Potential utility of anti-gravity treadmills in the realm of cardiovascular stress testing

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Lower body positive pressure (LBPP) treadmills, popularly known as anti-gravity treadmills are increasing in attractiveness, especially in sports and rehabilitation medicine.^{1–5} A key purpose of exercising on LBPP treadmills is to be able to maintain or enhance aerobic exercise capacity while restricting the stress induced by ground reaction forces on the lower extremities, experienced when running on a regular treadmill or on the ground, under natural conditions.⁶ In the past, before LBPP treadmills were available, such set-ups were created using harness systems that would be attached to the ceiling and provide upward force to mimic weightless running.⁷ The ‘anti-gravity’ effect afforded by the LBPP treadmills stems from the provision of body weight support (BWS) to the user. BWS is essentially an upward lifting force, allowing the user to train at a certain percentage of their body weight, and allowing aerobic exercise to occur at a reduced stress to the lower extremities. LBPP treadmills have the capability to decrease a user’s body weight from 100% to 20% of original body weight, in 1% increments. By virtue of providing BWS, exercising on LBPP treadmills requires less effort, than under natural circumstances, resulting in lesser cardiovascular training stimulus.⁸

Existing research has shown that exercising on a LBPP treadmill lowers metabolic expenditure, and increasing BWS further reduces oxygen consumption (VO₂). However, the exact correlation between VO₂, heart rate, and the BWS provided is not well established. Grabowski et al. showed the reduction in VO₂ is not linearly proportional to the amount of BWS provided, which is particularly true for higher levels of weight support.⁶ They demonstrated that metabolic expenditure was reduced by 45% when providing 75% BWS, compared to walking without BWS. Subsequently, in a study of 12 healthy active adults, Hoffman et al. showed that though the relationship between heart rate and VO₂ was linear, and not altered by three BWS levels (0%, 25% and 50%), the relationship between VO₂ and BWS was not linear.⁹ In another study, comprising male recreational runners, Vaughan et al. showed that a 20% reduction in body weight resulted in about 15% decrease in oxygen consumption and about 8% reduction in heart rate.¹⁰ The nonlinear change in heart rate with varying degree of BWS and different treadmill speeds is presented in the Table 1. Based on these findings, the following formula was proposed by the author for predicting VO₂ when running on a LBPP treadmill:

$$\begin{aligned}\text{VO}_2 = & (1.814 \times \text{Velocity}) \\ & + (0.202 \times \% \text{BW}) - (0.126 \times \text{BM}) \\ & + 3.448,\end{aligned}$$

where velocity is the running speed (km·hour), %BW is % body weight (or 100 - %BWS) and BM is body mass in kilogram.¹⁰

Studies have further demonstrated that though individuals are able to match their maximal oxygen consumption (VO₂-max) while running on a LBPP treadmill, when compared to running on a non-BWS treadmill, they achieve this by running at a faster speed or for longer durations. This is required to compensate for the decreased metabolic expenditure associated with

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Table 1. Percent reduction in heart rate while running with body weight support on lower body positive pressure treadmill

Running speed	Percentage body weight support		
	0–20% BWS	20–40% BWS	40–60% BWS
8 km-hour	8.4%	7.1%	4.7%
9.5 km-hour	7.2%	9.3%	6.2%
11 km-hour	8.7%	8.6%	7.6%

Adapted from Vaughan¹⁰

running at less than full body weight.^{6,11,12} In a population of experienced male runners, Raffalt et al. showed that LBPP treadmill does not limit the well-trained individual's ability to achieve true VO₂-max during incline running at 100% body weight, although time to exhaustion was 34.5% longer on the LBPP treadmill.¹² Furthermore, there was a systematic decline in the heart rate with increasing BWS at steady-state running. Additionally, they reported that steady-state running at 10 km-hour at full body weight resulted in a similar metabolic demand as running at 14 km-hour with 25% BWS (75% body weight) and 18 km-hour with 75% BWS (25% body weight).¹² From a population of recreational runners, Kline et al. have developed a user-friendly conversion Table 1 to determine the speeds required on a LBPP treadmill to match the equivalent metabolic output on a regular, non-BWS treadmill across a range of commonly used body weight percentages (50% through 100%).² Simply put, a greater BWS requires a greater running speed on LBPP treadmill. However, the authors interestingly noted that even without any BWS, there was still a decrease in metabolic demand. This is likely because the LBPP treadmill continues to lend a 3 to 5% BWS and provide lateral stabilization of the body, by being zipped in a pressurized chamber.^{6,8,11}

In this issue of the journal, Daly et al. examined the feasibility and safety of exercise stress SPECT myocardial perfusion imaging, with exercise stress being performed on an anti-gravity treadmill.¹³ The authors conducted a non-randomized study of 49 patients that were identified by a combination of self-perceived inability to exercise and visible physical limitations confirmed by stress lab personnel. They were then assigned to either exercise on the anti-gravity treadmill (test arm, *n* = 29) or to regadenoson stress with adjunctive low level exercise (control arm, *n* = 20). Patients in the test arm were exercised to limiting symptoms according to Bruce protocol while providing 25% BWS, with additional BWS to 50% if

they were unable to reach their target heart rate. Patients who were still unable to reach target heart rate, were injected with regadenoson at a slow walk. Patients in the control arm underwent a standard regadenoson stress test with a slow walk on a conventional treadmill. Images were acquired on a cadmium-zinc-telluride camera. Seventeen of the 29 patients in the test arm (5 requiring 25% BWS and 12 requiring 50% BWS) reached target heart rate with a mean exercise duration of 7 minutes and 36 seconds. In the entire cohort, 17 patients had abnormal perfusion results, of which 11 underwent coronary angiogram. Two patients in each of the study arms had >70% luminal narrowing on coronary angiogram. No significant difference in image quality was reported between the two groups using a subjective image quality scale. A higher resting heart rate was the only independent predictor of reaching target heart rate with exercise on the anti-gravity treadmill. This study by Daly et al. is a pilot research considering the possibility of using anti-gravity treadmill in the realm of cardiovascular stress testing. It may afford the testing physician an opportunity to exercise a patient who would otherwise be unfit to walk or run on a conventional treadmill. Given the prognostic value of exercise capacity, exercise ECG and symptoms during exercise, the ability to perform exercise stress test on an anti-gravity treadmill is extremely valuable, particularly when approximately 2/3rd of the patients referred for stress testing do not undergo an exercise stress test.

Exercise stress testing has been utilized for more than 60 years to detect myocardial ischemia in symptomatic patients with presumed coronary artery disease (CAD), as well as for prognostication and risk stratification of patients with known CAD. However, LBPP treadmills have not yet been studied in this population with suspected or known CAD, with majority of the literature stemming from exercising conditioned athletes or those undergoing physical rehabilitation. Exercise stress test on a conventional treadmill is performed according to established protocols, using a standard speed with incremental

resistance by increasing speed and incline. Patients referred for an exercise stress test may be converted to a pharmacological stress test or a combination of both if they are unable to exercise adequately for a meaningful period to allow for sufficient coronary vasodilation.¹⁴ Anti-gravity treadmills, on the other hand provide reduced cardiovascular stimulus by lowering metabolic expenditure and VO₂, while exercising at the same speed as that on a conventional treadmill. Therefore, it is likely that application of the standard Bruce or a modified-Bruce protocol, for exercise stress test on an anti-gravity treadmill, may not produce sufficient coronary vasodilation and result in falsely negative test results. One could extrapolate from previous studies of conditioned athletes that increasing the exercise duration by 35% may provide equitable stress when compared to standard protocols,¹² but this needs to be formally evaluated. Utilization of an anti-gravity exercise stress test is further complicated by reduction in cardiovascular stimulus with increasing BWS. For exercise on an anti-gravity treadmill to become clinically relevant in the realm of cardiovascular testing, rigorous development and validation of exercise protocols for differing levels of BWS will be required. Additionally, it will be critical to compare the diagnostic and prognostic value of an exercise stress test on an anti-gravity treadmill to the established clinical value of stress testing on a conventional treadmill.

Disclosures

Dr. Singh and Dr. Malhotra have nothing to disclose.

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