Muscle Use During Exercise: A Comparison of Conventional Weight Equipment to Pilates With and Without a Resistive Exercise Device

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ABSTRACT

Six subjects between the ages of 18 and 30 years old were examined to compare use of the quadriceps, hamstring, gluteus maximus, hip abductor, hip adductor, abdominal, gastrocnemius and paraspinal muscles as assessed by electromyogram (EMG). Muscle use was measured during all forms of exercise and exercise using conventional weight lifting equipment was compared to exercise during Pilates with and without a resistive device called the "Zone Pilates Sculpter" (Savvier LP, Santa Fe Springs, Calif). The ability of the Pilates device to restrict movement in adverse directions and thereby, reduce potential injuries during exercise was also assessed. The results of the experiments showed that Pilates, while good for endurance training, resulted in only minimal muscle activity in core muscles (abdominal and paraspinal muscles) compared to exercise on commercial weight lifting equipment. However, the addition of the resistive device to Pilates exercise, increased the workload substantially, such that exercise during Pilates was equivalent to a medium intensity workout on commercial weight lifting equipment. However, unlike commercial exercise equipment, Pilates and the resistive device exercised multiple muscle groups simultaneously and thereby provided a more efficient workout than commercial weight lifting equipment. The resistive device also restricted adverse movement at the joints during exercise making exercise smoother and safer.

INTRODUCTION

Physical inactivity is a predisposing factor to obesity. A key issue in obesity is

Table 1. General Characteristics of Subjects (group average)

	Age (years)	Height (cm)	Weight (kg)
Mean	25.3	169.9	69.8
SD	1.5	6.7	9.6

Male, n = 4; female, n=2

that it is highly correlated with inflammation in the entire body.[2] Adipogenesis is a highly regulated process and, with excess adipose tissue in the body, hormonal responses increase inflammatory cytokines.[3-5] Chronic inflammation associated with obesity eventually leads to disorders such as diabetes.[6,7]

Simply reducing weight through dieting, while increasing the uptake of glucose in muscle,[8] is not the best answer to the problem of obesity. While dieting increases thermogenesis[9] and oxygen consumption,[10] exercise and dieting together cause a twenty-four hour increase in metabolism and a reduction in inflammation in the body.[10-13]

Unfortunately, for people with disabilities or the elderly, reducing caloric intake coupled with heavy exercise for weight loss[14-16] is difficult due to physical limitations.[17] Because of the limitations in rehabilitation due to age, back and knee injuries, a number of investigators have used Pilates as an exercise modality.[18,19] Pilates is a form of exercise that originally involved low-impact floor and mat exercises without equipment. Subsequently, while some Pilates have remained in this pure form, others have modified Pilates exercise with the use equipment. Pilates has been used both in outpatient settings and in acute hospital settings.[17] Pilates has been tried alone and in combination with manipulation.[20] While Pilates has increased in popularity (10 years ago 5,000 people were involved in Pilates; today the number is over 5 million),[21] muscle strengthening with Pilates, while acceptable, is not as extensive as that seen after weight lifting exercise.[22]

Thus, while strength-training exercise is useful for building muscle strength, and aerobic exercise is useful for building endurance, in many cases, people with disabilities are unable to perform either of these exercises. In contrast, Pilates, without the use of equipment, increases cardiovascular fitness and the range of motion of joints, but does not provide adequate strength training compared to commercial weight lifting equipment.

An intermediary between the two types of exercise (Pilates and commercial weight lifting equipment) is a type of Pilates called Zone Pilates. In Zone Pilates, a light resistive band is used to keep the joints in alignment during exercise and to provide resistance. The present investigation was conducted to examine the effects of such a resistive band on muscle use compared to Pilates without a resistive band and to commercial exercise equipment.

SUBJECTS

The 6 subjects were male (4) and female (2) aged 18 to 35 years old. All subjects were fit and free of any cardiovascular, neuromuscular, or orthopedic injuries. All methods and procedures were explained to each subject who then signed a statement of Informed Consent approved by the Human Review

Figure 1. Measurement of maximum muscle strength in the hip adductors during manual resistance applied by one of the research personnel.

Figure 3. A study participant engaged in hip adduction against the resistive device used in the study. EMG was measured from 8 muscle groups.

Committee at Azusa Pacific University. The general characteristics of the subjects are shown in Table 1 including their average age, height, and weight.

METHODS

Determination of Muscle Activity

Muscle activity was determined through the use of the electromyogram (EMG). The electromyogram represents an interference pattern that reflects the

Figure 2. A study participant engaged in squatting exercises with the resistive device placed around the knees. EMG activity was measured from 8 muscle groups.

activity of the underlying muscle.[23] Since the relationship between tension and EMG is linear,[24,25] the electromyogram was used to assess movement. Muscle activity was assessed by determining the maximum EMG of the muscle during a maximal effort and then, during any exercise, assessing the percent of maximum EMG to calculate the percent of maximum muscle activity that was used.[25,26] Two electrodes were applied, one on the belly of the muscle and one 2 cm distal to the belly for any given muscle. A third electrode, the ground, was attached within 4 cm of the 2 active electrodes. The electrical output from the muscle was amplified with a biopotential amplifier whose frequency response was flat from DC to 1000 Hz and amplified with a gain of 5000 (Biopac Incorporated, Santa Barbara, Calif). The amplified EMG was digitized with an analog to digital converter (12 bit) and sampled at a frequency of 2000

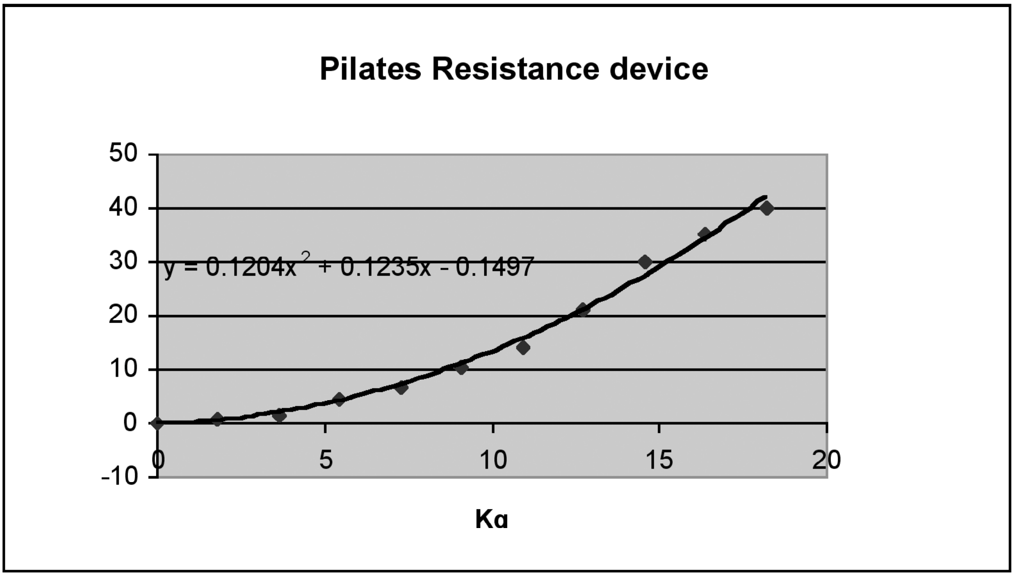

Figure 4. The relationship between the distance of separation of the Pilates' resistive device and force is illustrated. The relationship, as predicted by Hook's Law, is slightly non-linear. The regression equation with the second order Polynomial fit is $y = 0.1204x^2 + 0.1235x - 0.1497$. In use, however, the distance used to open the resistive device in actual exercises never exceeded approximately 20 cm and therefore, the device is used in a fairly linear range of resistance versus displacement.

samples per second and stored on an IBM Pentium 4 Digital Computer. The digitizer was an MP100 (Biopac Incorporated, Santa Barbara, Calif). The amplitude of the EMG was analyzed by taking the absolute value of the digitized data and then calculating the root mean square value of the EMG.

Maximum strength was measured over a three second period by asking the subject to exert a maximal effort with the body in a position to isolate each muscle being studied (Figure 1).[27] Three such contractions were exerted with 1 minute between contractions. The maximum EMG recorded during the 3 contractions was recorded to normalize all EMG data. During exercise, EMG was sampled over a one second period and the percent of muscle activity was assessed by dividing the EMG during exercise by the maximum EMG during a maximal effort. This technique is described elsewhere.[28]

Resistive Device During Pilates

The resistive device used during Pilates is an oblong ring with a resistive band included. On one part of the band there is a hinge and by opening the other end of the band, resistance is applied to the body (Figures 2 and 3). The relationship between band separation and tension is shown in the graph in Figure 4. As seen in Figure 4, the relationship between tension and stretch obeys Hook's Law and provides a linear change in resistance with the degree of expansion of the band. To exercise a given muscle, such as the hip adductors, the band was placed in position on the body (as shown in Figure 3), and the legs would be adducted while EMG was measured.

Commercial Weight Lifting Equipment

Back extensor and flexor, leg abduction-adduction (inner outer thigh machine), abdominal, quadriceps, and hamstring strength measurements and muscle

Table 2. Exercises Performed in Study

Pilates Exercise	Machine Exercise
45° squat	Quad machine
90° squat	Quad machine
Left leg adduction	Inner outer thigh
Right leg adduction	Inner outer thigh
Left hip extension	Hamstring machine
Right hip extension	Hamstring machine

activity during submaximal work was accomplished on a Keiser weight lifting system (Wilmington, Del). The system uses compressed air to operate pistons and to apply resistance during exercise.

PROCEDURES

Three series of experiments were performed on each subject. In the first series, exercise was performed during Pilates and EMG was sampled. The exercises chosen are shown in Table 2. The exercises were performed with and without the resistance device and included (as shown in Table 2) a variety of leg exercises involving flexion, extension, abduction, and adduction of the hip.

Table 3. Muscle Use Data from Commercial Weight Lifting Equipment as a Percentage of Maximal Strength*

Exercise	Abdominal	Paraspinal	Quads	Hams	Hip abs	Hip ads	Glut	Gastroc
Quad low	22.67	24.05	24.85	5.83	8.67	12.19	18.92	3.67
Quad med	18.13	25.54	33.83	7.67	6.83	24.57	20.60	4.83
Quad high	28.60	31.37	49.50	8.67	12.17	27.93	25.48	5.50
Ham low	18.57	30.92	13.00	21.67	15.30	11.46	36.20	11.05
Ham med	26.56	33.40	13.64	29.35	15.75	24.82	40.41	5.50
Ham high	29.17	36.96	16.83	43.57	16.23	29.99	43.76	6.10
Abd low	26.33	6.50	6.00	14.83	8.00	13.12	16.75	6.50
Abd med	34.49	11.87	5.83	9.00	10.00	10.50	7.89	5.83
Abd high	44.00	4.83	4.50	10.00	6.50	7.00	20.89	4.33
Back low	5.00	27.54	7.17	6.50	9.24	8.70	4.67	8.51
Back med	8.50	31.25	6.50	6.50	8.27	7.00	5.83	6.83
Back high	8.83	40.94	7.67	7.47	6.00	7.86	7.50	10.24

*Quads indicates quadriceps; hams, hamstring; hip abs, hip abductor; hip ads, hip adductor; gluts, gluteus maximus; and gastroc, gastrocnemius.

Table 4. Muscle Use Data from Commercial Weight Lifting Equipment—Standard Deviations

Exercise	Abdominals	Paraspinals	Quads	Hams	Hip Abs	Hip Ads	Glut	Gastroc
Quad low	2.25	16.29	1.95	1.47	3.14	6.40	9.24	1.75
Quad med	10.19	11.08	4.40	2.16	2.48	6.73	6.50	2.64
Quad high	15.43	12.65	6.09	2.58	5.56	9.34	6.16	2.43
Ham low	7.81	16.55	5.10	8.84	11.53	6.37	10.33	5.62
Ham med	11.40	13.75	4.24	3.79	7.85	6.91	10.98	1.87
Ham high	6.55	19.48	5.34	24.68	10.96	12.35	9.47	1.87
Abd low	4.18	1.87	1.41	4.17	3.03	8.94	8.23	3.27
Abd med	10.33	1.73	1.72	2.10	6.99	4.32	6.57	1.94
Abd high	6.36	1.47	1.05	4.65	1.87	4.43	13.56	3.33
Back low	1.79	11.65	3.76	1.87	6.18	2.62	2.50	6.49
Back med	2.88	16.02	1.05	1.87	6.86	1.41	1.72	1.60
Back high	2.32	15.02	2.73	1.03	1.79	4.43	2.43	6.23

*Quads indicates quadriceps; hams, hamstring; hip abs, hip abductor; hip ads, hip adductor; gluts, gluteus maximus; and gastroc, gastrocnemius.

In the second series of experiments on the same subjects, the same muscles were exercised and assessed, but with the addition of the rubber exercise band, as previously described. Finally, once EMG was assessed, exercise was performed in a gymnasium on standard exercise equipment (ie, quadriceps and hamstring weight lifting machines) and the weight applied on each exercise machine was determined to compare with the results of EMG activity during Pilates without resistance and with resistance. For the quadriceps machine, the workloads were 9 kg, 15.9 kg, and 22.7 kg for light, medium, and heavy loads. The loads on the hamstring machine were set at 9 kg (light), 13.6 kg (medium), and 18.18 kg (heavy). The workloads for the abdominal flexion machine were set somewhat higher at 18.1 kg (light), 36.3 kg (medium), and 54.5 kg (heavy). Finally, workloads were set at 22.7 kg (light), 29.5 kg (medium), and 36.3 kg (heavy) for the back extensor muscles.

Statistical Analysis

Statistical analysis involved the calculations of means, standard deviations, and *t* tests. ANOVA was also used to compare data between groups. The level of significance was set at $P < 0.05$.

RESULTS

Analysis of muscle activity was accomplished on 4 types of commercial exercise equipment, a quadriceps machine, a

Table 5. Muscle Use for subjects with No Resistance Band During Pilates Exercise as Percentage of Maximum Activity*

Exercise	Abdominal	Paraspinal	Quads	Hams	Hip abs	Hip ads	Glut	Gastroc
45° squat	23.7	27.7	28.2	4.8	22.1	20.7	27.2	19.1
90° squat	31.2	37.0	37.5	8.2	28.4	30.7	35.2	26.5
Left hip adduction	28.1	31.0	23.8	13.0	16.0	13.8	24.9	21.7
Right hip adduction	24.2	35.1	3.7	11.5	3.8	20.7	34.1	5.3
Left hip extension	29.9	37.4	29.8	12.3	13.0	9.8	24.3	15.2
Right hip extension	32.2	42.7	21.7	20.6	13.2	12.6	48.5	11.5

*Quads indicates quadriceps; hams, hamstring; hip abs, hip abductor; hip ads, hip adductor; gluts, gluteus maximus; and gastroc, gastrocnemius.

hamstring machine, an abdominal flexion machine, and a back extension machine, as described under methods. The results of the analysis of EMG of the abdominals (abs), paraspinal muscles (erector spinae), quadriceps, hamstring, hip abductors/adductor, gastrocnemius, and gluteus maximus muscles are shown in Tables 3 and 4. Table 3 shows the average EMG data, whereas Table 4 illustrates the respective standard deviations. The exercise was somewhat specific to the type of machine (Table 3). For example, exercise on the quadriceps muscles by leg extension with the lowest weight yielded muscle activity of 24.85% maximum strength. For the medium load, the muscle activity was 33.83%, and for high loads, it averaged 49.5%. The loads were different on different machines. Exercise on each machine showed a progressive increase in muscle use associated with an increase in the workload. However, it was surprising that the abdominals and paraspinals were also active. For example, to lift a medium load on the quadriceps machine, quadriceps activity was 33.8% of total muscle activity (Table 3). At the same time, the abdominal flexors were 18.1% active and paraspinals 25.54% active. Since the abdominal and paraspinal muscles are agonist/antagonist pairs, this seems to show an isometric component of the exercise, stabilizing the core muscles to extend the quadriceps muscles. This was also true during exercise on the quadriceps and hamstring machines.

The EMG activity of the quadriceps, hamstring, gluteus maximus, gastrocnemius, hip adductors, hip abductors, and the abdominal and paraspinal muscles is shown in Tables 5 to 9 for exercise using Pilates. The specific exercises performed were the 45° squat, 90° squat (Figure 2), left hip adduction (Figure 3), right hip adduction, left hip extension, and right hip extension. Muscle use was minimal during Pilates exercise as demonstrated by the EMG activity (Table 5, 6). In particular, abdominal activity averaged less than 10% of the strength of the muscles during any of the activities listed in

Table 6. Standard Deviation of Muscle Use for Subjects with No Resistance Band During Pilate Exercise*

Exercise	Abdominal	Paraspinal	Quads	Hams	Hip abs	Hip ads	Glut	Gastroc
45° squat	4.5	6.9	7.4	2.9	9.3	2.8	7.0	3.7
90° squat	4.3	3.2	13.4	4.9	6.7	6.1	3.9	11.8
Left hip adduction	4.6	6.4	3.6	4.3	3.8	7.2	3.4	2.6
Right hip adduction	2.6	3.5	2.2	2.5	1.5	3.9	6.9	3.5
Left hip extension	4.3	4.0	5.2	2.2	3.7	4.1	2.6	4.3
Right hip extension	2.9	2.6	2.4	2.9	2.2	4.0	6.1	1.0

*Quads indicates quadriceps; hams, hamstring; hip abs, hip abductor; hip ads, hip adductor; gluts, gluteus maximus; and gastroc, gastrocnemius.

Table 5. However, some muscles did become active in specific exercises. The most difficult exercise was the 90° squat, in which case the quadriceps muscles were approximately 40% active (Table 5,6). Thus for the 6 subjects shown in these experiments, normal extension and rotation of the hip (hip adduction, hip abduction, and hip extension) showed little muscle activity during standard Pilates exercises. Only when there was a significant load on the muscle, such as during the 90° squat, did muscle activity increase to higher levels.

This was not the result when the resistance band was added. When the resistive band was stretched from 0 cm to 40 cm, there was almost a linear relationship between load and the distance stretched (Figure 7). There was a slight non-linearity at higher loads, although this fits Hooks Law of elasticity. However, the maximum distance that was used to stretch the band during normal exercise was not even half this amount (Table 7). For example, during left hip abduction to a 45° angle of the hip, the total stretch of the bands was only 21 cm. This puts the band in the linear range of force versus stretch and removes the non-linearity's that are normally seen with any elastic structure under Hook's Law. As shown in this table, the greatest degree of stretch in the band was for hip adduction followed very closely by hip extension. Band movement was very slight during 45° and 90° squats. Thus, for example, the force exerted on the legs during a left hip abduction for a typical subject is 12 kg, whereas the force averaged approximately 10.5 kg for hip extension. The force exerted on legs during squats averaged 4.6 kg for a 45° squat and 5.5 kg for a 90° squat.

Forty-five degree and 90° squats, as cited above, have their own inherent workload placed on the body because of the fact that body alignment is from the neutral position where weight is born by

Table 7. Forces Applied by a Typical Subject During Exercise with Resistive Band

Exercise	Distance (cm)	Force (kg)
45° squat	4.5	4.6
90° squat	6.5	5.5
Left hip adduction	21.5	12.0
Right hip adduction	21.0	11.8
Left hip extension	17.5	10.3
Right hip extension	18.5	10.7

the joints (Table 8). Weight bearing is no longer down the axis of the bones and weight must be compensated for at the hips, knees, abdominal area, and back through muscle activity. Therefore, this exercise provides a good form of exercise. The bands reduce the amount of abductor/adductor activity; so with abductor/adductor activity low, the following conclusion can be drawn: it is obvious that there is more stability during the exercise provided by the bands than was achieved by voluntary control of joints, since muscles are not necessary to stabilize the joints (Table 8).

The results of muscle use during Pilates without resistance bands are shown in Table 6, and the standard deviations are shown in Table 7. The average muscle use of the subjects with the resistance bands for Pilates is shown in Table 8 and the standard deviations for these measurements are shown in Table 9. Muscle use during the 45° and 90° squat showed significantly higher use in the quadriceps, paraspinals, abdominals, gluteus maximus, and gastrocnemius muscles in the 90° squat compared to the 45° squat ($P < 0.05$) (Tables 8 and 9). The activity of the quadriceps muscles

Table 8. Muscle Use for Subjects with Resistance Band During Pilates Exercise as Percentage of Muscle Strength*

Exercise	Abdominal	Paraspinal	Quads	Hams	Hip abs	Hip ads	Glut	Gastroc
45° squat	27.1	29.5	27.2	3.3	11.2	11.3	29.0	22.1
90° squat	36.8	42.1	40.4	4.7	9.6	12.6	39.4	29.4
Left hip adduction	34.2	40.2	47.0	10.8	44.3	20.5	30.6	28.5
Right hip adduction	45.0	47.7	4.5	10.5	3.7	32.7	44.4	3.7
Left hip extension	33.4	45.6	21.7	12.5	11.5	13.5	26.4	13.3
Right hip extension	41.3	51.0	23.0	43.2	16.3	28.0	71.5	17.3

*Quads indicates quadriceps; hams, hamstring; hip abs, hip abductor; hip ads, hip adductor; gluts, gluteus maximus; and gastroc, gastrocnemius.

Table 9. Standard Deviation of Muscle Use for Subjects with Resistance Band During Pilates Exercise*

Exercise	Abdominal	Paraspinal	Quads	Hams	Hip abs	Hip ads	Glut	Gastroc
45° squat	4.7	5.3	4.3	6.7	5.1	7.3	8.2	5.1
90° squat	7.2	6.4	5.9	5.5	3.7	7.1	5.2	5.3
Left hip adduction	2.4	2.7	3.7	2.5	2.1	2.5	3.4	5.7
Right hip adduction	5.5	5.5	1.6	1.4	1.4	2.3	5.5	2.5
Left hip extension	6.2	13.5	2.2	1.9	3.8	7.8	8.1	5.5
Right hip extension	9.0	2.3	4.9	4.6	3.2	4.2	7.6	5.4

*Quads indicates quadriceps; hams, hamstring; hip abs, hip abductor; hip ads, hip adductor; gluts, gluteus maximus; and gastroc, gastrocnemius.

corresponded to the load on the quadriceps leg extension machine (commercial weight trainer) with equivalent activity between the low and medium load settings for the 45° squat and was equivalent to almost the highest load that we examined for the 90° squat. Therefore, abdominal and paraspinal activity, during the 90° squat without resistance, was higher than that seen on the commercial weight lifting equipment during quadriceps activity, but less than during activity on the abdominal exercising machine.

When resistance was added during squat exercises with the Pilates resistance device, intensity of muscle activity increased in the abdominal, paraspinal, and quadriceps muscles, while it did not affect the hamstring muscles. The activity in the hip abductors/adductors was reduced by over 50%. Gluteus maximus activity and gastrocnemius activity showed no significant difference ($P > 0.05$). In other words, the resistive device increased the workload slightly on the quadriceps and abdominal muscles and seemed to stabilize the hip joint, but lowered activity on the hip abductors and adductors (Tables 8 and 9).

The muscle use during left and right hip abduction and adduction with and without the use of the Pilates resistance device are also shown (Tables 8 and 9). For example, when performing Pilates with no resistance, the muscle use for the abdominals and paraspinals still remained somewhat high, but was not statistically different from that used to stabilize the core during squats ($P > 0.05$). With electrodes on the right side of the body, when the left hip was adducted, quadriceps activity averaged 23.8% of total muscle activity, this being equivalent to the lowest workload on the quadriceps leg extension machine. Hamstring activity was low, but hip abduction and adduction showed low levels of activity, while gluteus maximus activity was high to help stabilize the body. In contrast, when the opposite leg was adducted, abdominal and paraspinal activity again remained at about 25% with quadriceps activity no longer needed, while to extend the leg the hip abductors activity increased to about 20% of total muscle activity. Gluteus maximus muscle activity also increased to 34.1% of total muscle activity, whereas the gastrocnemius muscle was quiescent because of its lack of use on the extended leg. In contrast, once the resistive device was added, muscle activity changed (Tables 8 and 9). Since the resistance device provided resistance to adduction, the increased workload caused increased activity in the paraspinals and abdominal muscles (Tables 8 and 9). For example, during right hip abduction, (the side the electrodes were on) muscle activity ranged from 24% with no resistive device to 45.0% when the resistive device was used, more than doubling of muscle activity. This also was true of the paraspinal muscles. Quadriceps muscles also worked harder during left hip abduction, and hip abductors and adductors doubled their activity during the exercise. Gluteus maximus muscle activity increased by approximately 25%, as did the gastrocnemius muscle. Thus, the overall effect of adding a resistive device was to increase workload dramatically during hip adduction on both the left and right side of the body. It should be noted that with the resistance device for right hip abduction, the abdominal muscle activity was equal to the highest abdominal exercise used on the commercial gym equipment. Thus, the use of the resistive device provided a substantial increase in the level of workout equivalent to that of a heavy workout on commercial gym equipment, at least for the abdominal and paraspinal muscles.

Data was also collected showing muscle activity during left hip extension and right hip extension. Again here, electrodes were on the right leg. Quadriceps were more active during left hip extension than right hip extension because when the left hip was extended, the right quadriceps were used to help stabilize the body. Therefore, 29.8% of the quadriceps was active. Further, during left and right extension, there was significant activity in the abdominals and paraspinal muscles, amounting to about one-third maximum strength of the muscles as shown in the tables. The gastrocnemius muscle was slightly active to stabilize the lower leg but was barely used during these exercises. The greatest activity in the gastrocnemius was during left hip extension since the gastrocnemius muscle was used to help stabilize the fixed leg.

The change in muscle use for exercise involving left and right hip extension with the Pilates resistance band is shown in Table 8. With the resistance band applied, there was a significant ($P < 0.01$) increase in activity in the gluteus maximus, abdominal muscles, paraspinals, quadriceps muscles, and hamstring muscles. The hip abductor/adductors had only a small increase in activity whereas for the other muscles, there was a much larger increase in muscle activity. Obviously, for the side of body not involved in the exercise, there was still an increase in muscle activity but the increase was less than during active exercise. For example, when comparing the right hip extension with no resistance, the EMG activity for the gluteus maximus muscle on the right hip was 48.5% of total muscle activity (Table 6). Muscle activity increased to 71.5% with the resistive band applied. Abdominal muscle activity, with the band applied, was over 40% of total activity. On the commercial weight lifting equipment, abdominal crunch machine, this is equivalent to a resistance of 54.5 kg. Thus, with the resistance added during Pilates, muscle activity for the abdominals, paraspinals, gluteus maximus muscles, and hamstring muscles was equivalent to workouts exceeding 50 kg on commercial weight lifting equipment. The difference, however, was on the weight lifting equipment where the exercise was fairly specific for the muscle being tested whereas during Pilates exercise was seen on all 8 muscles groups examined here.

However, during hip adduction/abduction and extension/flexion, the additional load caused substantial increases in EMG activity. This is not surprising since the resistance band was placed halfway between the hip joint and the knee. As such then, by placing the resistance further away from the actual hip, the body had to work against a lever arm to extend the band. Therefore, the resistance of the band was amplified providing average muscle activity for the hip abductors of 44.3% (Table 8) compared to 13% with no band being used (Table 6). Thus exercise was substantially higher in intensity using the band for the exercises examined here.

Probably the best example of the high work levels being accomplished is to compare exercise on conventional weight lifting equipment to exercise with Pilates. Lifting 3 progressive loads during quadriceps leg extension, hamstring flexion, and other exercise, as shown in Table 4, established an equivalent workload to compare Pilates against. Muscle activity during Pilates with the bands was equivalent to the medium weight level on commercial exercise equipment. However, as noted in Table 4, most of the muscles were quiescent on these pieces of equipment except for the muscle being studied, ie, a quadriceps machine exercised the quadriceps muscle. In performing Pilates with a resistive band, all muscles were active, providing a more balanced workout for more muscle groups than provided on one piece of commercial exercise equipment alone.

DISCUSSION

It has been estimated in a recent magazine article in *Newsweek* that over 5 million people are using Pilates for exercise in the United States.[21] Harvard's Women's Health Watch promotes Pilates as a good, safe method for exercise and conditioning.[22] Chiropractors have also promoted Pilates for the treatment of adult scoliosis.[20] Pilates has also been used with acutely ill hospitalized adults.[17] While Pilates has been effective for treating lower back pain and other disorders,[18] it provides only minimal resistance exercise.[17] Without resistance during exercise, aerobic demand is not at a high enough level to reduce inflammatory cytokines, and increase whole body metabolism for weight control.[29,10,13] Thus to reduce leptin and reduce cytokines, heavier exercise is necessary.[30] In the present investigation, the use of a resistive device during Pilates increased the workload dramatically. The workload for Pilates alone in the present investigation was very light averaging 20% of the total muscle activity for the hamstring, quadriceps, and gluteus maximus muscles respectively. With the addition of resistive bands, the workload dramatically increased by at least 50%. This increase in muscle activity, in turn, will be beneficial for weight loss, muscle conditioning (firming, toning, and strength conditioning), and reducing inflammatory cytokines associated with diabetes and obesity. When compared to conventional weight lifting equipment, the exercise load is moderate. Much heavier activity in muscles can be seen with the use of conventional weight lifting equipment as shown in the present investigation, but such heavy loads would be detrimental to patients with disabilities or individuals wishing to simply increase aerobic fitness and muscle tone. Commercial weight lifting equipment generally causes an increase in muscle strength and hypertrophy in muscle without aerobic conditioning.[31] Therefore, the goals of lifting with conventional weight lifting equipment are very different than that of aerobic exercise. By adding a resistive device to Pilates, aerobic exercise can be done at a much greater level and should increase muscle tone more effectively than Pilates without the resistance device.

An added benefit of the resistive device is that by using an oblong resistive device that can circumvent the limb, the joints are stabilized and kept in alignment during exercise (ie, helps to guide the user through the movement). From an orthopedic standpoint, this places less stress on knees, hips, and ankle joints as well as upper body joints, so that there is less chance of injury. The present investigation then, showed a marked advantage in using this device during Pilates.

REFERENCES

1. Tremblay MS, Willms JD. Is the Canadian childhood obesity epidemic related to physical inactivity? *Int J Obes Relat Metab Disord*. 2003;27(9):1100-1105.
2. Harp JB. New insights into inhibitors of adipogenesis. *Curr Opin Lipidol*. 2004;15(3):303-307.
3. Bray GA. Medical consequences of obesity. *J Clin Endocrinol Metab*. 2004;89(6):2583-2589.
4. Juge-Aubry CE, Somm E, Chicheportiche R, et al. Regulatory effects of interleukin (IL)-1, interferon-beta, and IL-4 on the production of IL-1 receptor antagonist by human adipose tissue. *J Clin Endocrinol Metab*. 2004;89(6):2652-2658.
5. Cottam DR, Mattar SG, Barinas-Mitchell E, et al. The chronic inflammatory hypothesis for the morbidity associated with morbid obesity: implications and effects of weight loss. *Obes Surg*. 2004;14(5):589-600.
6. Lee YH, White MF. Insulin receptor substrate proteins and diabetes. *Arch Pharm Res*. 2004;27(4):361-370.
7. Weiss R, Dziura J, Burgert TS, et al. Obesity and the metabolic syndrome in children and adolescents. *N Engl J Med*. 2004;350(23):2362-2374.
8. Martin B, Robinson S, Robertshaw D. Influence of diet on leg uptake of glucose during heavy exercise. *Am J Clin Nutr.* 1978;31(1):62-67.
9. Thorne A. Diet-induced thermogenesis. An experimental study in healthy and obese individuals. *Acta Chir Scand Suppl.* 1990;558:6-59.
10. Bahr R, Sejersted OM. Effect of feeding and fasting on excess postexercise oxygen consumption. *J Appl Physiol*. 1991;71(6):2088-2093.
11. Hill JO, Heymsfield SB, McMannus C 3rd, DiGirolamo M. Aug Meal size and thermic response to food in male subjects as a function of maximum aerobic capacity. *Metabolism*. 1984;33(8):743-749.
12. Bahr R, Gronnerod O, Sejersted OM. Effect of supramaximal exercise on excess postexercise O_2 consumption. *Med Sci Sports Exerc*. 1992;24(1):66-71.
13. Samueloff S, Beer G, Blondheim SH. Influence of physical activity on the thermic effect of food in young men. *Isr J Med Sci*. 1982;18(1):193-196.
14. Petrofsky J, Macnider BS, Navarro BS, Bweir S, Lee S. Toward a more objective analysis of gait in patients with diabetes. *Diabetes.* 2003;52;2465.
15. Petrofsky JS, Bonacci J, Bonilla, T, et al. Cardiovascular and fitness benefits of a one-month home exercise and weight loss program. *J Appl Res*. 2004;4:610-624.
16. Petrofsky JS, Bonacci J, Bonilla T, et al. Can a one-week diet and exercise program cause significant changes in weight, girth and blood chemistry? *J Appl Res.* 2004;4:369-375.
17. Mallery LH, MacDonald EA, Hubley-Kozey CL, Earl ME, Rockwood K, MacKnight C. The Feasibility of performing resistance exercise with acutely ill hospitalized older adults. *BMC Geriatr*. 2003;3(1):3.
18. Maher CG. Effective physical treatment for chronic low back pain. *Orthop Clin North Am.* 2004;35(1):57-64.
19. Shand D. Pilates to pit. *Lancet*. 2004;363:1340.
20. Blum CL. Chiropractic and pilates therapy for the treatment of adult scoliosis. *J Manipulative Physiol Ther*. 2002;25(4):E3.
21. Chang Y. Grace under pressure. Ten years ago, 5,000 people did the exercise routine called Pilates. The number now is 5 million in America alone. But what is it, exactly? *Newsweek*. 2000;135(9):72-73.
22. Exercise: Pilates incorporates mind and body. *Harvard Women's Health Watch.* February 2000:6.
23. Bigland B, Lippold, O. The relation between force, velocity and integrated EMG. *J Physiol*. 1954;123:214-224.

24. Lind, AR, Petrofsky JS. The amplitude of the surface electromyogram during fatiguing isometric contractions. *Muscle Nerve.* 1979;2:257-264.

25. Petrofsky JS. Frequency and amplitude analysis of the EMG during exercise on the bicycle ergometer. *Eur J Appl Physiol Occup Physiol.* 1979;41:1-15.

26. Petrofsky JS. Computer analysis of the surface EMG during isometric exercise. *Comp Biol Med.* 1980;10:83-95.

27. Kendall FP, Kendall McCreary E. *Muscles: Testing and Function.* 4th ed. Hagerstown, Maryland: Lippincott Williams and Wilkins; 1993.

28. Petrofsky JS, Lind AR. Frequency analysis of the surface electromyogram during sustained isometric contractions. *Eur J Appl Physiol Occup Physiol*. 1980;43:173-182.

29. Pacy PJ, Barton N, Webster JD, Garrow JS. The energy cost of aerobic exercise in fed and fasted normal subjects. *Am J Clin Nutr.* 1985;42(5):764-768.

30. Hickey MS, Calsbeek DJ. Plasma leptin and exercise: recent findings. *Sports Med.* 2001;31(8):583-589.

31. Astrand PO, Rodahl K. Physiology of work capacity and fatigue. New York, NY: McGraw Hill; 1970.