# The Effect of Underwater Treadmill Exercise in the Rehabilitation of Surgical Anterior Cruciate Ligament Repair

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Running Head: The Effect of Underwater Treadmill Exercise

## ABSTRACT

To test the effect of underwater treadmill exercise in the post-surgical rehabilitation of anterior cruciate ligament (ACL) reconstruction, 16 subject were divided into two therapy groups and matched for age, gender, height, and weight. Four males and four females (age range 22 to 31 years) comprised each group. All had been arthoscopically diagnosed with complete rupture of the ACL, and had undergone primary reconstruction. Both groups adhered to the same physical therapy protocol, and were attended by the same staff; the critical difference was the cardiovascular conditioning equipment prescibed. The standard therapy group exercised on stationary cycles (Fitron™ and Schwinn Airdyne™) during each of the six weekly therapy sessions. As soon as wound healing permitted (10 to 14 days post-surgery), the experimental (water) group began using the AquaCiser™ Underwater Treadmill in three of the six weekly sessions; they cycled on the remaining days. At four and eight weeks post - surgery both groups were tested for range of motion; calf and thigh (quad) girth; quad strength and endurance; gastrocnemius endurance; and balance. Between-group analyses were performed on mean raw measures; four and eight week measurements were also compared. These four to eight week differences were analysed in paired t-tests between groups. Analyses performed on individual measurements demonstrated no significant differences between groups. However, analysis of the difference between the four and eight week measures indicated significant differences in the following areas:

Flexion within the water group increased by a mean of 14.6° (where p , .05); surgical calf girth increased by a mean of .4 in., and the quad firth of both surgical and nonsugical legs increased by a mean of .3 in. and .4 in., respectively. The standard group showed significant increase only inflexion (mena increase of 9.2°). A between group analysis of four to eight week changes indicated that nonsurgical quad girth increased significantly more in the water group (mean increase of .4 in.). Results suggest that underwater treadmill exercise is a beneficial additive therapy in ACL reconstruction rehabilitation; it may even be more effective than stationary cycling in the prevention of atrophy.

**The Effect of Underwater Treadmill Exercise**

**in the Rehabilitation of Surgical**

**Anterior Cruciate Ligament Repair**

While the rupture of the anterior cruciate ligament (ACL) is a common injury within the context of certain sports, it is also one of the most devastating to an athlete's career. In deciding upon the course of treatment. the athlete has, until recently, been faced with a dilemma:
The chronic instability of the untreated ACL-deficient knee results in a degenerative osteoarthritic condition (Lynch & Henning, 1988); yet surgical reconstruction requires a long and arduous rehabilitation.

Although different methods of surgical repair have met with varied degrees of success in the past (Hughson & Barrett, 1983), recent advances in diagnosis, surgical techinique, and post-operative management have made the injured athlete's return to competition more feasible. To accommodate the new, more aggressive approaches to ACL injury management, new rehabilitation protocols must be developed. Higgins and Steadman (1988) suggest that a team approach involving the patient, surgeon, therapist, and athletic trainer is vital to achiebing the following goals of knee reconstruction:

(a) to restore joint anatomy

(b) to provide static and dynamic knee stability

(c) to maintain cardiovascular and psychological conditioning and,

(d) to return the patient to activity in the shortest time possible

To this end, and in the light of accumulation evidence that musculoskeletal health depends on motion (Noyes, Butler, Paulos, & Grood; 1983), the traditional practices of plaster immobilization and non-weightbearing have been discarded in favor of more aggressive methods. Many post-surgical ACL rehabilitation protocols now in place in hospitals and training rooms include the common procedures of immediate passive motion and early weightbearing with a brace. In fact, some orthopaedic surgeons routinely prescribe that stationary bicycle exercise begin on the same day as surgery. (For an example of such a protocol, see Appendis A.)

Another modality which is now widely prescribed is active hydrotherapy. Because water tends to decrease pain and promote the viscoelasticity of connective tissue, it is helpful in the recovery of full range of motion. As an extension of hydrotherapy, swimming pool activity is also allowed in many protocols, beginning as soon as wound healing permits. The buoyancy provided by water protects the compromised joint from compressive forces, while water resistance challenges the muscles of the extremities (Louden, 1987). Thus, water exercise can be introduced relatively early in the rehabilitation process.

Still, the use of swimming, per se, as a major rehabilitative tool is problematic for the athlete; the body position and musculature used do not correspond well to those used in nonaquatic sports. This may explain why therapist have largely overlooked water as a desirable exercise medium.

If, however, a program were designed to utilize the posture and musculature biomechanically similar to running, then the injured athlete could engage in a more sport-specific activity, while taking full advantage of the warm water environment.

It was the purpose of this study to determine whether the inclusion of such a water exercise modality into an otherwise standard post-surgical ACL rehabilitation protocol would produce positive results in the areas of quadriceps/hamstring strength and endurance, gastocnemius strength and endurance, proprioception, atrophy prevention, and range of motion.

The investigation centered on the differences in performance between two groups: The standard therapy group followed the existing protocol of Vail Orthpaedics and Sports Medicine (Appendix A), while the experimental therapy group used a water exercise apparatus in addition to the standard cycle ergometer and dry treadmill. Functional test were administered to both groups at four and eight weeks post- surgery.

## METHOD

### Subject

Patients participating in the study were volunteers who had been arthroscopically diagnosed with complete rupture of the ACL, and had undergone primary reconstruction, either by patellar tendon transfer or semitendinosus graft. Patients with concomitant meniscal lesion repairs were excluded. All surgery was performed at Vail Balley Medical Center by the staff surgeons of Vail Orthopaedics and Sports Medicine.

Subjects who met the inclusion criteria and provided informed consent were assigned to either the standard therapy group or the experimental therapy group, and matched as closely as possilbe for age, gender, height and weight.

### Apparatus

The critical differences between the two therapy groups centered on the cardiovascular exercise equipment prescribed. The standard group used variable-speed/variable-resistance cycle ergometers (Schwinn Airdyne™ and Fitron™), five to six times per week during the first month post-surgery. The experimental (water) group substituted the use of an underwater treadmill apparatus manufactured under the name of AquaCiser™ (see Appendix B) three times per week, and used the cycle ergometers in the remaining sessions. The AquaCiser™ resembles a fiberglass shower stall, the floor of which is a variable -speed treadmill. Water temperature, depth, and treadmill speed are controlled externally. The interior of the stall is equipped with handrails.

Functional tests for specific variables were performed at four and eight weeks post-surgery; these included range of motion (ROM) at the knee, thigh (quad) girth, calf girth, quadriceps strength, quadriceps/hamstring endurance, gastocnemius endurance, and balance.

ROM was measured in degrees by means of a goniometer. Normal limits were defined as 0° of extension and 155° if flexion. Only the surgical leg was measured.

Muscle girth was measured in inches with a flexible tape measure.

Functional quadriceps strength was tested by retrostepping onto four-, six-, or eight-inch high stools; patients were observed for technique: successful stepping was characterized by isolated use of the quadriceps, while pelvic substitution indicated failure at a given stool height.

Gastrocnemius (gastroc) endurance was represented by the amount of time in seconds that a subject could perform continuous unilateral toe raises; both surgical and nonsurgical limbs were tested.

Quadriceps/hamstring endurance was represented by the amount of time in seconds that a subject could perform continuous unilateral knee dips while standing on a four-, six-, or eight-inch stool; times for both limbs were recorded. The height of the stool was determined by the subject's pain-free range of motion.

Functional balance was quantified as the length of time in seconds that a subject could stand on one leg; challenged balance involved closing the eyes while balancing. Times for both legs were recorded.

All testing procedures tool place at Vail Center for Physical Therapy, and were performed by staff physical therapists.

**Procedure**

For the initial two weeks post-surgery, subjects reported to Vail Center for Physical Therapy six to eight times per week. Thereafter, and for the duration of the study, the subjects were asked to attend physical therapy five to six times per week. Both groups were attended by the same staff, and adhered to the same ACL reconstruction therapy protocol (Appendix A). Beginning at ten days post-surgery, or as wound healing permitted, the water group trained three times per week in the AquaCiser rather than on a stationary cycle. Both groups were instructed to report any incease in pain felt during the activity, and any swelling following the activity. Patient tolerance determined the progression of speed and intensity for both groups; initial cycling was performed without resistance, and initial treadmill walking was performed without the Bledsoe™ brace in chest-deep water (102° F, 39° C). Exercise sessions lasted 20 min. Functional testing procedures tool place at four and eight weeks post-surgery. ROM, girth, quad strength and endurance, gastroc endurance, and balance times were analyzed in separate paired t-tests between groups. Within-subject comparisons of four-and eight-week measures were performed; these results, expressed as four- to eight- week changes, were also analyzed in between -group paired t-test.

## RESULTS

An initial analysis of subjects' age, height, and weight showed no significant differences between therapy groups (see Table 1).

Paired t-tests between therapy groups did not demonstrate any significant difference in four- or eight-week raw measurements, i.e. muscle girths, flexion, extension, quad strength, gastroc endurance, or challenged balance for either leg (see Table 2). Nor were there significant differences in four- or eight-week ROM, nor surgical/non-surgical leg comparison expressed as deficits.

However, paired t-test comparisons of the four-to eight-week changes yielded several important results: The water group showed significant improvement in flexion, with a mean increase of 14.6 °, where $p < .05$ (see Figure 1). Surgical calf girth increased by a mean of .4 in. (see Figure 3). Both surgical and nonsurgical quadriceps girth showed significant improvement, with mean increases of .8 in. and .4 in., respectively (see Figures 4 and 5). An improvement in surgical quadriceps strength was also demonstrated by a mean retrostep increase of 1.7 in. (see Figure 6).

The standard group showed significant improvement only in flexion, increasing by a mean of 9.2° (see Figure 2).

Neither group improved significantly in extension, nonsurgical calf girth, nonsurgical quadriceps strength, balance nor challenged balance for either leg, nor gastroc endurance for either leg (see Table 3).

A between-group analysis of these four- to eight-week changes showed that nonsurgical quadriceps girth increased significantly more within the water group (mean increase of .4 in.) . The water group also showed notable improvement in surgical quadriceps girth (see Table 4).

Quadriceps endurance times could not be meaningfully compared, due to the fact that some subjects were able to perform pain-free knee dips from an eight-in. step, whereas others could only tolerate testing from a height of two in.; the latter group had inordinately longer endurance times due to the limited ROM.

Test results for unchallenged balance disclosed a ceiling effect: all subjects achieved or exceeded the 30-second time interval defined by the therapists as "within normal limits."

## DISCUSSION

Gleim and Nicholas (1989) demonstrated that walking in water can greatly increase the oxygen cost of motion. This, together with the potential for safe and early post-surgical introduction, make the underwater treadmill an attractive option for the prevention of cardiovascular deconditioning.

Although there is little existing data on the efficacy of the apparatus in the rehavilitation of orthopadeic injuries, the results of the current study suggest that it is a beneficial additive therapy in the rehabilitation of ACL reconstruction.

The significant increase in surgical calf girth within the water group may indicate a limitation of post-surgical gastrocnemius atrophy; this is probably because stationary cycling does not specifically require plantar flexion, while walking does.

Limited atrophy was apparent at the quadriceps, as well. The greater increase of thigh girth withing the water group was likely due to repeated extension of the knee against water resistance. Perhaps stationary bicycle exercise with little or no resistance requires more involvement of the hip flexors and extensors, and less of the quadriceps; this may be particularly true of surgical knee patients.

No subject in the water group reported any negative effects associated with underwater treadmill walking. Subjective comments regarding the activity were positive. Attendance of the water group was recorded and compliance was very good.

Although attendace data were not available for the standard group, it should be noted that the researcher experienced some difficulity arranging a final testing session for some of the standard subjects.

In view of the positive effects demonstrated in the current study, further research should be directed at systematically evalauating the effects of underwater treadmill walking as an exclusive cardiovascular and muscular conditioning therapy, as opposed to an additive one. Baseline testing immediately before surgery would increse the sensitivity to the treatment effect.

Other possible applications such as post-acute fractures, chronic back pain, and arthritic conditions would bear investigation, as well.

## REFERENCES

Gleim, G.W. & Nicholas, J.A. (1989). Metabolic costs and heart rate responses to treadmill walking in water at different depths and temperatures. The American Journal of Sports

Medicine, 17, 248-252.

Higgins, R. W., & steadman, J. R. (1987). Anterior cruciate ligament repairs in world class skiers. The American Journal of Sports Medicine, 15, 439-447.

Hughson, J.C.. & Barrett, G.R. (1983). Acute anteromedial rotary instability. Long-term results of surgical repair. The Journal of Bone and Joint Surgery, 65, 145-153).

Louden, J. K. (1987). Pool Therapy. Athletic Training, 22, 326-327.

Lynch, M. A. & Henning, C. E. (1988). Osteoarthritis in the ACL-deficient knee. In Feagin (ed.), The Crucial Ligaments (pp. 385-391). Edinburgh: Churchill, Livingston.

Noyes, F. R., Butler, P. L., Paulos, L. E., & Grood, E. S. (1983). Intraarticular cruciate reconstruction. 1. Perspectives on graft strength, vascularization, and immediate motion after replacement. Clinical Orthopaedics and Related Research, 172, 71-77.

Silfverskiold, J., Stead,am. J.R. Higgins, R.W. & Atkins, J.A. (1988). Rehabilitation of the anterior cruciate ligament in the athlete. Sports Medicine, 6, 308-319.

Steadman, J.R. (1983). Rehabilitation of acute injuries of the anterior cruciate ligament. Clinical Orthopaedics and Related Research, 172, 129-132.

TABLE 1
SUBJECT CHARACTERISTICS

| Group | Total # | # Males | # Females | Age Mean ± SD | Height Mean ± SD | Weight Mean ± SD |
|---|---|---|---|---|---|---|
| Standard Group | 9 | 4 | 4 | 26.625 ± 1.149 | 68.375 ± 0.713 | 151.875 ± 8.853 |
| Water Group | 8 | 4 | 4 | 24.5 ± 0.681 | 67.312 ± 1.411 | 147.375 ± 8.192 |

## FUNCTIONAL TEST RESULTS (MEAN ± STANDARD ERROR)

| Measurement / Leg (Sugical/nonsurgical) | Water Group Mean ± SE | Standard Group Mean ± SE | Mean Δ Water vs Standard | t-value | Probability Level |
|---|---|---|---|---|---|
| 4 wk flexion | 141.4 ± 3.6° | 141.6 ± 3.2° | 0.5° | 0.095 | 0.9275 |
| 8 wk flexion | 154 ± 1.7° | 153.3 ± 1.7° | 0.7° | 0.336 | 0.7481 |
| 4 wk extension | 8 ± .6° | .9 ± .9° | -0.2° | -1.446 | 0.1913 |
| 8 wk extension | 0 ± 0° | 3.0 ± 1.2° | -.09° | -1 | 0.3559 |
| 4 wk calf girth/s | 13.6 ± .3 in. | 14.0 ± .6 in. | -0.4 in. | -0.892 | 0.402 |
| 4 wk calf girth/n | 14.0 ± .3 in. | 14.3 ± .5 in. | -0.3 in | -0.669 | 0.5252 |
| 8 wk calf girth/s | 13.8 ± .2 in. | 13.6 ± .3 in. | 0.2 in. | 0.524 | 0.619 |
| 8 wk callf girth/n | 14.0 ± .2 in. | 14.0 ± .4 in. | 0 in. | 0 | -- |
| 4 wk quad girth/s | 17.5 ± .4 in. | 17.5 ± .8 in. | 1.0 in. | 1.4 | 1 |
| 4 wk quad girth/n | 18.1 ± .4 in. | 18.2 ± .8 in. | -0.1 in. | -0.101 | 0.9222 |
| 8 wk quad girth/s | 17.9 ± .7 in. | 16.9 ± .5 in. | 1.0 in | 1.487 | 0.1876 |
| 8 wk quad girth/n | 18.3 ± .3 in. | 17.6 ± .6 in. | 0.7 in. | 0.839 | 0.4338 |
| 4 wk quad strength/s | 6.3 ± .7 in | 5.5 ± .5 in. | 0.8 in. | 0.753 | 0.4758 |
| 4 wk quad strength/n | 8.0 ± 0 in. | 7.5 ± .9 in. | 0.5 in. | 1.5 | 0.1705 |
| 8 wk quad strength/s | 7.7 ± .3 in. | 7.0 ± .7 in | 0.7 in. | 1 | 0.3632 |
| 8 wk quad strength/n | 8.0 ± 0 in. | 7.3 ± .4 in | 0.7 in | 1.6 | 0.1747 |
| 4 wk challanged balance/s | 19.9 ± 7.8 s | 17.8 ± 4.0 s | 2.1 s | 0.287 | 0.7822 |
| 4 wk challanged balance/n | 11.8 ± 2.9 s | 16.4 ± 3.7 s | -4.6 s | -0.881 | 0.4073 |
| 8 wk challanged balance/s | 22.9 ± 3.6 s | 24.1 ± 3.8 s | -1.3 s | -0.238 | 0.8196 |
| 8 wk challanged balance/n | 23.1 ± 4.0 s | 25.0 ± 3.6 s | -1.9 s | -0.335 | 0.7492 |
| 4 wk gastroc endurance/s | 65.6 ± 17.9 s | 37.5 ± 6.7 s | 28.1 s | 1.531 | 0.1626 |
| 4 wk gastroc endurance/n | 71.9 ± 19.8 s | 33.6 ± 4.9 s | 33.25 s | 1.549 | 0.1554 |
| 8 wk gastroc endurance/s | 76.4 ± 18.2 s | 42.0 ± 7.3 s | 47.0 s | 1.81 | 0.1445 |
| 8 wk gastroc endurance/n | 79.3 ± 19.0 s | 44.0 ± 8.3 s | 49.0 s | 1.8 | 0.1467 |

s = surgical leg; n = nonsurgical leg $p < .05$

TABLE 2

4 WEEK TO 8 WEEK CHANGES

| Measure | Mean s 4 to 8 weeks | Paired t value | Probability (*p < .05) |
|---|---|---|---|
| Flexion W | 14.6* | 4.241 | * .0054 |
| Flexion S | 9.2* | 4.568 | * .006 |
| Extension W | 1* | 1.382 | 0.2163 |
| Extension S | 2.1* | 1.598 | 0.1403 |
| S Calf Girth W | 0.4 in | 4.137 | * .0061 |
| S Calf Girth S | 0.1 in | 0.523 | 0.5196 |
| N Calf Girth W | 0.2 in. | 1.64 | 0.1522 |
| N Calf Girth S | 0.1 in. | 0.985 | 0.3626 |
| S Quad Girth W | 0.8 in | 5.956 | *.001 |
| S Quad Girth S | 0.1 in. | 0.833 | 0.4368 |
| N Quad Girth W | 0.4 in | 6.856 | *.0005 |
| N Quad Girth S | 0 in. | 0.223 | 0.8311 |
| S Quad Strength W | 1.7 in | 3.286 | *.0167 |
| S Quad Strength S | 1.3 in. | 2 | 0.1019 |
| N Quad Strength W | 0 in. | - | - |
| N Quad Strength S | 0.3 in. | 1 | 0.3632 |
| S Chal. Balance W | 2.29 s | 1.297 | 0.7766 |
| S Chal. Balance S | 7.43 s | 2.201 | 0.061 |
| N Chal. Balance W | 11.86 s | 2.314 | 0.0599 |
| N Chal. Balance S | 7.43 s | 1.311 | 0.2377 |
| S Gastroc Endurance W | 5.71 s | 0.402 | 0.7014 |
| S Gastroc Endurance S | 10 s | 1.907 | 0.1292 |
| N Gastroc Endurance W | 1.43 s | 0.907 | 0.9306 |
| N Gastroc Endurance S | 10.2 s | 1.909 | 0.1289 |

N = Nonsurgical leg
S = Surgical leg

W = Water Group
S T = Standard Group

TABLE 3

COMPARISON OF 4 TO 8 WEEK CHANGES
WATER vs STANDARD GROUPS

| CHANGE | DF | MEAN ~ W vs ST | PAIRED t VALUE | PROBABILITY ($p < .05$) |
|---|---|---|---|---|
| Flexion | 5 | 5.8° | 1.436 | 0.2104 |
| Extension | 6 | -1.1° | -0.691 | 0.5153 |
| S Calf Girth | 6 | 0.3 in. | 1.558 | 0.1703 |
| N Calf Girth | 6 | 0.1 in. | 0.526 | 0.6175 |
| S Quad Girth | 6 | 0.6 In. | 2.417 | 0.0521 |
| N Quad Girth | 6 | 0.4 In. | 3.017 | *.0235 |
| S Quad Strength | 5 | 0.3 in. | 0.277 | 0.7926 |
| S Gastroc Endurance | 4 | 15 s | 1.762 | 0.1529 |
| N Gastroc Endurance | 4 | 11.8 s | 0.899 | 0.4194 |
| S Challanged Balance | 6 | -5.1 s | -0.622 | 0.5571 |
| N Challanged Balance | 6 | 4.4 s | 0.627 | 0.5538 |

W = Water Group    ST = Standard Group

TABLE 4

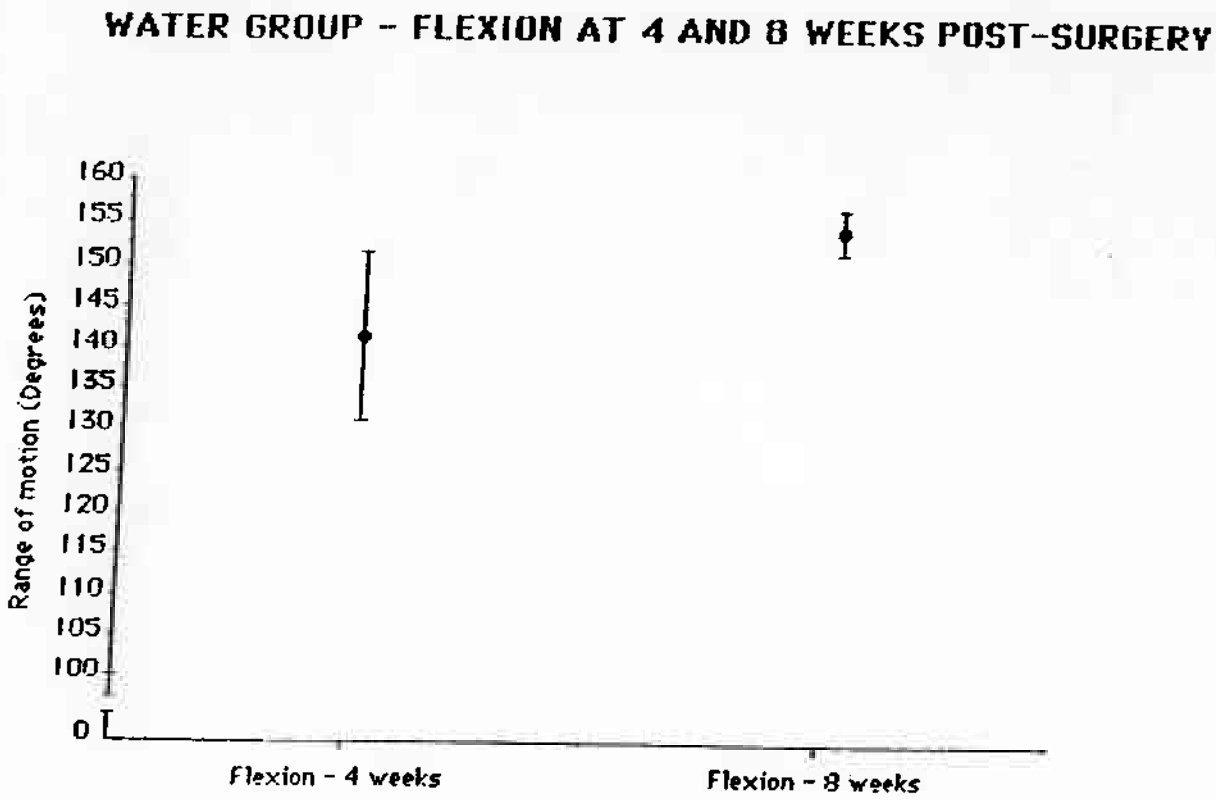
WATER GROUP - FLEXION AT 4 AND 8 WEEKS POST-SURGERY
Range of motion (Degrees)
160
155
150
145
140
135
130
125
120
115
110
105
100
0
Flexion - 4 weeks
Flexion - 8 weeks

FIGURE 1

STANDARD GROUP – FLEXION AT 4 AND 8 WEEKS POST-SURGERY

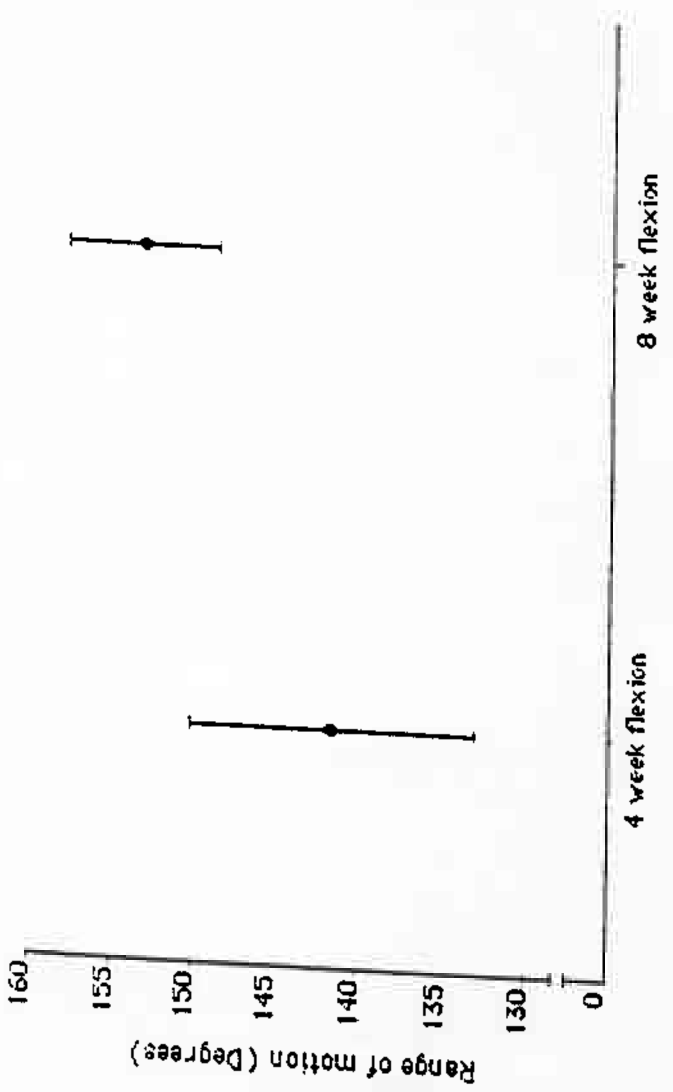


FIGURE 2

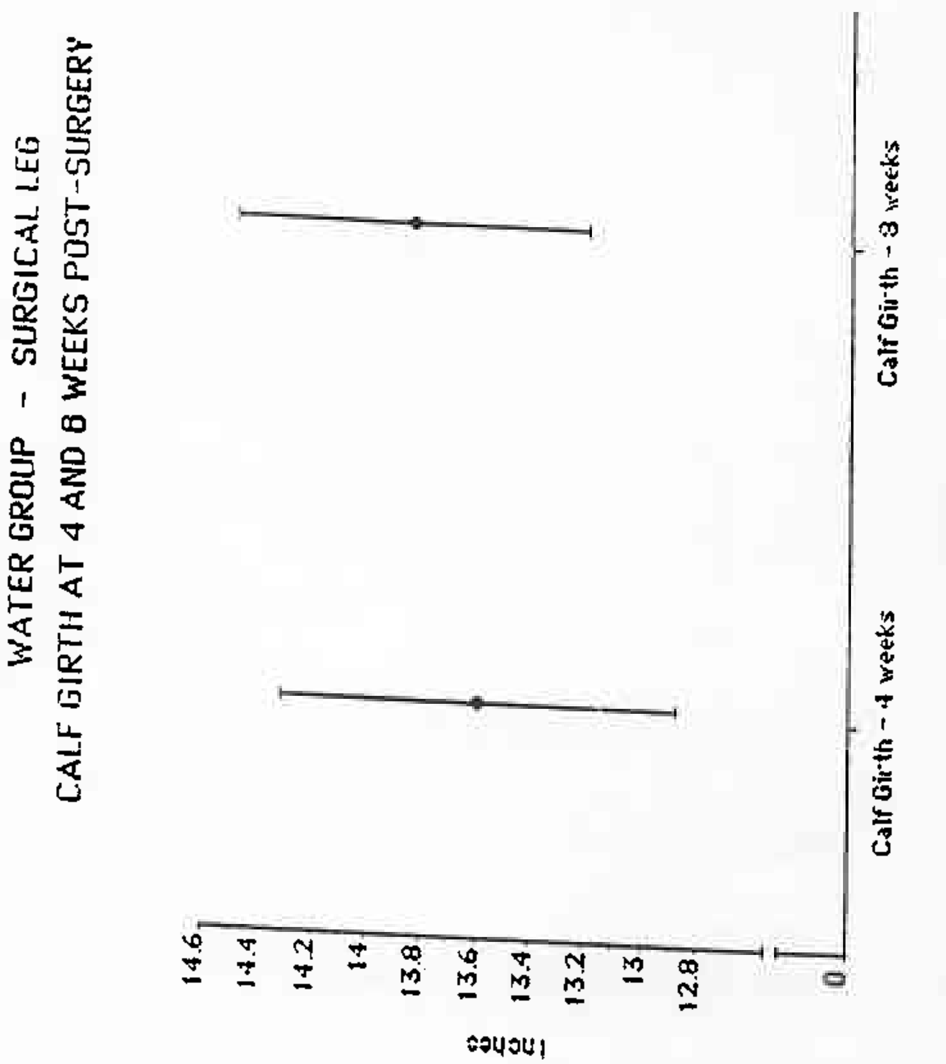
WATER GROUP - SURGICAL LEG
CALF GIRTH AT 4 AND 8 WEEKS POST-SURGERY
Inches
14.6
14.4
14.2
14
13.8
13.6
13.4
13.2
13
12.8
0
Calf Girth - 4 weeks
Calf Girth - 8 weeks

FIGURE 3

WATER GROUP - SURGICAL LEG

QUADRICEP GIRTH AT 4 AND 8 WEEKS POST-SURGERY

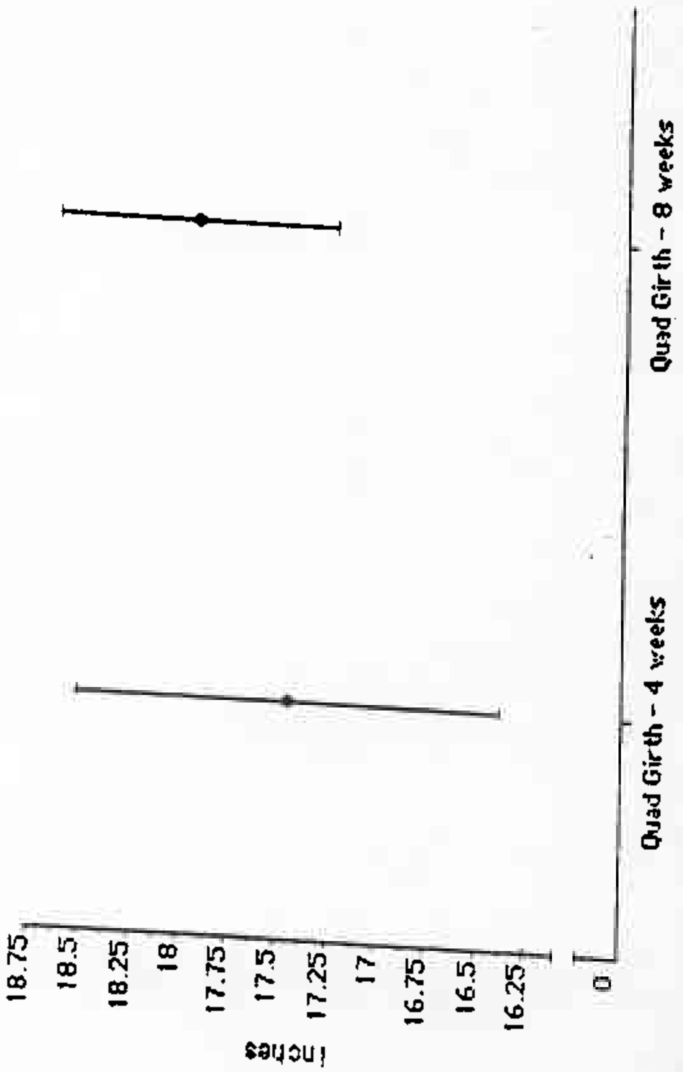


FIGURE 4

WATER GROUP - NONSURGICAL LEG
QUADRICEP GIRTH AT 4 AND 8 WEEKS POST-SURGERY

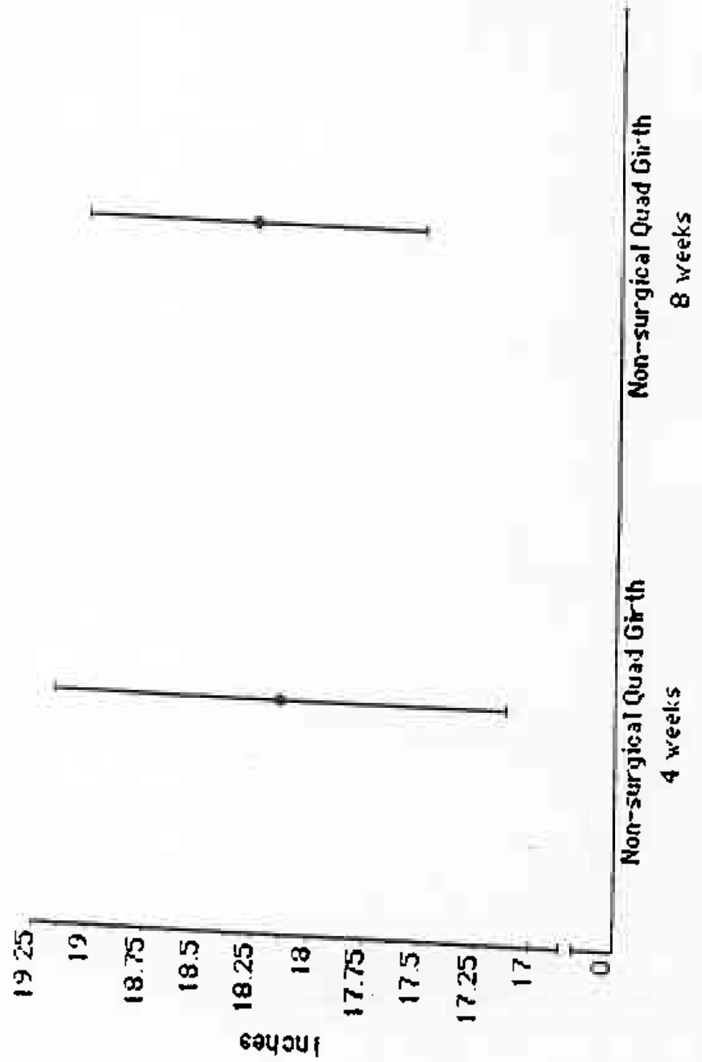


FIGURE 5

WATER GROUP - SURGICAL LEG

QUADRICEP STRENGTH AT 4 AND 8 WEEKS POST-SURGERY

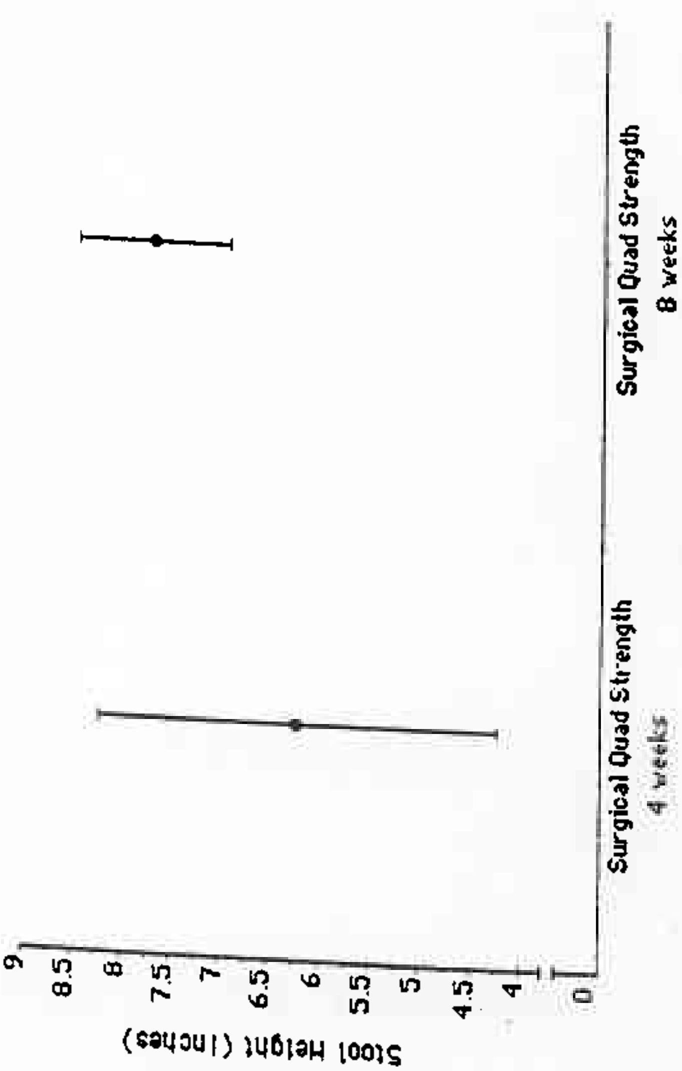


FIGURE 6

Appendix 5

aquaCiser

**AquaCiser™, Inc.**
996 Bluff City Boulevard
Elgin, IL 60120
312-931-7170



## Specifications

Overall dimensions: 7'L x 9'W x 5'11 (to top of tank).
Weight empty: 1,500 lbs.
Weight filled: 5,300 lbs.
Electrical requirements: 50 amp 220V or 208 single phase.
Water requirements: No special plumbing.
Pumps: 1/2HP filtration with pre-filter 2HP tank fill and whirlpool.
Heater: 5KW electric.
Treadmill drive: Hydraulically powered.
Belt speed: Variable, 0 to 6.5 mph.
Maximum water height: 40 inches.
Water jets: 10 adjustable nozzles.
Timer: 0 to 100 minutes.
Temperature control: Adjustable with monitor on console.
Filters: Replaceable paper cartridge.
Control consol: Main power, controls for 3 motors, water temp. monitor, timer, and mph display.
Delivery: 12 weeks.