

Comparison Between an Abdominal Curl with Timed Curls on a Portable Abdominal Machine

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ABSTRACT

Seven male and 4 female subjects were examined to assess muscle use, while performing standard abdominal crunches lying in the supine position versus abdominal crunches performed in the seated and supine positions using an exercise device called the 6 Second Abs. The results of the experiments showed that much of the work in a supine sit up was due to work against gravity. The addition of resistive bands, when exercising in the supine position, caused an increase in work accomplished during abdominal exercise by at least 15-fold. Further, significant exercise was accomplished when using the machine in the seated position facing forward. More significantly, by rotating the trunk to the seated position, muscle use can be switched from the rectus abdominus, facing forward to the obliques when the trunk is rotated to the side, thereby increasing oblique work 15-fold over standard crunches. In addition to advantages of abdominal exercise in the normal population, this type of exercise is

important for people with disabilities, since work may not be possible in a supine position. Abdominal exercise in the seated position with the 6 Second Abs machine appears to control timing better and is more muscle specific than exercise in the supine position.

INTRODUCTION

Abdominal exercise is a common type of exercise because of body image and posture concerns. Weak abdominal muscles are also associated with low back pain.^{1,2} Because of the importance of the abdominal muscles, historically, the United States Army has assessed abdominal endurance in their physical fitness test, as a means of screening applicants.³

Posture is particularly important for people with disabilities. When seated in a wheelchair, the abdominal and lower back muscles are important in maintaining proper posture and preventing scoliosis, kyphosis and lordosis.^{4,5} In addition, abdominal exercise can be useful in rehabilitation programs to improve bowel and bladder function in people with disabilities.⁶

The most common abdominal exercise is a partial curl. These exercises can be

performed supine with the feet on the floor with the heels 12 to 18 inches apart and the knees flexed.⁷ Abdominals are flexed to lift the shoulders and head off the floor to an angle of 30°. The arms can either be crossed on the chest or placed at the level of the head with the fingers next to the ears. The closest to the ideal position for maximizing the use of the abdominal muscles is the partial curl. Another common position is with the knees flexed to 90° with the feet on a wall, which emphasize the rectus abdominus muscles.⁸ In an effort to train the abdominal muscles, many machines have been developed for athletic training,⁹ and rehabilitation after abdominal surgery¹⁰. In some of these exercise machines, abdominal exercise can be accomplished in the seated position.^{11,9} Other machines place the subject in the supine position. Whether an abdominal exercise is performed by a machine in the seated position or on the floor, there seems to be a great deal of variability in muscle activity during exercise. Substitution of other muscles is common and hinders learning of only the abdominal muscles.¹² In a recent publication Szasz et al³ questioned the abdominal physical fitness test used by the United States Army because of substitution of hip flexors for abdominal muscles during standard supine crunches. The analysis of muscle use was accomplished through the surface electromyogram (EMG).¹³

The EMG, when measured by surface electrodes above an active muscle, represents an interference pattern giving the summation of activity of the underlying muscle fibers.¹⁴ The amplitude of the surface EMG is generally related to the tension developed in muscle.^{15,14} Therefore, the EMG has provided a useful measure in assessing both the extent of muscle activity and muscle fatigue.^{16,17,18,19} Different investigators have published contradictory results. Some investigators point to a linear relationship between the amplitude of EMG and tension in muscle during brief contraction.^{16,20} However, others point to, at least with cer-

tain muscles, such as the biceps, a slightly non-linear relationship.²¹ While some of the variation has been attributed to the type of electrode (needle or surface) or the size or position of the electrodes^{22,23} much of the difference remains to be explained. However, the EMG still provides the best estimate of muscle activity.

The type of exercise performed and the position of the body affect both muscle strength and the EMG.¹³ Muscle position is important because it determines the amount of overlap between actin and myosin in the muscle myofibrils and thereby affects strength. Further, muscle position can affect the EMG, since as muscles contract under electrodes, the contracting muscle either moves toward or away from the electrodes changing the amplitude of the EMG. For this reason, then, controlling muscle position is important both in determining strength and the extent of exercise, as well as, the muscle use, as assessed by the EMG.

This is confounded even further when performing abdominal exercise in the seated versus the supine position. Certainly, in the seated position, gravity would increase the apparent strength of the muscle, as would the contribution of other muscles associated with posture. In the supine position, individuals work against gravity whereas the postural muscles are totally relaxed while lying on the floor. In this respect, then, while abdominal exercise is performed in different positions with different types of machines,¹¹ no studies have measured the differences in abdominal muscle strength in various body positions, and attempted to eliminate the effect of gravity in strength measurements.

Thus, some of the differences seen in various studies between different abdominal machines may be positionally related, as well as due to the machine itself. Further, unlike bicycle ergometry, where exercise can be timed against a metronome or speedometer, abdominal exercise can be variable in length depending on the wishes of the individual accomplishing the exercise.

Table 1. General Characteristics of Subjects

Subject	Height (cm)	Weight (kg)	Age (yrs)	Sex
1	166	56.4	23	F
2	174	71.4	22	F
3	152.5	52.3	26	F
4	171	70.9	24	F
5	173	71.4	34	M
6	173	72	23	M
7	178	71	24	M
8	182.5	87.3	29	M
9	175	77.3	26	M
10	188	95.5	34	M
11	185.4	79.5	26	M
Mean	174.4	73.2	26.5	
SD	9.8	12.2	4.2	

The purpose of the present investigation was 1) to first assess muscle strength and 2) through the use of EMG, to assess muscle use during abdominal crunches in 2 different body positions (supine with the legs straight, and supine with the knees bent at 90°) and compare this to a regimented machine called the 6 Second Abs machine, with which timing and load to assess muscle use and muscle training could be controlled, in both the supine and seated position.

SUBJECTS

Four female and 7 male research subjects participated in these experiments. Table 1 lists heights, weights, age, and sex of participants.

METHODS

6 Second Abs Machine

The 6 Second Abs machine is a commercial exercise device (Savvier Inc, Indian Wells, Ca). The device consists of a rectangular plastic frame with rubber bands on the inside to adjust resistance. Resistance can be increased in a number of different stages so that it becomes increasingly more difficult to compress the rectangle (Figures 1 and 2). As shown in Figure 2, as the

machine was compressed to the first, second and third click position with 3 different resistance bands, there was a linear increase in load. The upper part of the rectangle was placed under the subject's arms (under the triceps muscles bilaterally) or held in the person's arms against the chest, while the base of the rectangle was placed on top of the middle of the quadriceps muscles. Both the upper and lower rectangles were padded.

Electromyogram

The EMG was recorded through 2 bipolar vinyl adhesive electrodes (silver silver-chloride) with an active surface area of 0.5 cm². The first electrode was placed over the belly of the active muscle. The second electrode was placed 2 cm distal to the active electrode. EMG was amplified using a 4-channel EMG amplifier with a flat frequency response from DC to 1000 Hz. The common mode rejection ratio of the amplifier was greater than 120 Db. The EMG was then digitized at 2000 samples/second by a Biopac (Biopac Corp., Santa Barbara, Ca), 12-bit analog to digital converter, and displayed and stored on an IBM computer for later analysis. To help hold the electrode in place, a layer of collodian was applied around and on top of the electrodes, so that the electrodes would adhere to the skin and

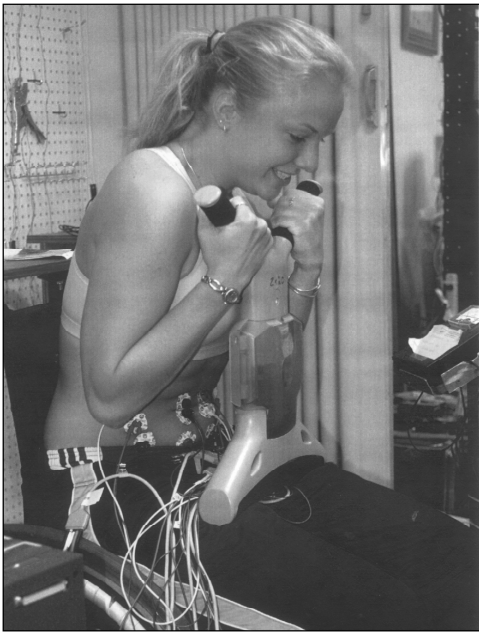


Figure 1. Subject in the seated position using the 6 Second Abs machine.

would not shift impedance during data collection. We have previously used this technique over a period of as long as 4 hours during exercise, with no movement of the electrodes.¹⁷ The amplitude of EMG was assessed by digitizing and half wave rectifying the raw data and calculating the RMS voltage of EMG.

Measurement of Abdominal Muscle Strength

Isometric strength of the abdominal muscles was measured in both the seated and supine positions. To accomplish this, initially subjects sat or lay with the hips at a 90° angle and a cotton strap was placed around the chest and connected to an isometric string gauge transducer. The strain gauge was linear from 0 to 200 kg of force. The output of the transducer was amplified with a strain gauge conditioner amplifier that had a gain of 1000 times and digitized in a Biopac 12 bit analog to digital converter. It was displayed and stored on an IBM computer. The output was stored and analyzed, as the average strength over the middle of a 3 second contraction. Strength was measured by

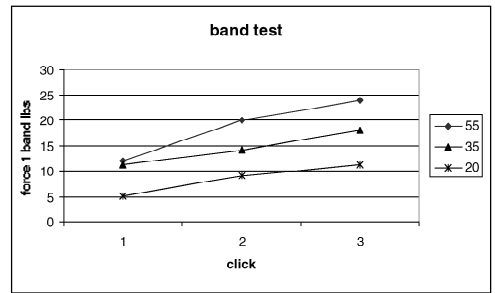


Figure 2. Relationship between click number and force to move the 6 Second Abs machine with bands of 20, 35 and 50 lbs resistance. The results are the average of 3 machines.

an isometric contraction with various angles at the hip to examine the relationship between muscle strength and position of the hip. At least one minute was allowed between contractions to allow for recovery.

PROCEDURES

Two series of experiments were performed as outlined below.

Series 1: Affect of Gravity on Strength of the Abdominal Muscles at Different Joint Angles.

The strength generated at the abdominal muscles was assessed with gravity, against gravity, and gravity eliminated during a three second maximum effort. This was accomplished with subjects in the following positions: seated, lying supine on the floor, and floating in a seated position in a hydrotherapy pool. The hip angles were measured using a Goniometer. The stationary arm was aligned with the midline of the trunk and the fulcrum placed over the greater trochanter; the moving arm was angled towards the lateral epicondyle of the femur. Strength was measured at 45°, 60°, 75°, and 90° angles. During this contraction, the subject's arms were crossed over their chest while their feet remained on the floor. In the supine position the subjects were on an examining table with their hips and knees at a 90° angle against a wall. The subject's trunk was then held stationary by the same transfer belt and recording device,

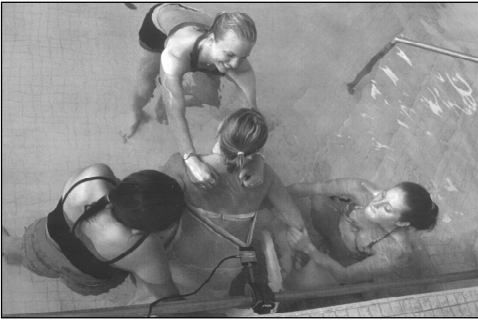


Figure 3. Subject undergoing testing for lower back strength in the pool.

while a research assistant supported their head on a pillow.

The third position was measured in the water to eliminate gravity. (Figure 3) Each subject was required to wear a swimsuit and enter a pool up to 4 feet of water. Water temperature was maintained at 36°C. Each subject was placed in a chair with 2 research assistants stabilizing the chair. A third research assistant recorded angle measurements on the back with a Goniometer and strength was measured

Series 2: Muscle Use During Various Abdominal Exercises

EMG was measured over the left and right rectus abdominus and left and right oblique muscles during the following exercises:

The first position was the seated position, in which the upper part of the rectangle of the machine was placed under each subject's arms (under the triceps muscles), and the base of the rectangle was placed over the middle of the quadriceps muscles. The subject's arms were locked to avoid arm (biceps) substitution, since the device is designed to be a pure abdominal exerciser. In different experiments, subjects either exercised by flexing the abdominals and thereby, bending over or decreasing the angle at the hips by raising the legs off of the floor.

In the second position, the abdominal machine was positioned over the left quadriceps only, and the right arm was placed over



Figure 4. Subject doing an abdominal 6-second crunch.

the handles. This twisted the body to the left and performed the oblique side-bending bout. The contraction of the device was then accomplished in this position in order to gain involvement of the oblique muscle group.

In the third position, the standard curl was performed while laying supine on the floor with the hip and knees bent to approximately 45° with arms folded and crossed over the chest. No device was used, and the subject lifted their torso high enough for his or her inferior border of the scapula to clear the floor.

The final two exercises were performed against a wall with the knees and hips at 90° angles. One exercise was performed using the 6 Second Abs machine (Figure 4) and the other exercise was performed without the machine. The subject curled straight up and then slowly returned to the start, high enough to clear the inferior border of the scapula off the floor.

Statistical Analysis

Statistical analysis involved the calculations of means standard deviations and T tests. The level of significance was $P < 0.05$.

RESULTS

Series 1 – The Relationship Between Strength and Angle of the Hip

Figure 5 shows the relationship between strength (in pounds) and the angle of the hip for subjects in the seated position, lying on the floor, and standing in water. Each

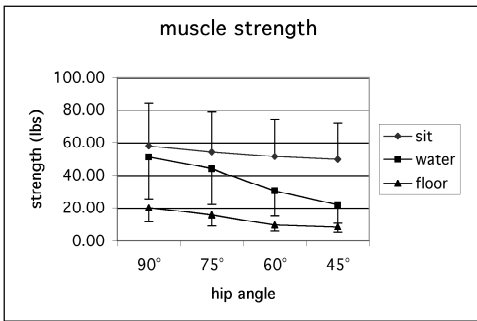


Figure 5. The strength of the abdominal muscles during flexion measured at 90°, 75°, 60°, and 45° at the hip when seated, supine and in the water.

point in Figure 5 represents the mean for 10 subjects (6 male, 4 female) \pm the appropriate standard deviations (SD). The standard deviations are large because the male and female groups have been added together in this particular figure. The highest strength was found when subjects were in the seated position with the hip angle at 90°. In this position strength averaged 57.9 \pm 29.9 pounds (26.3 kg). As the hip angle was decreased, strength was almost reduced in a linear manner such that when the hip angle was 45°, the strength averaged 49.7 \pm 29.7 pounds (22.5 kg). The lowest strength recorded was when subjects were laying on the floor (Figure 5). In this position subjects had to contract their abdominal muscles against gravity. Because of the influence of gravity on the body, the reduction in strength was dramatic (Figure 5). When lying on the floor at a hip angle of 90°, the maximum strength was 20 \pm 12.4 pounds (9.1 kg), demonstrating a reduction well over 70% from strength measurements in the seated position. In this position, the standard deviations were large as well. For example, at a hip angle of 45°, strength averaged 8.9 \pm 12.9 pounds (4.0 kg). Intermediary between these measurements in the chair and floor were measurements in the water. In the water, subjects were neutrally buoyant such that there were no gravitational effects either aiding the measurement of strength, as was seen in the

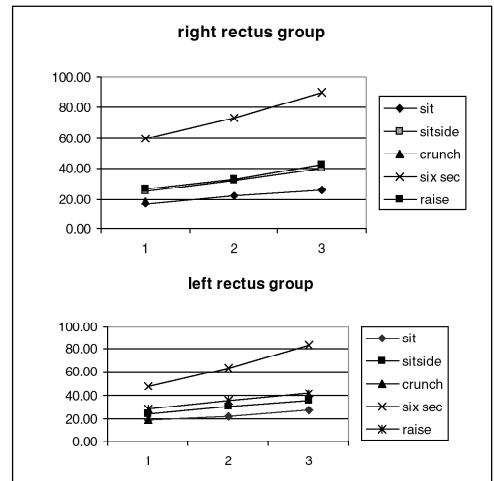


Figure 6. The average EMG amplitude of 10 subjects is shown during abdominal exercise at either 20 (1), 35 (2), or 55 (3) pounds of resistance using the abdominal machine or performing free abdominal crunches (triangles) for the left and right rectus muscles. Because of differences between individuals, EMG amplitudes have been normalized as a percent of the EMG amplitude during a maximal voluntary effort. The ordinate is expressed as a percent of the maximum EMG generated by the abdominal muscles. This corresponds to a percent of muscle activity. Using the 6 Second Abs method, exercise against the heaviest workload (3) the average subject used 90% of their muscle power. The graph also illustrates the relationship between workload and normalized EMG activity, when subjects exercised in the sitting and side sitting position, performed free abdominal crunches, 6 Second Abs crunches, and seated leg raises (see methods).

seated position, or opposing the contraction of the muscles, as is seen when subjects are in the laying position. In the water, for example, the average strength with the hip angle at 90° was 50.9 \pm 30.2 pounds (23.1 kg). The strength was also linearly reduced such that the hip angle of 45° to average strength was 21.9 \pm 14.9 pounds (9.95 kg). The slope of the line relating strength to angle was significantly steeper with subjects sitting in the pool, when compared to the subjects sitting against the wall ($P < 0.01$), or lying on the floor ($P < 0.01$).

Series 2 – Muscle Use During Various Types of Abdominal Exercises

The results of this series of experiments are

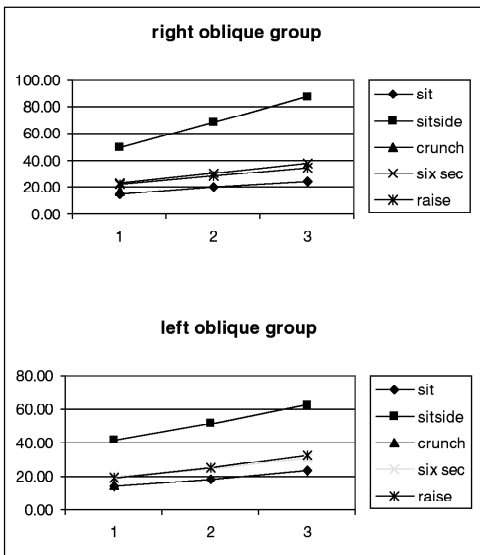


Figure 7. The average EMG amplitude of 10 subjects during abdominal exercise at either 20 (1), 35 (2), or 55 (3) pounds of resistance using the 6 Second Abs machine or doing free abdominal crunches (triangles) for the left and right oblique muscles is illustrated. EMG amplitudes, because of differences between individuals, have been normalized as a percent of the EMG amplitude during a maximal voluntary effort. The ordinate is expressed as a percent of the maximum EMG generated by the abdominal muscles. This corresponds to a percent of muscle activity. The 6 Second Abs machine during exercise against the heaviest workload (3) the average subject used 90% of their muscle power. Graphs show the relationship between workload and normalized EMG activity when subjects exercised in the sitting and side sitting position, performed free abdominal crunches, 6 Second Abs crunches, and seated leg raises (see methods).

shown in Figures 2, 6, 7, 8, and 9. Each figure shows the average results of 10 subjects performing standard abdominal crunches and using the 6 Second Abs machine: in the seated position with the body turned sideways to the left by approximately 30°; with the seated leg raise abdominal crunch (only in some of the studies); and the 6 Second Abs machine abdominal crunches. Because of the number of graphs in each panel, standard deviations have been omitted. For example, Figures 6 and 7 show the peak EMG activity for the right rectus

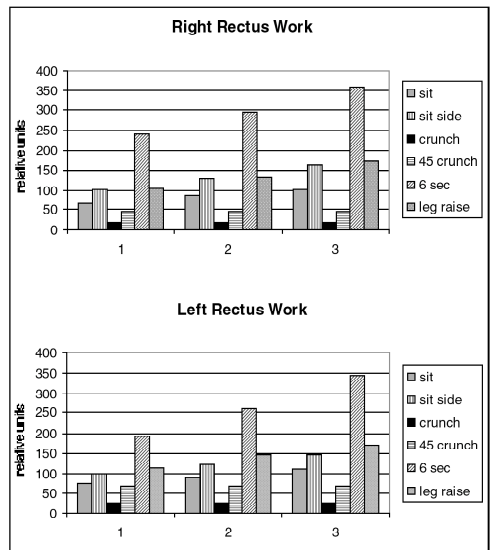


Figure 8. The total work done during the abdominal exercise against loads of 20 (1), 35 (2), and 55 (3) pound bands for exercise using the abdominal machine in the sitting and side sitting position, during the horizontal 6 Second Abs method and the sitting leg raise positions for the left and right rectus muscles. The data are compared against total muscle work during standard abdominal crunches laying horizontal on the floor, with the legs and hips at 90° against the wall (approximately 45° crunch). Each bar represents the mean of 10 subjects. EMG is expressed in relative work units (the product of the duration of the exercise and the average EMG activity).

abdominus muscles, (Figure 6), left rectus abdominus, the right oblique muscles (figure 7), and left rectus muscles. The numbers shown represent the average peak EMG activity of 10 subjects, exercising with loads of 20 (1), 35 (2), and 55 (3) pounds while using the abdominal machine. The crunch subjects simply lay on the floor and performed standard abdominal crunches. Therefore, only one data point is shown for the crunch in the figures, since there was no way to adjust the load except by the amount of work necessary to move the body against gravity. As can be seen in these figures, the greatest muscle activity for the right and left rectus muscles was during the 6 Second Abs method. Standard abdominal crunches used approximately 25% of the muscle activity

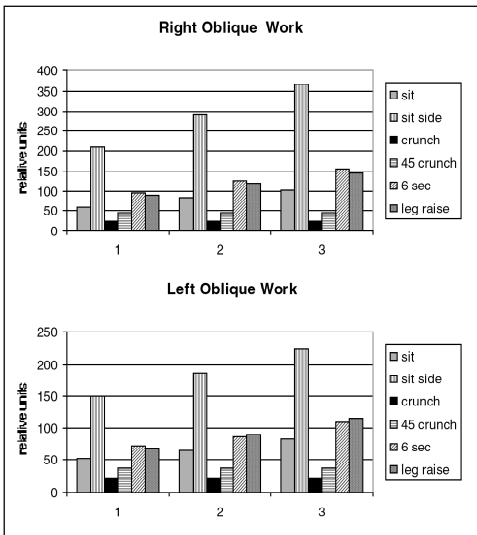


Figure 9. This figure illustrates the total work done during the abdominal exercise against loads of 20 (1), 35 (2), and 55 (3) pound bands for exercise using the abdominal machine in the sitting and side sitting position, during the horizontal 6 Second Abs method and the sitting leg raise positions for the oblique muscles. This data is compared against total muscle work during standard abdominal crunches laying horizontal on the floor and with the legs and hips at 90° against the wall (approximately 45° crunch). Each bar represents the mean of 10 subjects. EMG in this figure is expressed in relative work units, which is the product of the duration of the exercise and the average EMG activity.

for the right rectus abdominals, when compared to the 6 Second Abs machine used lying on the floor. These differences by paired T test were significant ($P<0.01$). The rectus muscle activity as assessed by the EMG during side sitting exercises or leg raises and even in the seated position was still higher than the EMG activity, which was measured when the exercise was accomplished by a standard floor abdominal crunch. For the right and left rectus muscles, muscle use during a crunch was equal to muscle use while performing side sitting and leg raises with the 6 Second Abs machine using the lowest setting (20 pounds). Therefore, even using the lightest bands in the machine, the 6 Second Abs machine provided as good as or a better exercise than exercising while laying on the

floor or performing abdominal crunches.

The best workout for the oblique muscles was in the seated position while rotating the trunk was rotated. Even using the lowest strength band, oblique muscle use was 4 times that of standard floor crunches ($P<0.01$). Using the strongest band, muscle use was 6 times greater than standard crunches. The exercise was even more specific when rotated to only one side, in which only one abdominal set received heavy exercise (Figure 5).

However, these figures do not tell the full story. The average time during the muscle activity while performing standard abdominal crunches, with the subject lying on the floor, was $2.1 \pm .34$ seconds for the group of 10 subjects. Whereas the 6 Second Abs method, performed in the seated position, the horizontal position, or the side position, is purported to have an average time of 6 seconds, but in fact the average time was 5.4 seconds for the 6 Second Abs method. These differences were significant ($P<0.01$). It is important to recognize that since the exercise was performed over a longer period of time using the 6 Second Abs versus standard abdominal crunches, simply looking at the average EMG amplitude during the method does not truly represent the amount of work being performed during exercise. Therefore, the data is represented as a measure of total work performed by multiplying the EMG amplitude and the duration of the exercise (Figures 7 and 8). For example, the work of the right rectus abdominus muscle (the work load in relative units for work against the 20, 35, and 55 pound bands) in the sitting, side sitting, 6 Second Abs method (45° crunch), and leg raise method are shown as the average for all 10 subjects. Two different crunches are shown in this figure, the standard crunch with the subject laying in a horizontal position on the floor, and a 45°-crunch position. The 45° crunch, while not using the 6 Second Abs machine, was performed with the hip at an angle of 90° and the knees at 90°, in a similar position to

the 6 Second Abs method, for basis of comparison. As can be seen in these figures, the average workload of the subjects when comparing the 6 Second Abs method to the 45° crunch was about 6 times as high. ($P < 0.01$) When comparing the total work performed by the rectus abdominal muscles using the 6 Second Abs method to a standard abdominal crunch, the work was as least 10 times as high for the subjects. Thus for all muscles examined (the right or left rectus abdominus or the right or left obliques) work loads were substantially higher by about 15 fold when using the 6 Second Abs method compared to standard abdominal crunches (Figures 2,7,8,9).

The true work of the abdominal muscles, in the seated position with the trunk rotated, was also higher than figure 6 shows. In this position, the oblique muscles worked as much as 20 times harder in the seated position with the 6 Second Abs machine when compared to the standard crunch (Figure 9). This difference was significant ($P < 0.01$).

DISCUSSION

The abdominal muscles have an important function in maintaining posture while standing and sitting. For example, Snigders et al²⁴ showed that in healthy subjects, during unconstrained sitting, both the internal and external oblique muscles were very active compared to standing as assessed by EMG. In most of the subjects, the activity of the oblique abdominals was significantly less when sitting on a soft car seat than when compared to sitting on a hard office chair. Their data seemed to indicate that the oblique abdominals help to stabilize the base of the spine, in particular, the sacroiliac joint, while sitting or standing. As such, strengthening the abdominal muscles seems to be important in alleviating back and pelvic pain during prolonged standing and sitting.^{24,2}

Despite higher body weight, abdominal muscles are weaker in women prone to back pain and back injury due to obesity.²⁵ Thus

impairment in this muscle group, predisposes them to a number of other medical problems.

Certainly, for someone in a wheelchair, such as a stroke patient or a patient with an incomplete spinal cord injury, where the abdominal muscles are partially active, posture becomes a crucial component for maintaining stability while seated in the wheelchair. Proper posture can also help to avoid scoliosis, kyphosis and lordosis.⁵ And yet, for people with disabilities, abdominal exercise has always been difficult to accomplish. In fact, even for the non-disabled population, the abdominal muscles have been hard to isolate with any specific exercise due to substitution of other muscles, such as the hip flexors.³ This is especially true for what is termed the abdominal crunch, a type of exercise performed laying in the supine position and flexing the trunk.

In an effort to specifically train abdominal flexors, a number of studies have compared various types of abdominal training devices to standard abdominal crunches.⁹ Many of the commercially available devices keep the subject in the seated or supine position. The results are somewhat contradictory and variable. However, logically, there certainly would be advantages and disadvantages to exercising the abdominal muscles in the seated position (as would be done with a commercial exercise device such as a Universal Gym) versus the supine position. In the seated position, the hips and pelvic area are supported on a seat, use of the hip flexors is minimal and therefore, the abdominal flexors are easier to isolate. As cited above, co-contraction of the hip flexors has been a significant problem in assessing abdominal muscle strength.³ In contrast, in the supine position, it is easy to substitute the hip flexors, such as the psoas major or iliopsoas, for the abdominals, and it would be much more difficult to isolate muscles if the hips are allowed to move in several degrees of freedom. Gravity is a complicating factor, when changing from one body position to another.

As reported under results, muscle strength was almost 3-fold higher in the seated position than in the supine position. When measuring strength in a pool, to negate the effect of gravity, the true strength of the muscles can be assessed. Thus in the therapeutic pool, when measuring strength, the true strength is measured and the actual strength of the abdominal flexors was about halfway between that measured in the seated versus the supine position. The greatest strength of the muscle was with the lower back and hips at an angle of 90°. This is particularly important since many abdominal exercises usually start at 90°, in either the supine or sitting positions.

The fact that muscle strength varies with joint angle is certainly not new. When muscle is passively changed in length, the overlap between the actin and myosin in the muscle myofibrils changes and alters the maximum strength developed in muscle.²⁶ This is called the length tension relationship. However, unlike muscles such as the biceps and handgrip, where peak strength occurs about halfway between relaxation and full flexion,¹⁴ the peak strength of these muscles occurs with the hips at 90° and the back straight. Any lesser angle reduced strength further.

In addition, in other muscles, such as the biceps, the length tension relationship is very sharp; tension varies by more than 50% over the normal range of motion of the muscle. In contrast, strength varies only a small amount for the abdominal muscles, over a wide range of motion in the supine or sitting position. Normally a muscle, such as the rectus abdominus, would show a great deal of variation in strength with position due to the "long arrangement" of fibers in this muscle. As muscle contracts, overlap increases between actin and myosin and strength is reduced at decreasing joint angles maximally, if the muscle fibers are in the long arrangement. The body normally minimizes the length tension relationship by placing muscle fibers in a pennate arrangement. Here, in the sitting or supine posi-

tions, the change in strength is small with decreasing joint angles. The difference between the observed and expected results may be due to gravity.

In the seated position, as the trunk is bent forward, progressively more upper body weight is removed from the spine and body weight, rather than being supported through the bones in the spine, is supported through the lower back muscles. If the lower back muscles relax, the weight of the upper body now provides a force to cause flexion of the trunk. This force adds to the strength of the abdominal muscles giving a totals force that equals;

Muscle Force for flexion= active force of the abdominals + passive weight of the upper body

Thus at a 45° angle at the hip, 70% of the body weight is born by the lower back muscles. Therefore the measured muscle strength would be:

muscle strength = abdominal active muscle strength + 70% upper body weight

Therefore, while muscle strength may decrease at reduced hip angles, in the seated position, gravity progressively adds to apparent strength. By simply relaxing the back extensors, apparent strength can increase by 70% of the body weight. The overall result is, when sitting, joint angle has very little affect on strength, as demonstrated by the following formula:

$$S = M_s + B_m * \text{Cos}A$$

S= muscle strength for the abdominal flexors, M_s = true strength of the abdominal flexors at a given back angle, A= angle of back relative to hip,

B_m = body mass for upper body

When in the supine position, a similar effect is seen. With the back at a 90° angle, full body weight is born by the abdominal muscles when flexing the trunk upwards, so that strength is reduced by upper body weight. As the angle of the trunk is reduced, more weight is born by the spine, and therefore, it becomes easier to flex the spine at decreasing angles. But decreasing

muscle length also reduces muscle strength. Therefore the length tension curve reacts to joint angle less than expected.

The overall result is that strength decreases little with joint angle when sitting as demonstrated by the following formula:

$$S = M_s - B_m * \text{Cos}(90 - a)$$

S = muscle strength for the abdominal flexors, M_s = true strength of the abdominal flexors at a given joint angle, A = angle of back relative to hip

In water, there is no effect of gravity. Therefore, the true length tension relationship is seen, establishing the true strength of the abdominal flexors at a given joint angle at a given joint angle.

The fact that muscle strength varies so little, over a wide degree of trunk angles, demonstrates no disadvantage to exercising the rectus and oblique muscles at hip angles of 10°, 20°, or 30°. The effective workload seems to be the same and therefore, the joint position does not need to be compensated for the workload produced on the exercise device. Thus, it would seem that a device, which provides a linear change in force with angle of the lower back, would be appropriate for exercise. But the opposite is true. Muscle strength weakens quickly with decreasing hip angle. Therefore, a progressive exercise device such as the 6 Second Abs machine provides a better workout than a constant weight device, since in order to give a constant workout, an increasing load would compensate for the effect of gravity on muscle strength. In this respect, simple crunches cause relative load to decrease with joint angle, due to the effect of gravity, and thereby, decrease the workload, as the abdominals are flexed in the seated or supine positions. Since the workload increased as the machine is compressed past the first, second, and third click positions (Figure 2), the decreased load due to gravity is compensated for by increasing the load in

order to maintain a good workout. The decrease in muscle strength during a 30° crunch (Figure 5) was about 40%. However, gravity added 30% to apparent strength during a reduction of 30° in hip angle (Figure 5). Since the increase in force to compress the machine to the third position was almost double the first position (Figure 2), gravity was more than compensated for.

When ab roller devices have been compared to standard abdominal crunches, this relationship has been emphasized dramatically. For example, when Demont et al⁹ compared 2 abdominal roller training devices to a standard abdominal crunch, they found little difference in work or muscle use. This is not surprising since the roller devices, cause the trunk to flex over more of an angle, and would still provide the same relative work as an abdominal crunch. This first series of experiments in this study yielded similar results, as shown in the strength diagram (Figure 5). The results of the studies by Demont et al⁹ are not surprising. This also confirms other findings that show moderate repetitive loads build endurance but not strength, while the most effective modality for building strength is high load and low repetition.^{27,28} If the load is too light or too heavy, training is inhibited. Thus a small Ab roller or other device would use too light a load for proper strength training, while large Ab machines probably use too heavy a load. Further, multiple sets must be used to make strength training effective.²⁹

In the present investigation, as cited above, when comparing a 6 Second Abs machine to standard abdominal crunches, the EMG activity using the rectus abdominus muscles was substantially higher using the 6 Second Abs machine in the supine position than for standard crunches. Since this is a progressive resistance device, decreasing joint angle increases the workload and increases muscle use. The workload with 30° of flexion was at least 15-fold higher with the 6 Second Abs machine than

with standard abdominal crunches. This means that strength training can progress much faster and more efficiently than with other devices. Quantifying the effect of workload on the efficiency of training is difficult to accurately establish but it can be assumed that there would be significant advantages in using such a machine. Based on studies of AB crunches by the United States Army,³ there may be a 100-fold advantage in strength training with progressive resistance devices, such as with the device examined here. Further, by using a clicking device, the variability in the timing of abdominal crunches can be reduced. Although individuals were told to perform the standard abdominal crunches slowly, inevitably exercise was performed over a brief and variable period of time, averaging only 1 or 2 seconds per crunch. With a clicker in the machine, it was much easier to maintain proper timing and spend approximately 6 seconds per exercise cycle. By contracting the muscles over a heavy load and over a long period of time, the total work accomplished was much higher for the rectus abdominus muscles in the supine position when compared to standard crunches.

Even in the sitting position, workload on the rectus abdominus muscles was substantially higher with the 6 Second Abs machine than performing standard crunches lying in the supine position. However, as can be seen from the strength diagram (Figure 5), since muscle strength, due to gravity, is much higher in the seated position, much higher resistances must be added to the machine to exercise effectively in the seated position when compared to the supine position. However, given this restriction of using higher workloads in the seated position, the level of muscle activity and total work gain was substantially higher than that of supine crunches.

For someone with disabilities, supine crunches may be a total impossibility because of the level of disability; the only type of exercise that might be accomplished may be from the seated position.

Individuals that are grossly overweight or individuals that have muscle weakness may not be able to get into the supine position on the floor, but they could exercise from a seated position and still receive a better workout than lying on the floor and trying to perform a standard crunch. Further, if the trunk is rotated to a 30° angle and exercise is performed in the seated position, at least a 15-fold increase in total work is accomplished on the oblique muscles, and the rectus abdominus muscles. Therefore, even for someone without disabilities, the machine seems to be very specific in the seated position, simply flexing the trunk forward; the main muscles used are the rectus abdominus. Whereas, when rotating the trunk the main muscles used are the obliques. Therefore, in the seated position, the machine can specifically train the rectus abdominus versus the oblique muscles without interference from the hip flexors.

Previous studies have shown that using a resistance exercise program to train abdominal muscles while performing standard abdominal crunches or using some of the large abdominal machines has been ineffective in changing girth and skin fold measurements over the abdominal area.³⁰ In the past, exercise programs that were designed to improve the appearance and function of the abdominal muscles were only moderately effective or totally ineffective.^{31,32} However, the failure in training was probably due to a failure in technique and equipment. The present investigation only explored muscle use and total work during bouts of 10 contractions. In the same studies, specific muscle use of the abdominals could not even be isolated during brief, let alone sustained workouts.³ The implication is that the 6 Second Abs machine is a very effective device for training endurance and muscle strength in the abdominal muscles. Studies historically have pointed to the fact that strength training requires overload of muscles in a standard resistance program.²⁶ Without sustaining a workload at a heavy level, no significant training will be seen. If

muscles can be substituted, then overload is difficult to establish and this is why previous workout machines have been ineffective in abdominal training. Here, with the 6 Second Abs machine subjects could achieve overload, making it an effective training device. The additive effect of timing of the exercise through a clicker on muscle training, by forcing a progressive load against the muscle and allowing the body to flex without rotation (maintaining form), helps to reduce substitution of muscles and provides a more regulated workout. The fact that a variety of resistance bands are available, from very weak bands for people with disabilities to very strong bands for the athlete, make it more useful than large exercise machines, in which weight can only be changed in 10 pound increments, and the minimal load is high due to the inertia of the machine. In a large exercise machine, by using a load to exercise against, less time is needed for a workout, since the workout is conducted at a higher level of activity. Finally, it is human nature to work less as fatigue ensues. By using a clicker to set pace and load, subjects are forced to work hard with this machine as they fatigue whereas with crunches, as fatigue approaches, people work faster and at less of an angle of flexion.

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