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Energy cost of walking with flat feet

*S. OTMAN, **O. BASGÖZE and ***Y. GÖKCE-KUTSAL

**School of Physiotherapy and Rehabilitation, Hacettepe University.*
***Department of Physical Medicine and Rehabilitation, Hacettepe University*
****Ankara Rehabilitation Centre, Ankara, Turkey*

Abstract

A comparative study has been conducted to assess the effects of arch support on oxygen consumption in 20 subjects with flat feet who were generally complaining about fatigue, and also to explore whether their feeling of weariness was objective or not. The resting, walking and final recovery heart rates, blood pressures, and walking oxygen consumption values of the patients with flat feet were measured and calculated and compared to a control group using treadmill and oxygen consumption devices. In stage one the patients did not wear any arch support. Then suitable arch supports were prepared for each patient and in stage two they wore these arch supports. The results did not show any significant difference between the resting heart rates, blood pressure and oxygen consumptions. However, differences in walking heart rate, systolic blood pressure, final recovery heart rate, oxygen consumption, and energy cost values were found to be significant between stage one and two of the test in the patient group. The difference in walking diastolic blood pressure values without and with arch support were found to be insignificant. It may therefore be deduced that oxygen consumption during walking is decreased when a suitable arch support is applied to patients with flat feet.

Introduction

The term flat foot is commonly used to describe the foot in a pes valgoplanus position, in which the arched contour along the medial side of the foot is not evident. A typical feature of the condition is an outward rotation of the base of the calcaneus, called valgus because of the weight-bearing line of the leg. When a pronation deformity is present, the head of the talus, navicular, and first cuneiform bones are displaced downward and medially. An abducted forepart may be observed in the visible flat foot. The equilibrium of these structural components may change if the arches continue to deteriorate (Gray, 1969).

The mechanism of arch support in the foot remains controversial despite years of investigation. According to one theory, the arches are maintained by the contraction of muscles, according to a second, by the strength of passive tissues, and according to a third, by the combination of both muscles and passive structures (Basmajian and Stecko, 1963).

The energy cost of walking in disabled persons has received little attention except when assisted ambulation is considered. Waters and associates (1976) found that the energy cost of walking in amputee patients is increased compared with that of normal subjects, and McBeath et al (1974) and Pugh (1973) showed that in patients using different types of canes or crutches, 30 to 80 per cent more oxygen is consumed.

A survey of the recent literature has shown no comparative study on oxygen consumption of patients with flat feet before and after utilization of arch supports.

The purpose of the present work was to investigate the effects of arch support on oxygen consumption of 20 subjects (all female) with flat feet during treadmill walking.

Patients and methods

Oxygen consumption was measured in 20 patients who had flat feet and in 20 healthy people (all female) used as controls, during treadmill walking. The patients with flat feet were selected according to their X ray findings.

The subjects ranged in age from 18 to 38 (mean: 25.8 ± 1.31) in the patient group and

All correspondence to be addressed to Dr. Y. Gökce-Kutsal, Tunali Hilmi Cad, Binnaz Sok. Artek Apt. 5/14, Kavaklidere/Ankara, Turkey

from 20 to 35 (mean: 28.0 ± 1.22) in the control group. All of the subjects were evaluated clinically by means of physical examination and postural analysis, and radiographically and it was found that all were in good health.

For the diagnosis of flat feet lateral radiographs of the feet of all the subjects were taken. The angle of plantarflexed talus and the talocalcaneal angle were calculated and the values were found to be normal in the control group (Cavagna et al, 1963, Pugh, 1973). The mean values for the patient group was 40.6 (30-55) degress for angle of plantarflexed talus and 49.5 (38.5-59) degrees for talocalcaneal angle.

Footprints of the patients with flat feet were taken and the head of the first metatarsals, medial tubercle of calcaneus and sustentaculum tali were marked and the distance of these points from the heel were calculated to prepare a suitable medial longitudinal arch support made of polyethylene. The arch support was placed between insert and leather to avoid its displacement in the shoe.

Before the test each subject was evaluated electrocardiographically and no pathological change was observed.

Before the actual measurements were made, the subjects were trained to walk on the treadmill with a respiratory mask in place until they felt perfectly at ease with the apparatus. The measurements were made two hours after the patients had eaten a meal, at an ambient temperature of 18 to 20 degrees Celsius and a relative humidity of 40 to 60 per cent. The body weight and height of each patient was determined prior to each test.

The subjects were made comfortable in the sitting position and their resting oxygen consumption was measured by Versatronik Oxygen Consumption Computer Model 0-1000. Then their electrocardiographs were taken from CR_4 derivation in standing position and resting heart rates with the systolic and diastolic blood pressures were also measured.

In the first step of stage one the subjects walked steadily with the respiratory mask in place at a speed of 4.83 km. per hour on level ground for six minutes. In the second step of stage one they walked at a speed of 6.44 km. per hour on an incline of 10 per cent for six minutes. In the third step they walked at a speed of 8.05 km. per hour on an incline of 20 per cent for six minutes. Their blood pressures were measured, electrocardiographs taken, and heart rates and oxygen consumption were calculated for the walking results of stage one.

After the treadmill was stopped the recovery systolic and diastolic blood pressures of the patients were measured while sitting again and heart rates were calculated at the first, third and fifth minutes for the final recovery results of stage one.

The patients with flat feet were given their arch supports and were told to use it continuously for two weeks. In stage two the same measurements were made again for both of the groups and resting, walking and final recovery heart rates, blood pressures and oxygen consumptions were calculated.

All results were evaluated by computerized statistical methods to assess significance by means of Student t-test.

Results

The patients ranged in height from 1.55 to 1.69 metres (mean : 1.60 ± 0.00036) and the controls ranged in height from 1.60 to 1.71 metres (mean: 1.63 ± 0.00025). The patients ranged in weight from 43 to 63 kilograms (mean: 53.25 ± 1.18) and the controls ranged in weight from 45 to 62 kilograms (mean: 52.31 ± 2.01).

The resting heart rates, blood pressures and oxygen consumption values do not show a significant difference in stage one and two for both of the groups, so it can be considered as a criterion of the objectiveness of these tests ($p > 0.05$) (Table 1). The tests were planned to start in the same conditions.

Walking heart rates, systolic blood pressure, oxygen consumption, and energy cost values are given in Table 2, showing a significant decrease in stage two where the subjects wore arch supports ($p < 0.01$). No significant

Table 1. The mean resting values of the patients (n = 20).

	Stage 1	Stage 2	Difference (Std. deviation)	
Heart rates (per minutes)	91.25	89.35	0.75	(2.67)*
Systolic blood pressure (mm Hg)	113.50	111.75	1.75	(4.06)*
Oxygen consumption (ml/min)	241.25	238.50	2.75	(6.38)*

* $p > 0.05$

Table 2. The mean walking values of the patients (n = 20).

		Stage 1	Stage 2	Difference	(Std. deviation)
Heart rates (per minute)	First step	117.75	112.70	5.05	(4.79)*
	Second step	143.05	134.50	8.55	(8.66)*
	Third step	186.20	171.60	14.60	(12.34)*
Systolic blood pressure (mm Hg)	First step	118.75	116.50	2.25	(3.43)*
	Second step	128.75	124.00	4.25	(3.73)*
	Third step	138.50	131.75	6.75	(4.06)*
Oxygen consumption (ml/min)	First step	737.50	677.50	60.00	(30.78)*
	Second step	1115.50	1023.00	92.50	(90.69)*
	Third step	1618.50	1493.50	124.50	(59.25)*
Energy cost (ml/kg/min)	First step	13.90	12.76	1.14	(0.39)*
	Second step	21.07	19.30	1.76	(0.75)*
	Third step	30.79	28.28	2.51	(1.40)*

* $p < 0.01$

decrease was observed in stage two of the control group ($p > 0.05$).

Walking diastolic blood pressure values in stage one and two for both of the groups showed no significant difference ($p > 0.05$). During exercise diastolic blood pressure changes do not occur so in this test the values before and after the arch support in the patient group did not show a difference. Also the values of the control group in stage one and two did not show a difference.

The oxygen consumption values (millilitres per minute) increased during the exercise period but the increase is significantly less in stage two of the test where the subjects in the patients group wore arch supports ($p < 0.01$). No significant decrease was observed in the control group in stage two ($p > 0.05$).

The energy cost values (millilitres per kilograms per minute) were found to be significantly less in stage two ($p < 0.01$) of the patient group but no significant decrease was observed in stage two of the control group ($p > 0.05$).

Discussion

In 1938 Margaria analysed the energy cost of walking for normal subjects — uphill, downhill and on level ground at different speeds. He showed that the optimum speed (least energy cost per unit of distance) is higher the more gradual the incline, being about four to five kilometres per hour when the subject is walking on level ground. At this speed the oxygen consumed is about 100 millilitres per kilogram of body weight per kilometre. At higher or lower speeds the energy cost increases disproportionately.

According to Fisher and Gullickson (1978) normal and disabled persons naturally attempt to walk at a speed which is most efficient in terms of E_e/kcal/min. Disabled persons decrease their speed of walking, so that their E_e/kcal/min decreases toward the normal range. The more disabled a person, the more determinants of gait are lost, therefore the more E_e/unit distance is used in ambulating and the less efficient is the gait.

The energy cost of locomotion has also been analysed during treadmill walking (Falls and Humprey, 1976; Margaria, 1968; Passmore and Durnin, 1955; Bobbert, 1960). The treadmill allows control of the experimental conditions, particularly the speed of locomotion, and it has been clearly shown that treadmill walking gives substantially identical results to normal walking, the only difference being in air resistance, which is negligible at walking speeds.

When an individual is walking uphill, there is less lowering of the centre of gravity of the body (negative work) compared with the preceding lift because of the incline of the terrain, hence, there is less reutilization of the kinetic energy and a higher metabolic cost. Other aspects of the interchange of energy may also affect metabolic cost. For example, higher deceleration when the foot strikes the ground may require compensatory increase of positive work to maintain constant speed, and this higher energy cost will mean increased oxygen consumption (Veicsteinas et al. 1979).

Buskirk and Taylor (1957) reported that

maximum oxygen consumption with an incline of 10 per cent and a speed of 5-6 km per hour is 50.02 ml per kg per min in healthy people. These values are higher than in this series of tests. The results of Kasch et al (1966) were 48.25 ± 4.5 ml per kg per min maximal oxygen consumption for 12 healthy people, and Pandolf and Goldman (1975) reported 34.69 ± 2.25 ml per kg per min maximal oxygen consumption for eight healthy people. The authors' results are parallel to this.

Veicsteinas et al (1979) reported that only subjects with rigidity of the talocalcaneal joint showed increased oxygen consumption which reached 5 to 20 per cent above normal. They also showed an increased step frequency, probably as a compensatory mechanism to reduce the mechanical work performed during each step.

A control group was used in this study because it was possible that if the same patients were re-examined at two weeks without the arch support they might have improved their performance without, simply because they were now used to the test.

As a conclusion from the results of the tests it can be proposed that oxygen consumption can be decreased in patients with flat feet simply by applying a suitable arch support. This may be because flat feet require more muscular effort to accommodate the strain and avoid pain or because of abnormal forces due to the loss of the mid foot rocker.

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