Research Report

Mechanical Unweighting Effects on Treadmill Exercise and Pain in Elderly People With Osteoarthritis of the Knee

Background and Purpose. People with osteoarthritis (OA) of the knee who have pain generally exhibit decreased activity and physical deconditioning. This study investigated the effects of mechanical unweighting on knee pain and exercise responses in people with OA of the knee who have pain. **Subjects.** Four men and 23 women, with a mean age of 67.9 years (SD=11.3, range=50–88) and having a 12-year average duration of knee OA, participated. **Methods.** A mechanical unloading device enabled subjects to perform a modified Naughton treadmill exercise test at 0%, 20%, and 40% of body weight support (BWS). Oxygen consumption ($\dot{V}O_2$), heart rate (HR), and perceived pain were measured during the last minute of each exercise stage. **Results.** Mechanical unweighting at 20% and 40% BWS decreased the $\dot{V}O_2$ and HR responses to treadmill exercise but did not decrease knee pain during walking in this sample. **Conclusion and Discussion.** These findings indicate that treadmill exercise accompanied by BWS permits recommended training intensities to be obtained in elderly people with OA, but may not provide pain relief in this group. [Kline Mangione K, Axen K, Haas F. Mechanical unweighting effects on treadmill exercise and pain in elderly people with osteoarthritis of the knee. *Phys Ther.* 1996;76:387–394.]

Key Words: *Arthritis, osteoarthritis; Exercise, general; Geriatrics; Heart rate; Lower extremity, knee; Oxygen consumption; Pain; Unweighting.*

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Osteoarthritis (OA) of the knee is a common rheumatological disease characterized by pain, stiffness, and decreased range of motion.[1-4] Decreased activity due to knee pain can lead to physical deconditioning, which, in turn, further attenuates the ability to carry out basic and instrumental activities of daily living. This self-perpetuating downward spiral of diminishing activity and consequent deconditioning is considered to be a major cause of the functional decline seen in some people with OA.[3,5-7]

Minor and colleagues[8,9] reported that an aerobic exercise program decreased pain, depression, and disability in a sample of deconditioned people with OA. Premature termination of exercise because of knee pain, however, might prevent people with OA from training at sufficient duration and intensity to achieve aerobic training adaptations. Exercise programs designed to minimize knee pain may therefore enable people with OA to perform longer or more strenuous exercises and thereby attain a higher level of cardiovascular reconditioning.

Aquatic exercises have been recommended for patients with knee pain because these exercises presumably cause less pain than full weight-bearing exercises, such as jogging.[10,11] There have been no reported studies that have investigated this recommendation. The use of aquatic exercises to quantify the effects of unweighting on exercise and knee pain is complicated by the uncertain effects of (1) viscosity of water on external work, (2) buoyant forces on lower-extremity joint stress, and (3) water temperature on cardiovascular function.[11,12]

The purpose of this study of 27 persons with painful OA of the knee was to investigate the effects of unweighting on knee pain and exercise responses. This investigation was accomplished by comparing the oxygen consumption ($\dot{V}O_2$), heart rate (HR), and pain responses to an individualized submaximal treadmill exercise stress test performed at three discrete levels of unweighting (0%, 20%, and 40% of body weight support [BWS]). To circumvent the technical problems inherent in aquatic exercises, unweighting was accomplished by means of a mechanical unloading system that utilized a harness suspended from a cable to reduce body weight by a predetermined amount.

The research hypothesis was that, at any given treadmill speed and inclination, $\dot{V}O_2$, HR, and perceived pain would be less at 40% of BWS as compared with 0% and 20% of BWS and less at 20% of BWS as compared with 0% of BWS.

Method

Experimental Design

A within-subjects, repeated-measures design, in which participants served as their own control, was used. Subjects performed an individualized treadmill exercise stress test at three different levels of BWS. The independent variables were the amount of mechanical unloading (%BWS) and exercise stage. The dependent variables were $\dot{V}O_2$, HR, and perceived pain.

Subjects

A convenience sample of persons 50 years of age or older with painful OA in one or both knees was recruited through flyer distribution, local advertisements, and referrals from an orthopedic surgeon. The physician who made the diagnosis of OA in each subject also gave verbal consent for the treadmill exercise tests. Exclusion criteria included the presence of rheumatic diseases other than OA; neurological disorders; cardiopulmonary conditions that precluded treadmill exercise; and

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use of medications for hypertension, cardiac disease, or pulmonary disease.

Instrumentation

Mechanical unloading during exercise was made possible by the use of a Zuni Exercise System* (Fig. 1) positioned directly above a Q55t2 treadmill.† The treadmill was calibrated prior to data collection. This system utilized a harness suspended from a cable equipped with a tensiometer that allowed a preset weight reduction to be maintained during treadmill ambulation.

Participants breathed through a mouthpiece fitted with a J valve attached to a counterweighted head support. The J valve enabled inspiration to occur from the atmosphere, and breath-by-breath samples of expired gas were collected by a Physiodyne Aerobic Analyzer.‡ The oxygen and carbon dioxide analyzers were calibrated prior to each use with room air and with 10% carbon dioxide in nitrogen. Reliability of the gas analyzers and flow and volume measurements is reported to be greater than 99%.‡ Heart rate was monitored using a single-lead electrocardiogram obtained from surface electrodes at the second intercostal space on each side of the chest and at the fifth intercostal space on the left side of the chest. These instruments provided averaged measurements of $\dot{V}o_2$ and HR every 30 seconds. Oxygen consumption and HR data for the last minute of each stage were calculated by averaging data from two 30-second periods.

Perceived pain was measured using a visual analog scale (VAS) in which participants drew a mark across a vertical line that ranged from 0 mm (no pain) to 100 mm (the worst pain imaginable). The reliability and validity of measurements obtained with the VAS have been reported by Revill et al[13] and Price et al.[14]

The Arthritis Impact Measurement Scale (AIMS2) was used to measure 12 areas of health status, to collect demographic data, and to obtain a measure of the participants' assessment of the functional and psychological impact of OA on their lives. The reliability and validity of measurements obtained with the AIMS2 have been reported by Meenan and colleagues.[15–17]

Protocol

Subjects were asked to refrain from taking pain medications for 12 hours prior to the study. Each participant gave informed consent to perform a treadmill exercise stress test under conditions of 0%, 20%, and 40% of BWS (0% of BWS was the control and first condition; the remaining conditions were randomly assigned) and then filled out the AIMS2 questionnaire. Subjects were not informed of the amount of unloading or of the possible effects of unloading on knee pain.

During an initial familiarization period, subjects received instruction and practice in treadmill walking and in the usage of the VAS to assess knee pain. After an individually determined rest period, each subject donned the harness, was unweighted to the predetermined BWS, inserted the mouthpiece, and straddled the treadmill belt. Treadmill speed was gradually increased from zero until it reached the level deemed comfortable by the subject during an initial familiarization trial (1.0–2.0 mph, depending on the subject). In accordance with the Naughton protocol,[18] treadmill speed was held constant while treadmill inclination was incremented by 3.5% at the end of every 3-minute period, or stage. All subjects held onto the handrail of the treadmill at all times. During the last 30 seconds of each stage, the subjects made a mark on their VAS (mounted on a hard surface) to indicate their perceived knee pain during exercise.

Figure 1.
Subject using the mechanical unweighting system.

*Soma Unloading™, 10711 Burnet Rd, Suite 210, Austin, TX 78758.
†Quinton Instrument Co, 2121 Terry Ave, Seattle, WA 98121.
‡Physiodyne, 34 Jeanette Dr, Massapequa, NY 11758.

Table 1.
Demographic Data of the Participants

	$\bar{X}$	SD	Range
Age (y)	67.9	11.3	50–88
Years with osteoarthritis	11.7	8.3	2–35
Height (cm)	164.4	10.7	132–188
Weight (kg)	71.1	15.0	52–103

Table 2.
Frequencies of Self-Report Measures

Pain Medication Usage	Response[a]
Every day	25.9% (n=7)
Most days	11.1% (n=3)
Some days	14.8% (n=4)
Few days	25.9% (n=7)
No days	18.5% (n=5)
Areas to improve	
Osteoarthritis pain	88.0% (n=24)
Ability to walk and bend	74.1% (n=20)
Mobility	33.3% (n=9)

[a]Percentage of participants who responded; 1 subject did not answer this question.

We planned to terminate the treadmill exercise tests when the following conditions were met: (1) attainment of an HR corresponding to 65% to 75% of the age-predicted maximum HR (220 − age [in years])[19]; (2) electrocardiographic abnormalities; or (3) complaints of discomfort from the breathing apparatus, fatigue, dizziness, chest pain, or excessive knee pain. Following each period of treadmill exercise, subjects sat quietly for an individually determined period of time until their HR returned to resting levels. Subjects stated that they were ready to resume exercise before the remaining BWS conditions (20% and 40% of BWS) were tested.

Data Analysis

Oxygen consumption per kilogram of body weight (expressed as milliliters per minute per kilogram) and HR data were analyzed by using a repeated-measures multivariate analysis of variance (MANOVA). The effects of condition (%BWS) and exercise stage were the independent factors used in the MANOVA model. A univariate analysis of variance (ANOVA) and contrasts[20] were used to test under which conditions the differences in means were statistically significant. The alpha level was set at .05. The nonparametric Sign test was used to analyze pain responses because the data obtained from the VAS were not normally distributed.[21] Frequency distributions, means, and standard deviations were calculated for each of the variables itemized in the AIMS2 questionnaire.

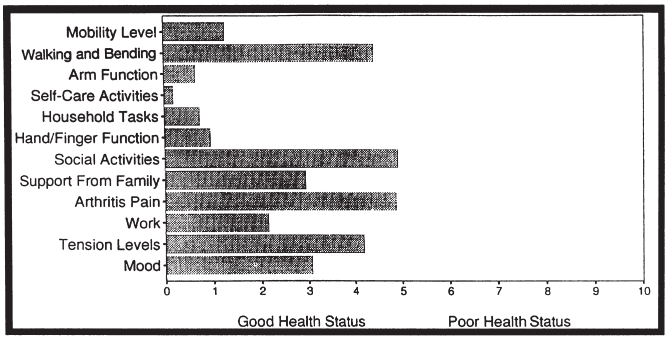

Figure 2.
Mean arthritis Impact Measurement Scale health status scores (n=27, except for work subscale [n=11]).

In the full weight-bearing condition (0% of BWS), 27 subjects completed stage 1 of the protocol (0% grade for 3 minutes), 16 subjects completed stage 2 (3.5% grade for 3 minutes), and 5 subjects completed stage 3 (7% grade for 3 minutes). Given that the statistical power for the analysis of 5 subjects was too small to detect differences between conditions,[22] only data obtained from 16 participants during the first two stages were analyzed for statistical significance.

Results

Demographic Data

This study was performed with 4 male and 23 female participants, having a mean age of 68 years and an average history of OA of nearly 12 years (Tab. 1). Assessment of the impact of OA on each subject's life was obtained from responses to the AIMS2 questionnaire, which provided (1) health status scores ranging from 0 (good health status) to 10 (poor health status) in several categories (Fig. 2), (2) data pertaining to the frequency of pain medication usage (Tab. 2), and (3) information describing the subjects' reported priority areas for improvement (Tab. 2).

The randomization was evenly distributed, as 13 subjects ambulated with 0%, 20%, and 40% of BWS and 14 subjects ambulated with 0%, 40%, and 20% of BWS. Eleven subjects ambulated at 2 mph, 7 subjects ambulated at a speed between 1 and 2 mph, and the remaining 9 subjects ambulated at 1 mph.

Effect of Unweighting on Oxygen Consumption

Figure 3 plots each subject's $\dot{V}o_2$ response during the last minute of each 3-minute stage against time for each of the three BWS conditions. In the full weight-bearing condition (0% of BWS, left panel), individual $\dot{V}o_2$ responses to treadmill exercise increased with exercise stage. The magnitude of these responses was smaller at 20% of BWS (middle panel) and even smaller at 40% of BWS (right panel). Table 3 itemizes the means and standard deviations of the $\dot{V}o_2$ data. Repeated-measures

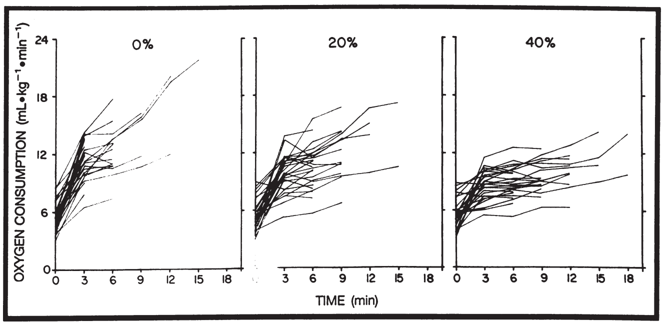

Figure 3.
Individual oxygen consumption ($\dot{V}O_2$) responses obtained during the last minute of each exercise stage plotted against time under conditions of 0%, 20%,and 40% of body weight support. Positive slope indicates $\dot{V}O_2$ increased with exercise stage.

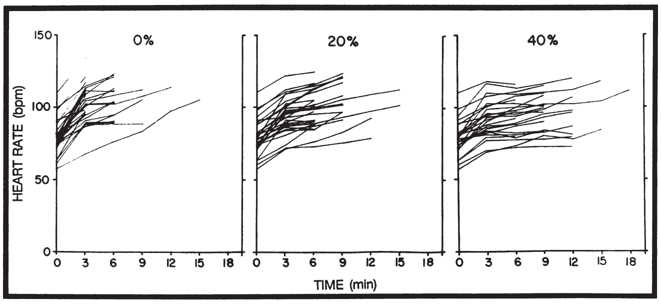

Figure 4.
Individual heart rate responses obtained during the last minute of each exercise stage plotted against time under conditions of 0%, 20%, and 40% of body weight support. Positive slope indicates heart rate increased with exercise stage.

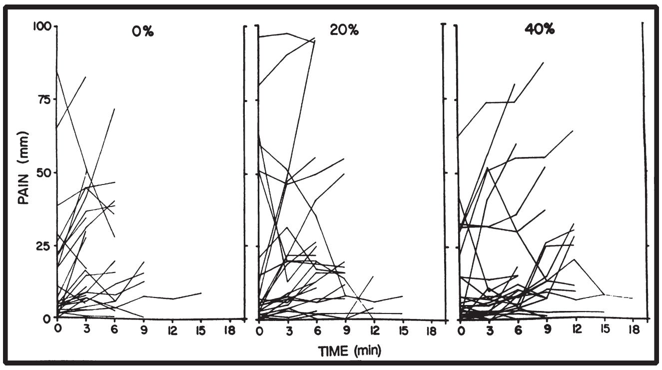

Figure 5.
Individual pain responses obtained during the last minute of each exercise stage plotted against time under conditions of 0%, 20%, and 40% of body weight support. Positive and negative slopes indicate increasing and decreasing pain, respectively.

MANOVA testing (Tab. 3) showed that $\dot{V}O_2$ decreased with unloading and increased with exercise stage.

Effect of Unweighting on Heart Rate

Figure 4 plots each subject's HR response during the last minute of each 3-minute stage against time for each of the three BWS conditions. In the full weight-bearing condition (0% of BWS, left panel), individual HR responses to treadmill exercise increased with exercise stage. The magnitude of these responses was smaller at 20% of BWS (middle panel) and even smaller at 40% of BWS (right panel). Table 3 itemizes the means and standard deviations of the HR data used in the MANOVA test. Repeated-measures MANOVA testing (Tab. 4) and univariate *F* tests showed that HR decreased with unloading and that HR increased with exercise stage (Tab. 4).

Effect of Unweighting on Pain

Figure 5 plots each subject's pain response during the last minute of each stage against time for each of the three BWS conditions. Pain responses to treadmill exercise were highly variable. Positive slopes indicate pain increased with exercise time, whereas negative slopes indicate that pain decreased with exercise time. Comparisons of conditions showed no obvious trends. Table 3 shows the means and standard deviations of the VAS data. The Sign test showed that there were no differences in VAS scores in comparisons of paired values of BWS, but differences were found in comparisons of paired values of exercise stage (Tab. 5).

Because the subjects were ambulating at the time of the marking of the VAS and were balancing the $\dot{V}O_2$ headgear, the possibility of a marking error of a few millimeters was considered. To account for this possibility, two additional Sign tests were done in which two pain measurements would be considered different only when the data differed by more than 5 mm in either direction in one analysis and 10 mm in another analysis. Results of the initial analysis (no correction factor) and the two supplemental analyses (5-mm and 10-mm correction factors) all agreed that pain did not change from condition to condition, but did increase with exercise time (Tab. 5). There was no effect on order on reported pain as determined by the Kruskal-Wallis one-way ANOVA test.

Discussion

Responses to the AIMS2 questionnaire indicated that the subjects in our study experienced problems with (1) walking and bending, (2) social activities, and (3) arthritis pain (Fig. 2); often used medication to alleviate pain (Tab. 2); and regarded pain as a priority area for improvement (Tab. 2). These data indicate that our sample of 27 people with OA of the knee closely resembled those described by Minor and colleagues,[8,9] Meenan et al,[16] and Kovar et al.[23]

Figures 3 through 5 and Table 4 support the hypothesis that, at any given treadmill speed and inclination, $\dot{V}O_2$ and HR will vary inversely with BWS. These results agree with initial reports that unweighting decreases the $\dot{V}O_2$

Table 3.
Effect of Unweighting on Oxygen Consumption ($\dot{V}O_2$), Heart Rate (HR), and Pain[a]

Percentage of Body Weight Support	$\dot{V}O_2$[b] ($mL \cdot min^{-1} \cdot kg^{-1}$)			HR[c] (bpm)			Pain[d] (mm)		
	Rest	3 min	6 min	Rest	3 min	6 min	Rest	3 min	6 min
0%									
X̄	5.3	11.1	12.2	77	99	104	15	21	21
SD	1.3	2.1	2.5	12	14	15	22	18	20
Range	3.1–7.9	6.6–14.5	7.4–17.9	57–99	68–115	76–124	0–85	1–51	1–72
20%									
X̄	5.3	10.0	10.6	77	93	97	19	21	23
SD	1.3	2.3	2.6	12	14	14	29	27	26
Range	3.1–7.9	5.4–13.8	5.7–15.5	57–99	71–111	73–116	0–96	0–97	0–94
40%									
X̄	5.3	8.8	9.3	77	92	93	12	16	19
SD	1.3	1.8	1.8	12	15	13	17	24	27
Range	3.1–7.9	5.5–11.5	5.3–12.7	57–99	69–118	71–113	0–62	0–74	0–80

[a]Values are means, standard deviations, and ranges of averaged data from subjects who completed 6 min of treadmill exercise for all body weight support conditions.
[b]n=15; 1 subject excluded due to technical problem with oxygen analyzer.
[c]n=14; 2 subjects excluded due to technical problem with oxygen analyzer.
[d]n=16.

Table 4.
Results of Pillais Multivariate *F* Tests for Main Effects

Source	n	df	F	P
Oxygen consumption				
%BWS[a]	15	2,13	18.40	.000
Time	15	2,13	29.36	.000
Heart rate				
%BWS	14	2,12	29.43	.000
Time	14	2,12	28.10	.000

[a]%BWS=percentage of body weight support.

and HR responses to a given treadmill speed in asymptomatic subjects[24,25] and those with spastic paresis.[26]

Aerobic training programs generally recommend that asymptomatic elderly people train with an HR approximating 60% of the age-predicted maximum.[5,27,28] Using this criterion, 27 subjects attained this target HR with 0% of BWS, 19 subjects attained it with 20% of BWS, and 13 subjects attained it with 40% of BWS. If the broader criterion recommended by the American College of Sports Medicine were applied (ie, 55%–90% of the age-predicted maximum),[29] 27 subjects attained this target HR at 0% and 20% of BWS and 25 subjects attained it at 40% of BWS. The fact that most subjects attained a target HR during the unweighted conditions, coupled with the fact that people exercised longer during these conditions (Figs. 3–5), suggests that the treadmill exercises described (1–2 mph with elevation) accompanied by 20% and 40% of BWS should be adequate to induce some aerobic training effects in elderly people with arthritis, who are likely to be deconditioned.[9,30] The effect of training protocols using mechanical unweighting, however, requires further investigation.

Although all stress tests were terminated because subjects either attained the target HR specified in the protocol or stated that the breathing apparatus became too uncomfortable, most subjects reported that pain increased during treadmill exercise (Fig. 5). The individual pain responses were characterized by intersubject and intrasubject variability in preexercise levels of pain as well as variability in both magnitude and direction of pain changes during exercise (Fig. 5). As a result, the group VAS data did not support the hypothesis that, at a given treadmill speed and inclination, perceived pain would be less with increasing BWS.

This marked variability in pain responses suggests that factors other than body weight might exacerbate knee pain during treadmill walking in people with OA. Possible factors include joint reaction forces, intra-articular inflammation and extra-articular forces. Unweighting reportedly reduces joint reaction forces at the knee during walking,[31] but its effects on acceleration and deceleration of the leg are not known. In a kinematic study of gait in asymptomatic young adults, mechanical unweighting decreased the percentage of stance and double support and decreased the knee mean swing angle, but did not change cycle time,[32] suggesting that the swing phase is lengthened with unweighting. Other theories suggest that pain emanates from capsular or ligamentous stretch, bony impingement, ischemia, or crystal or enzyme release.[33,34] Thus, the etiology of pain appears to be a multifactorial phenomenon ranging

Table 5.
Sign Test Results for Comparison of Pain Values by Time

Comparison Pair	Marking Error Factor[a]		
	0 mm	5 mm	10 mm
Rest to stage 1[b]			
0%	n=22*	n=14*	n=11*
20%	n=18*	n=9	n=6
40%	n=12	n=6	n=6
Rest to stage 2[c]			
0%	n=13*	n=7	n=5
20%	n=9	n=4	n=3
40%	n=12*	n=4	n=3

[a]The number of people who reported increased pain at stage 1 or stage 2 as compared with rest under the three conditions of body weight support (0%, 20%, 40%) for the three analyses of 0-mm, 5-mm, and 10-mm marking error. Asterisk (*) indicates $P<.05$.
[b]n=27.
[c]n=16.

from ground reaction forces to muscular forces to joint inflammation. These considerations might explain why mechanical unweighting, by itself, did not reliably reduce the sensation of pain in people with knee OA.

Conclusion

Mechanical unweighting at 20% and 40% of BWS blunts the $\dot{V}O_2$ and HR responses to treadmill exercise at any given level of exercise in people with OA of the knee. Unweighting did not decrease knee pain during walking in this sample of people.

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