily living (ADL) is one of the key sources of dissatisfaction amongst TKA patients. These include activities such as walking, standing, squatting, and transitional movements (e.g., sit-to-stand, getting out of a car) (Nakahara et al., 2015). THA and TKA provide a marked improvement in ADL scores, with the proportion of patients scoring “good” increasing from 1-3% in the pre-operative group to 20-25% in the post-operative group (Rissanen et al., 1995). After one year, patients of both TKA and THA are seen to have physical function levels similar to healthy age-matched populations without TKA and THA (Ethgen et al., 2004). Improving patient ability to complete ADLs is important to increasing patient quality of life and post-surgery satisfaction.

Post-surgical pain is influenced by a surgical stress response, which causes inflammation, and psychological status, which can impact pain perception (Dalury et al., 2011; Ranawat & Ranawat, 2007). Patients experience higher levels of and more persistent post-operative pain in

TKA when compared to THA (Aasvang et al., 2015; de Beer et al., 2012). In rapid recovery programs, which combine rapid rehabilitation alongside perioperative pain management and minimally invasive surgery, 90% of TKA patients were able to be mobilized on the first post-operative day with pain having limited effect on functional mobility (Holm et al., 2010). Thus, addressing perception and management of pain allows patients to participate in rapid rehabilitation programs, improving overall rehabilitative success.

Another factor that may influence the length of hospital stay and return to function is the timing of rehabilitation. Rapid rehabilitation, defined as physical therapy beginning on the day of surgery, has a length of hospital stay 0.5 days less than physical therapy beginning on the first post-operative day (Haas et al., 2016; Pagnotta et al., 2017; Tayrose et al., 2013). Furthermore, patients undergoing rapid rehabilitation for TKA are 2.5 times more likely to have a positive rehabilitation trajectory than patients initiating physical therapy later (Pagnotta et al., 2017). A rapid recovery program, combining rapid rehabilitation alongside perioperative pain management and minimally invasive surgery techniques, resulted in a length of hospital stay three days shorter than the control group – which did not undergo a rapid recovery program (Isaac et al., 2005). Another similarly structured rapid recovery program without the use of minimally invasive surgery techniques demonstrated a reduction in length of stay for THA patients from 4.04 days to 2.66 days, along with a significantly decreased rate of readmission. In TKA patients, there was a decrease in average length of stay to 2.8 days from 3.9 days (Berend et al., 2004). In patients with comorbidities, including cardiopulmonary disease and prior use of mobility aids, and an age greater than 80 years, length of stay under rapid rehabilitation programs is likely to be greater than 4 days but less than that of patients not undergoing rapid rehabilitation (Jørgensen & Kehlet, 2013). Therefore, early commencement of rehabilitation is associated with earlier attainment of discharge requirements and more rapid gain of functional mobility.

Challenges to current post-operative care of THA and TKA patients:

Given that there is no consensus on best practices for rehabilitation, physician approaches and outcome measures may vary drastically. Post-operative patient reported outcomes include continued joint pain and decreased capacity for physical activity. Orthostatic intolerance and loss of range of motion have been determined to be significant challenges as well. Each of these are described in detail below.

One of the major challenges in post-surgical care is pain and pain management. A systematic review found that 7-23% of THA patients and 10-34% of TKA patients report chronic pain (Beswick et al., 2012). Understanding the mechanisms behind pain and how to equip patients to effectively manage it is crucial to rehabilitative therapy. Education about expected levels of pain and pain management are shown to have an impact on post-operative function (Lemay et al., 2017). Identifying risk factors for increased pain and pain perception, such as poor mental health and pre-operative levels of pain, may also help estimate post-operative pain and affect pain management (Wylde et al., 2018). Decreasing weight-bearing can decrease pain perception and allow for early rehabilitation (Goebel et al., 2012).

Orthostatic intolerance is dysfunction that arises from a shift in posture and a corresponding drop in blood pressure. Its symptoms including dizziness, headache, nausea, sweating, lightheadedness, and tunnel vision (Lee & Kim, 2016). Orthostatic intolerance is a commonly seen disorder following THA (Husted et al., 2011), with one study showing 42% of patients experiencing orthostatic intolerance within 6 hours of surgery and 19% experiencing it 24 hours after surgery (Jans et al., 2012). Orthostatic intolerance may impact patient ability to participate in rehabilitative therapy at early post-operative periods, impacting their return to function.

The ability to walk with minimal assistance is a commonly used requirement for discharge (Westby et al., 2014). However, patients may experience a chance in their gait mechanics after surgery. One study shows that as far as 10 months post-surgery, THA patients had significantly different gait mechanics in the lower limbs – possibly as a pain-avoidance mechanism (Beaulieu et al., 2010). Another study indicates that 85% of post-operative THA patients do not regain normal gait 6 months post-surgery (Madsen et al., 2004). This alteration in gait mechanics, while persistent even a year post-surgery, does not differ between different surgical methods with all groups reporting side-to-side asymmetry (Queen et al., 2014; Zeni et al., 2018). Identifying methods to preserve normal gait mechanics is important to regain patient's quality of life.

The transition from seated to standing posture is an important function in the day-to-day lives of post-knee and hip surgery patients. The average adult performs a sit-to-stand movement 60 times a day, with this number rising in subjects with indoor sedentary occupations (Dall & Kerr, 2010). Improving this action and regaining a return to function is important in rehabilitation. The sit-to-stand transition is significantly affected by quadriceps strength (Alnahdi et al., 2016; Davidson et al., 2013; Mizner & Snyder-Mackler, 2005). However, there is also a significant loss in quadriceps strength after TKA, thereby affecting the patient's ability to complete sit-to-stand transitions (Mizner et al., 2005; Stevens et al., 2003). Decrease in quadriceps strength is due primarily to failure in muscle activation as well as muscle atrophy (Mizner et al., 2005). Addressing quadriceps activation failure may require biofeedback and neuromuscular electrical stimulation in addition to addressing strength for muscle atrophy (Stevens et al., 2003).

Use of Lower Body Positive Pressure to Supplement Rehabilitation:

Lower Body Positive Pressure (LBPP) is a method to simulate microgravity. It is used in rehabilitative therapy as well as to study the effects of microgravity environments on the human body. To use LBPP, individuals are placed in a waist-high pressure chamber with an airtight seal along the waist. Through the use of vacuums and pumps, the interior air pressure of the sealed chamber can be modified to differ from atmospheric pressure. By increasing chamber pressure, researchers can mimic the effects of microgravity on the human body – primarily on the cardiovascular system and in load bearing. Researchers can also induce negative pressures by causing a vacuum that results in a lower chamber pressure than atmospheric pressure. This method is used in microgravity environments to mimic normal earth gravity and on Earth to undergo resistance training (Hargens et al., 1991; K. M. Harris et al., 2020).

Currently, LBPP is mainly used in conjunction with a treadmill in rehabilitative therapy for ambulation and preservation of gait mechanics (Eastlack et al., 2005; Kataoka et al., 2021; Kristiansen et al., 2019; Takacs et al., 2013). The sealed chamber includes a treadmill, completely enclosed, where the subject can walk or run while still being held by the waist seal. Decreased body weight through the LBPP mimics weight loss, which can facilitate greater mobility.

One of the core concerns following knee and hip surgery is pain in the lower limbs during exercise and activity. By decreasing body weight through the LBPP, pain experienced by the patients could be lessened. Patients who are overweight with knee osteoarthritis are shown to experience a significant decrease in knee pain when subject to a mean reduction in bodyweight of 12.4% (Takacs et al., 2013). In patients with anterior cruciate ligament (ACL) reconstruction, subjects reported up to an 80% decrease in pain after use of the LBPP treadmill (Eastlack et al., 2005). In women with hip osteoarthritis and using LBPP, they reported significantly lowered pain scores at 75% and 50% of bodyweight compared to full body weight (Kataoka et al., 2021).

Because LBPP treadmill use has been shown to decrease knee forces in healthy subjects (Patil et al., 2013), it could possibly be applied to post-operative total knee arthroplasty patients. Use of LBPP would minimize the stress placed on the post-operative limb and facilitate rehabilitative exercise. For example, post-operative knee surgery patients are shown to have a higher range of motion at higher levels of chamber pressure. As early as the first week post-surgery for anterior cruciate ligament repair, patients were able to ambulate and obtain 21 degrees of dynamic range of motion at 20% of their bodyweight, while they were unable to do so at full bodyweight (Eastlack et al., 2005).

Use of the LBPP has also been shown to counter orthostatic hypotension (Dziuda et al., 2018). Orthostatic intolerance is dysfunction that arises from a shift in posture and a corresponding drop in blood pressure. Its symptoms including dizziness, headache, nausea, sweating, lightheadedness, and tunnel vision (Lee & Kim, 2016). As the LBPP counters normal gravity fluid shifts, it could prevent a sharp drop in blood pressures – a symptom of orthostatic hypotension. When experiencing positive pressures, subjects undergo a fluid shift, similar to that seen in microgravity. The increased positive pressure on the lower limbs causes an increase in mean arterial pressure and central venous pressure (Bevegård et al., 1977; Nishiyasu et al., 1998). In excess of 20 mmHg, stroke volume and cardiac output increase (Nishiyasu et al., 1998; Shi et al., 1993; Stucky et al., 2018). Compared to atmospheric pressure, heart rate decreased in upright individuals at increased chamber pressures after exercise (Cutuk et al., 2006; Eastlack et al., 2005; Nishiyasu et al., 1998; Raffalt et al., 2013; Stucky et al., 2018). In effect, the use of LBPP could minimize risk of orthostatic intolerance in post-operative patients by preventing orthostatic hypotension.

The LBPP chamber used in this project was constructed for use in Dr. Alan Hargens' laboratory at University of California, San Diego. By using the chamber to decrease load bearing, limit the chances of orthostatic intolerance, and counter pain, while preserving gait mechanics, we may be able to demonstrate an additional use of LBPP in rehabilitative therapy. We aimed to evaluate the feasibility of using this machine in rehabilitative therapy for post-knee and hip surgery patients, specifically for easing the transition between seated and standing postures.

METHODS

Study Subjects

Thirteen volunteers from the University of California, San Diego were recruited for this study. The University of California, San Diego Institutional Review Board approved this study, and all volunteers gave oral and written consent to participate. Three subjects were missing 3 measurements (baseline blood pressure and heart rate), 2 were missing 4 measurements (age, sex, height, and maximum positive pressure tests), which left us with a complete analysis dataset of 8 subjects.

Blood Pressure, Heart Rate, Perceived Exertion, and Five Times Sit to Stand Test

Outcomes for our study included systolic and diastolic blood pressure, heart rate, Borg perceived exertion scale, and the Five Times Sit to Stand (FTSTS) test. Blood pressure and heart rate were measured by a digital sphygmomanometer. Blood pressure and heart rate were measured once, immediately after completion of the FTSTS test, with subjects in a standing position. Borg scale values range from 6 to 20 (with 6 being the lowest level of exertion and 20 being the highest) (Borg, 1998; Grant et al., 1999). Subjects were presented with a laminated copy of the Borg scale, complete with numeric levels and short descriptions, as well as orally taken through the scale. After completing the physical activity, subjects self-reported their perceived exertion using the scale. The FTSTS test was used as a measure of mobility and lower-extremity strength, as it is a standardized measurement following knee and hip arthroplasty (Medina-Mirapeix et al., 2018; Özden et al., 2020; Whitney et al., 2005). Subjects were required to begin from a standing position with their arms outstretched and not supporting the body (Figure 1). The subject then transitioned to a seated posture and again to a standing position, five times, as fast as possible. The time taken to complete five full transitions from a seated to standing posture was measured and recorded using a digital timer.

Lower Body Positive Pressure

The Lower Body Positive Pressure (LBPP) machine (Figure 2) is a patented machine constructed by Hargens and colleagues (Eastlack et al., 2005). The machine consists of a waist-high pressure chamber with a treadmill inside and a waist seal that allows for an airtight chamber (Eastlack et al., 2005). Subjects experienced a randomized series of six pressures (-25 mmHg, -20mmHg, -10mmHg, 10mmHg, 20mmHg, 25mmHg) in an alternating negative-positive pattern, beginning with a positive chamber pressure. Chamber pressures were modified using two tubes connected to vacuums that either increased air in the chamber – creating positive pressures- or extracted air from the chamber – creating negative pressures.

Figure 1: Image of LBPP machine with subject in standing position

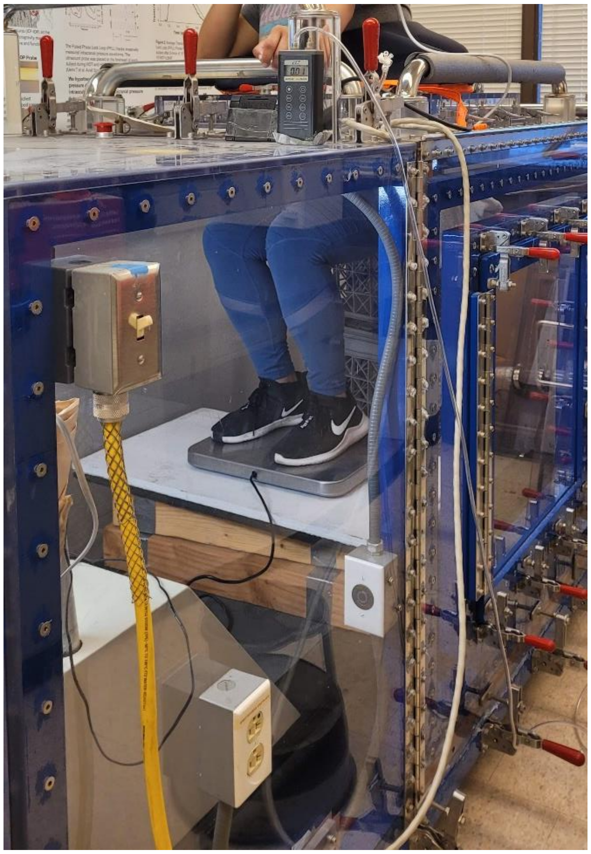


Figure 2: Image of LBPP machine and subject in seated position

Experimental Design

The experiment required subjects to undergo six stages over the course of 30 minutes. Patients first self-reported their heights and body weight was measured through a digital scale. The initial stage was a baseline period, where the subject was placed in the LBPP in a standing position for five minutes with the machine turned off. Nearing the end of the five minutes, a subject's heart rate and blood pressure were measured and recorded. Next, the subject was asked to complete the FTSTS test. At the end of the stage, subjects evaluated their own level of exertion on the Borg scale and heart rate and blood pressure were once more be measured and recorded. Body weight was then measured through a digital scale placed inside the pressure chamber.

Figure 3: Image of seat within LBPP machine

In the next stage, subjects were randomly assigned a series of pressures from a list of values (-25 mmHg, -20mmHg, -10mmHg, 10mmHg, 20mmHg, 25mmHg) in an alternating negative-positive pattern. Subjects were not able to be blinded to the chamber pressure value as the physical experience at each chamber pressure was clearly different. The subjects experienced the first negative pressure value through the use of the LBPP chamber. The subject remained standing for approximately one minute, while pressure in the chamber reached the desired value. The subject then repeated the FTSTS test. Once again, the subject evaluated and reported their own level of exertion on the Borg scale while heart rate and blood pressure were measured and recorded. Body weight was measured and recorded at the end of the stage. The subject was then allowed to rest for two minutes, with the pressure chamber turned off. This process was repeated with the corresponding positive pressure value (ex: first -10mmHg, then 10mmHg). This was repeated four more times, for a total of 7 chamber pressure values (-25 mmHg, -20mmHg, -10mmHg, 0mmHg, 10mmHg, 20mmHg, 25mmHg).

For extreme pressures, -25mmHg and 25mmHg, the protocol was modified due to technological constraints and safety concerns. Subjects were not allowed to spend an extended period of time in the -25mmHg condition due to the risk of syncope and proceeded with the FTSTS immediately after the chamber reached -25mmHg. At the positive extreme, due to air escaping through the waist seal, not all subjects consistently reached 25mmHg. Therefore, the machine was simply pushed to maximum capacity to reach a positive pressure above 20mmHg.

Statistical Analysis

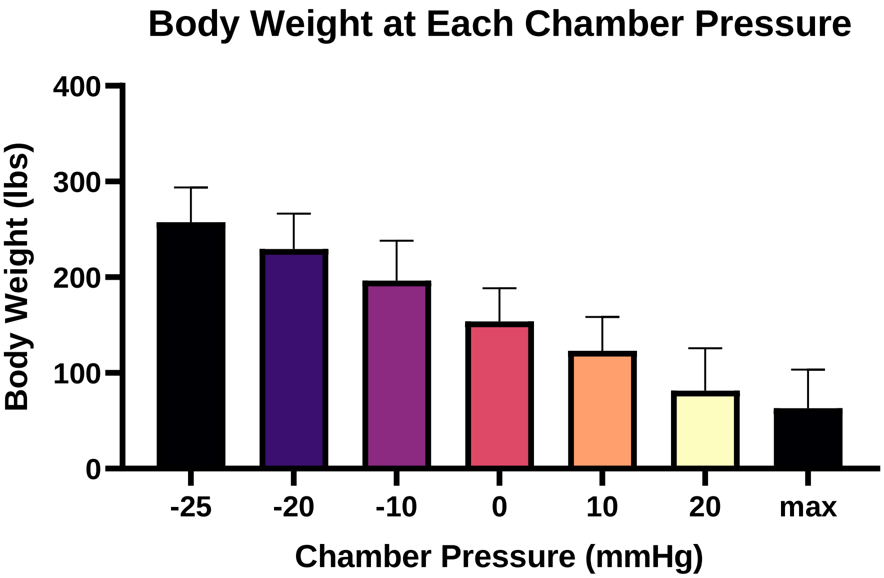
Population characteristics were presented as means ± standard deviations and proportions. To determine differences between outcomes for each tested chamber pressure, we performed a one-way repeated measures ANOVA to account for multiple chamber pressures per person. We used a Bonferroni post-hoc correction to account for comparisons between individual pressures for each outcome. We used SPSS (ver 28.0) for all analysis. A p-value <0.05 indicated statistical significance. All graphs were made in GraphPad Prism 9.

RESULTS

As shown in Table 1, 8 participants completed the study. Their average age was 23 ± 1 years, average weight was 154 ± 35 pounds, average height was 66 ± 4 inches, and 50% were women.

Table 1: Mean and standard deviation of baseline characteristics.

	(n = 8)
Age, yrs	22.63 (1.06)
Weight, lbs	153.69 (34.69)
Height, in	66.25 (3.808)
Sex, % women	50
SBP, mmHg	112.13 (13.86)
DBP, mmHg	73.88 (12.82)
HR, bpm	75.63 (13.70)

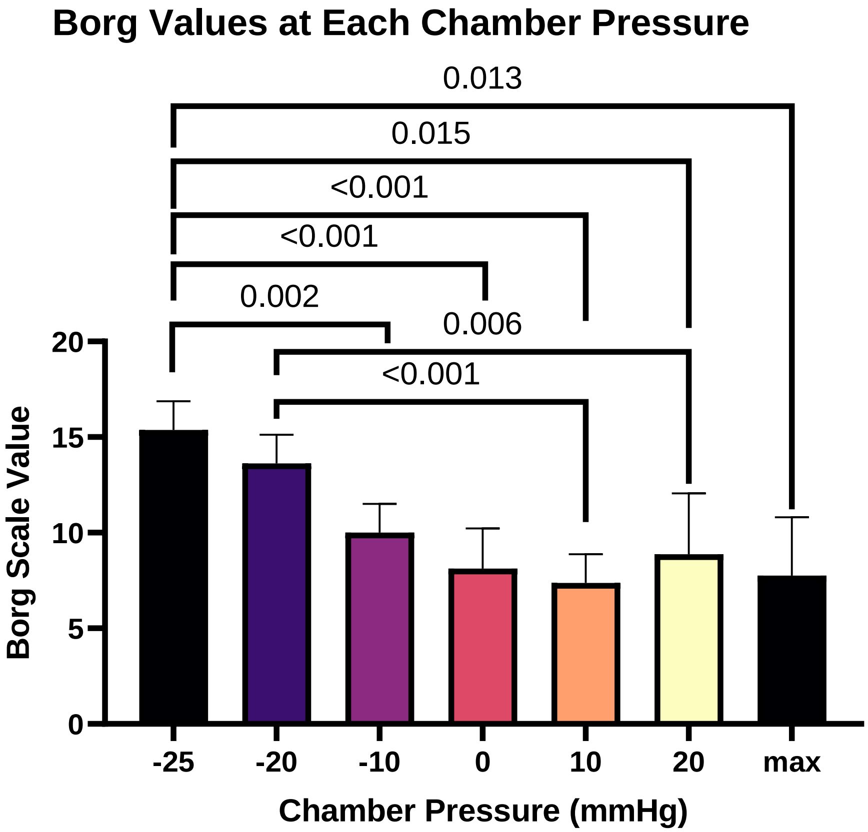


Graph 1: Average effective body weight across chamber pressures. All values are significantly different from one another.

Table 2: Mean and standard deviation of body weight across chamber pressures.

	-25mmHg	**-20mmHg**	**-10mmHg**	**0mmHg**	**10mmHg**	**20mmHg**	**max**
BW (lbs)	257.65 (36.02)	229.38 (37.20)	196.66 (41.50)	153.71 (34.80)	123.21 (35.25)	81.34 (44.51)	63.20 (40.42)

As shown in Figure 1 and Table 2, comparing chamber pressures from -25mmHg through >20mmHg, we observed effective body weight is higher for negative chamber pressures and lower for positive chamber pressures across the gradient of chamber pressures. Differences between body weight for each chamber pressure were significantly different from one another (p<0.015).

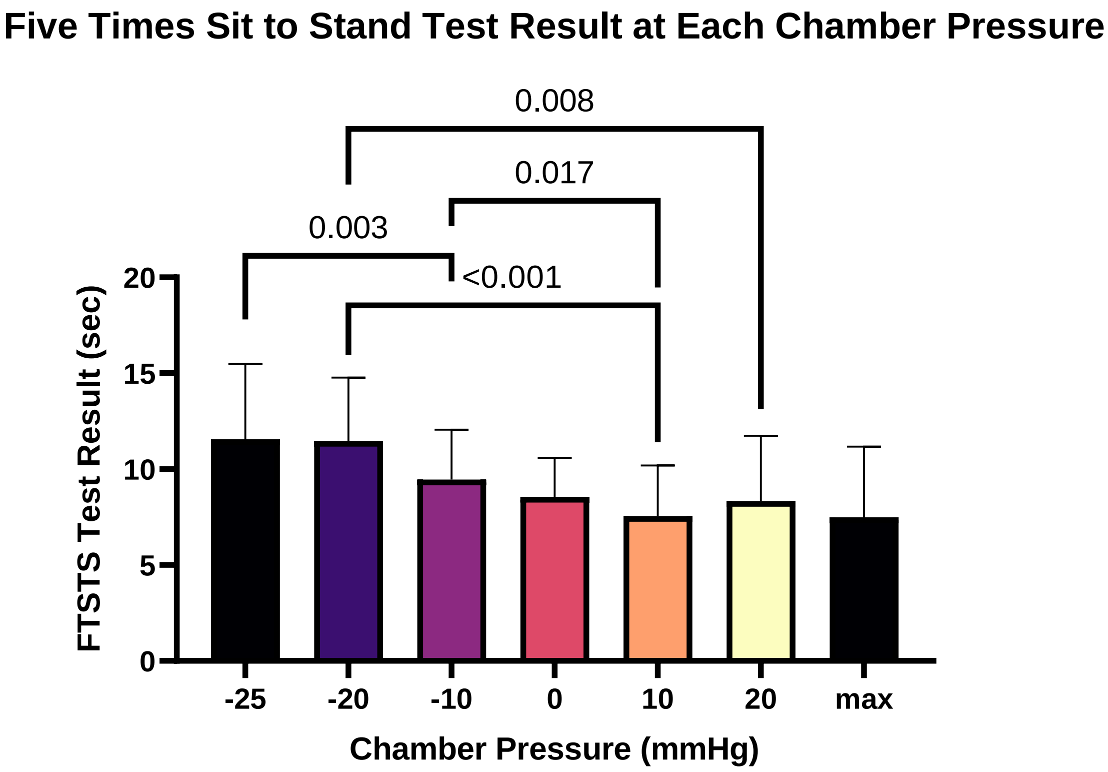


Graph 2: Average Borg values across chamber pressures. P-values for significant differences are shown on the graph.

Table 3: Means and standard deviations of Borg values across chamber pressures.

	-25mmHg	**-20mmHg**	**-10mmHg**	**0mmHg**	**10mmHg**	**20mmHg**	**max**
Borg Values	15.38 (1.50)	13.63 (1.50)	10.00 (1.51)	8.13 (2.10)	7.38 (1.50)	8.88 (3.18)	7.75 (3.05)

Lower Borg values indicate lower levels of perceived exertion, with higher values indicating higher values of perceived exertion. Adjusting for bodyweight, the exertion perceived at all positive pressure values (10 mmHg, 20mmHg, max pressure) were indistinguishable from one another as well as baseline pressure (0mmHg). However, when compared to -25mmHg, perceived exertion values for all other chamber pressures were significantly different (-25mmHg compared to: -10mmHg ($p = 0.002$), 0mmHg ($p < 0.001$), 10mmHg ($p < 0.001$), 20mmHg ($p = 0.015$), max ($p = 0.013$)) with lower levels of exertion. Notably, subjects described feeling increased levels of perceived exertion at extremely high-pressure values due to the restriction of movement. However, the data do not indicate that positive pressure values were significantly different from baseline pressure. (Figure 2 and Table 3)

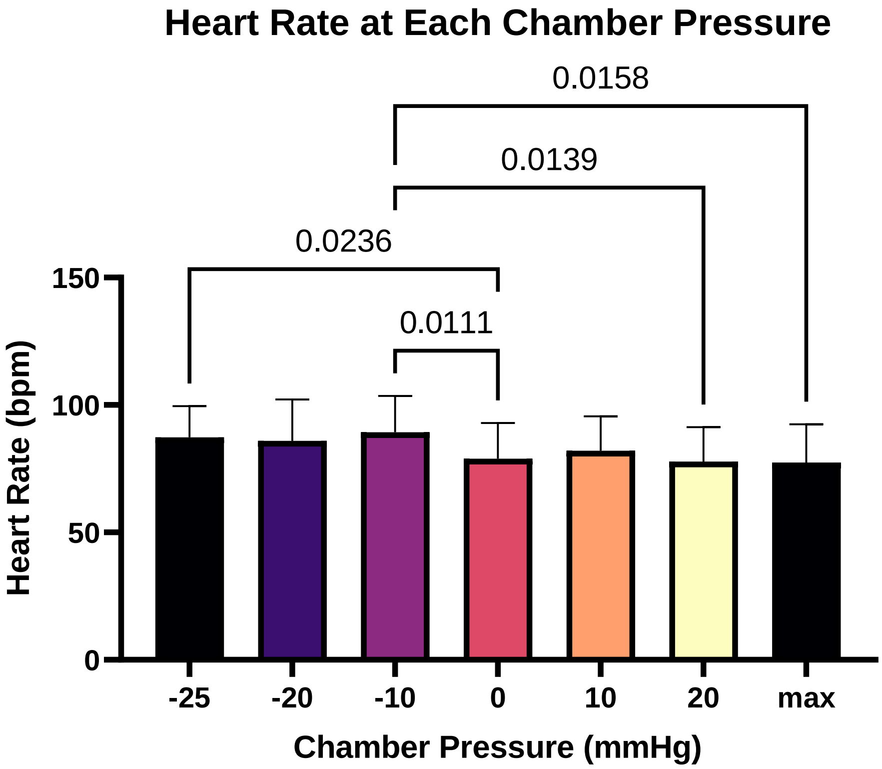


Graph 3: Average Five Times Sit to Stand Test Result across chamber pressures. P-values for significant differences are shown on the graph.

Table 4: Means and standard deviations of five times sit to stand test results across chamber pressures.

	-25mmHg	**-20mmHg**	**-10mmHg**	**0mmHg**	**10mmHg**	**20mmHg**	**max**
FTSTS (sec)	11.56 (3.93)	11.47 (3.30)	9.47 (2.59)	8.55 (2.04)	7.55 (2.64)	8.34 (3.39)	7.50 (3.68)

As shown in Figure 3 and Table 4, adjusting for bodyweight, the FTSTS test result at 10mmHg chamber pressure was significantly different from negative chamber pressures (-20mmHg ($p < 0.001$), -10mmHg ($p = 0.017$)). Transitioning from a seated to standing position can be done faster at 10mmHg compared to negative chamber pressures. However, there was no significant difference between 10mmHg and -25mmHg ($p = 0.061$). The time to complete the FTSTS test at -20mmHg was also significantly different from 20mmHg ($p = 0.008$), as well as between -25mmHg and -10mmHg ($p = 0.003$).



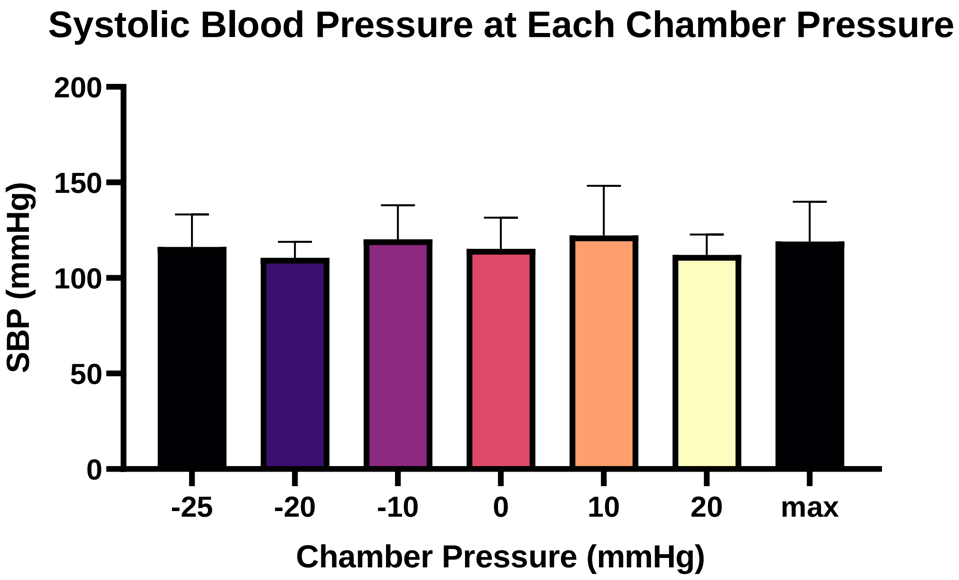
Graph 4: Average heart rate across chamber pressures. P-values for significant differences are shown on the graph.

Table 5: Means and standard deviations of heart rate across chamber pressures.

	-25mmHg	**-20mmHg**	**-10mmHg**	**0mmHg**	**10mmHg**	**20mmHg**	**max**
HR (bpm)	87.25 (12.37)	85.88 (16.33)	89.25 (14.31)	78.88 (14.10)	82.00 (13.56)	77.75 (13.58)	77.38 (15.06)

Baseline heart rate, prior to any exercise, did not differ significantly from heart rate at any positive chamber pressure. Similarly, heart rate under 0mmHg chamber pressure after completing the FTSTS test did not differ significantly from heart rate at any positive chamber pressure. Therefore, positive chamber pressures do not significantly increase cardiovascular stress for short-term exercise in our healthy young adult populations.

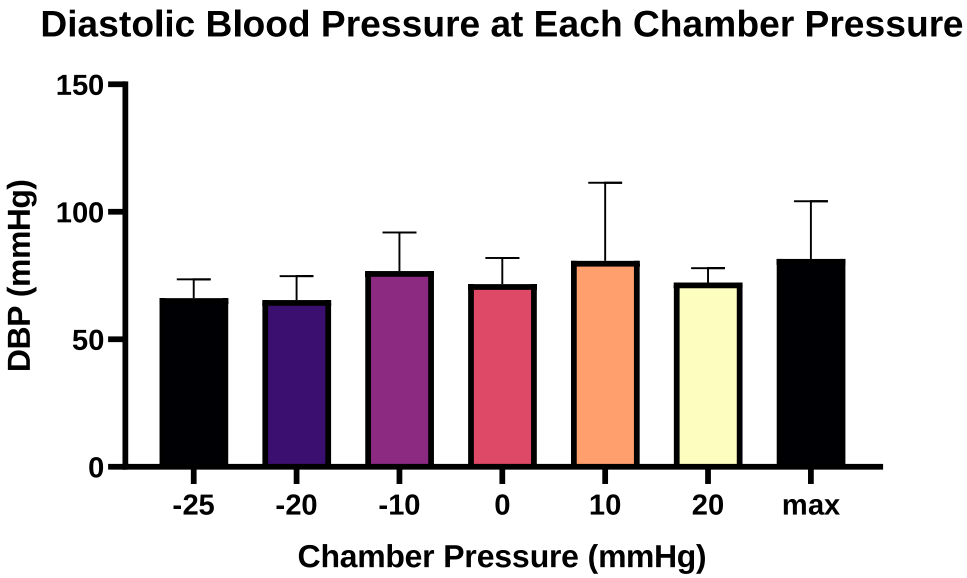
Among the negative chamber pressures, heart rate at -10mmHg significantly differed from heart rate at 0mmHg (p = 0.0111) as well as 20mmHg (p = 0.0139) and maximum (p = 0.0158) chamber pressure. Heart rate at -25 mmHg significantly differed from heart rate at 0mmHg (p = 0.0236).



Graph 5: Average systolic blood pressure across chamber pressures. No values are significantly different from one another.

Table 6: Means and standard deviations of systolic blood pressure across chamber pressures.

	-25mmHg	**-20mmHg**	**-10mmHg**	**0mmHg**	**10mmHg**	**20mmHg**	**max**
SBP (mmHg)	116.25 (17.03)	110.63 (8.22)	120.25 (17.79)	115.25 (16.40)	122.25 (26.06)	112.13 (10.58)	119.13 (20.74)



Graph 6: Average diastolic blood pressure across chamber pressures. No values are significantly different from one another.

Table 7: Means and standard deviations of diastolic blood pressure across chamber pressures.

	-25mmHg	**-20mmHg**	**-10mmHg**	**0mmHg**	**10mmHg**	**20mmHg**	**max**
DBP (mmHg)	66.13 (7.41)	65.38 (9.41)	76.75 (15.20)	71.63 (10.29)	80.75 (30.62)	72.25 (5.70)	81.50 (22.63)

As shown in Figures 5, 6 and Tables 6, 7, systolic and diastolic blood pressures did not significantly differ across various chamber pressures or from baseline blood pressures.

DISCUSSION

This feasibility study evaluating the effect of lower body positive pressure (LBPP) on young healthy adults showed that Borg values, FTSTS results, heart rate, and blood pressure were not negatively impacted by the use of the positive pressure. LBPP was used to decrease load bearing and ease the transition from seated to standing postures. All chamber pressures were significantly different from one another in resulting body weight – with more negative chamber pressures increasing load bearing and more positive chamber pressures decreasing load bearing. This decreased load bearing then results in decreased loading on the joint, increasing ease of movement.

The FTSTS test and Borg values showed no significant difference between baseline (0mmHg) and positive chamber pressures. Therefore, use of LBPP does not have any negative effect on healthy subjects' ability to complete the transition from a seated to standing position. Negative chamber pressures increased FTSTS test results and Borg values, indicating higher levels of difficulty and perceived exertion in completing the transition from seated to standing positions. Some subjects did describe more difficulty at higher chamber pressures, specifically in the transition from standing to seated, potentially due to greater resistance caused by the positive air pressure within the chamber. There may also be a training effect in play, as most subjects had never experienced LBPP before. Unfamiliarity with the machine may have caused Borg values and FTSTS values to be lowest at 10mmHg chamber pressure, which was similar to a reasonable degree of weight loss, versus higher chamber pressures which simulate drastic changes in body weight and were described as foreign sensations. Increased exposure to the machine may limit the effect that unfamiliarity has on moving within the machine. In line with other studies that use LBPP, this study demonstrated no significant differences in blood pressure – with all chamber pressures having no significant difference from baseline measurements. Similarly, heart rates under positive chamber pressures showed no significant difference from baseline measurements, which is consistent with prior work. (Chiu et al., 2012; Cutuk et al., 2006; Su et al., 2008). These findings indicate that LBPP can be used for exercising in short intervals without raising heart rate or blood pressure in the patient, making it a potential supplement to traditional physical therapy in patients where cardiovascular stress is contraindicated.

Limitations and Future Directions

There were several limitations to the current study. The subjects recruited for this study were of a relatively homogenous population: young, healthy college students who are not the primary patients of TKA or THA. While useful in evaluating feasibility, future studies recruit individuals of the same demographics as those undergoing THA and TKA for another feasibility study; and eventually a trial among THA/TKA patients and their controls to assess efficacy of LBPP on rehabilitation. Another limitation was the small sample size. We were limited in subject recruitment due to the COVID-19 pandemic. Therefore, we were unable to analyze the effect of any extraneous factors (such as age, sex, weight, and height) on the use of LBPP for easing the transition from seated to standing postures.

The activity performed in the chamber was relatively short, with each subject remaining at each pressure for a maximum of five minutes. To evaluate longer-term effects of LBPP on blood pressure, heart rate, exertion, and general patient wellness – a longer acclimatization period and more strenuous activity may be required.

Due to machine limitations, there is no set maximum value – because the quality of the waist seal differs with each individual, some subjects were able to reach higher pressure chamber values than others. Therefore, the maximum pressure is not an entirely distinct and uniform group. Furthermore, the study focused on the application of various chamber pressures rather than comparing differences in weight-bearing. As rehabilitative guidelines often use a percentage-based measurement for recommended weight bearing, calculating individual differences in weight bearing will be included in future experiments.

The measurements taken for this study were heart rate, blood pressure, FTSTS test times, Borg scale values, and body weight. Incorporating common rehabilitation metrics, such as range of knee and hip motion, may provide more relevant data as to the applicability of LBPP. Ground reaction forces may be another valuable metric as that may indicate any compensations in movement introduced by the use of LBPP.

Conclusion:

In conclusion, this study demonstrates that, in healthy populations, the use of LBPP in functional exercise does not result in negative effects on cardiovascular markers (heart rate and blood pressure) and does not increase exertion (Borg value and FTSTS test). In post-operative subjects, where rehabilitative therapy is required, LBPP may potentially be used to ease the transition between seated and standing postures. It will, at minimum, have no negative effects on heart rate and blood pressure or on the transition from seated to standing postures. Using negative chamber pressures as a comparative situation of increased stress, healthy patients have a higher ease of movement at positive chamber, seen in the lower Borg values and FTSTS test results. Therefore, post-operative subjects could potentially use LBPP to decrease load-bearing and ease the transition between seated and standing postures. Future studies are needed to determine whether LBPP can facilitate easier transitions from sit to stand in populations undergoing rehabilitation for THA and TKA.

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