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MUSCLE PRESERVATION IN LONG DURATION SPACE MISSIONS: THE ECCENTRIC FACTOR.

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INTRODUCTION

In our quest to understand, and eventually prevent, the loss of muscle strength and mass that occurs during prolonged periods in microgravity, we have organized our research approach by systems and useful terrestrial analogs.

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In previous papers and presentations at earlier Nihon University symposia I have described our progression through this program plan. Our work in electromyostimulation and tissue analysis following, 30 days of 6 degree head down bedrest, have been the primary subjects of these reports.

It should, perhaps, be repeated that the reasons for undertaking this work are two fold. First, the problem of muscle loss in the microgravity environment is very real and methods used to date have not been fully successful in preventing this change. The loss is deleterious to the crewpersons postflight activities, potentially life threatening if full physical vigor is required in a descent and landing emergency, and not with out impacts to the individual ego. The second problem concerns the operational impact of attempts to maintain muscle mass and strength in space. Past experience with exercise programs lasting 2 to 4 hours daily have been, as stated in other published observations, disappointing in terms of results, and the inordinate amount of time removed from the work schedule increases the expense of productivity in space. We must also consider the volume in cubic meters required for exercise equipment, the disturbances to microgravity critical activities caused by vibrations from treadmills, and in some projected cases, the electrical power that could be removed from this already overtaxed resource.

With all of the foregoing in mind, it behooves us to be certain we understand the cellular as well as the gross physical nature of the problem and thus to be able to prescribe an exercise program that addresses the known, specific elements.

In the 1988 symposium, I reported the results of the joint Kennedy Space Center - Ames Research Center 30 day bedrest study. Our primary interests were the changes in the cellular morphology and biochemistry of the vastus lateralis and soleus muscles after 30 days of uninterrupted 6 degrees head down bedrest. The finding that type 1 or slow twitch fibers did not preferentially atrophy contrasts with the reported changes in the muscles of the suspended rodent model. Moreover, bedrest decreased the activity of enzymes of aerobic, but not anaerobic metabolism. An intervention group that received electromyostimulation showed less signs of deconditioning. Details of this research have since been published in a series of papers in Aviation, Space, and Environmental Medicine, volume 60, 1989.

Our primary thrust since the bedrest effort has been toward understanding the elements required for muscle hypertrophy.

PROBLEM STATEMENT

It is tempting to assume that the elements necessary for building muscle mass are well understood. Books and magazine articles have been written on the subject for over 100 years. Yet minimal scientific research has been done on humans to verify claims made for the methods promulgated in these writings. Since the late 1940s magazines catering to the interest in weight lifting and bodybuilding have crowded the news stands, and each month a new method for creating larger muscles in some part of the body is the cover story.

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Indeed, quite startling examples of human muscular development are readily available, and the owners of these physiques are well paid for revealing their training methods. But a clear scientific judgment of these methods cannot be made without experimental data, and what worked for Arnold Schwartzenegger, starting at age 19, is not necessarily a reasonable plan for a more mature person starting from a more sedentary life style.

Not only is it necessary for us to understand such things as intensity, duration, and frequency of stresses to be placed on individual muscle groups, but it is important that we learn the most simple and effective way of administering that stress. We must learn whether or not the dynamic movements involved in the lifting of free weights on Earth is significantly more effective than isokinetically limited movements or isometric contractions. We must also better understand the metabolic demands of selected exercises and the most constructive period of rest between bouts of exercises.

In formulating the methods to be used in our first attack on the problem of creating measurable muscle fiber hypertrophy, two guiding limitations were imposed. First, the exercise required must be of a commonly accepted type, with at least some basis in experience that would lead us to expect positive results. (The opposite end of this would be electromyostimulation, for which every element is controversial.) The second limitation was, that we had to have some reasonable expectation of providing equipment and cubic area in the space habitat to permit these exercises. Following a rather interesting process of elimination, the quadriceps femoris was chosen as the muscle group, dynamic, isotonic like, movements were selected as the most natural and commonly used in training exercises, and eccentric, or lengthening muscle actions, were selected as the movement component to evaluate for relative effectiveness and necessity. The reason is, of course, that muscle is substantially loaded during eccentric actions in 1-gravity, with essentially the complete loss of such muscle action in microgravity.

HYPOTHESIS

Our hypothesis was that: The eccentric movement, or lengthening component, of dynamic, resistive exercise, is required for the production of the greatest gains in strength and muscle hypertrophy in the most metabolically efficient, and time effective manner.

METHODOLOGY

The exercises selected were, (1) leg presses,

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(2) leg (knee) extensions,

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and (3) hamstring curls.

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In this 30 week study, 38 male subjects, between the ages of 25 and 50, were divided into four groups. One group performed 5 sets of 8-12 repetitions per set of conventional concentric/eccentric (CON/ECC) exercises. Another group performed only the concentric (CON) movement on the same schedule. The third group performed twice the number of sets in the concentric only mode (CON/CON), and the last group served as controls. The maximum reasonable resistance training loads were selected for each individual during the equipment and methods familiarization period that lasted for 4 weeks and ended one week prior to the experimental training. During this time, all subjects were tested for their 3 repetition maximum strength in the leg press and knee extension exercises. Each exercise was performed with concentric only or concentric and eccentric muscle actions in each repetition. Subjects were again tested after 20 weeks of training, and then after 4 weeks of detraining.

Each group trained twice weekly with at least 48 hours of rest required between sessions. Training sessions were under strict supervision with encouragement and guidance given to each subject on a one-to-one personal basis. These sessions lasted from 30 to 40 minutes, and each set was performed to failure. Careful records were maintained by the training supervisors of the weight used in each exercise set, and the number of repetitions fully completed.

The equipment used in the training was unique in that it was customized to our particular requirements. Each piece was tested for differential friction losses in either the concentric or eccentric mode, and linearity of resistance. We discovered that friction losses in certain popular commercial knee extension and flexion machines were in excess of 25%. This resulted in an unacceptable decrease of the force presented to the subjects in the eccentric mode, and required extensive rebuilding of the machines with replacement of the proprietary cam/pulleys and bearings.

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The other custom feature of these pieces of resistive exercise equipment is the addition of hydraulic cylinders. These were selectively attached to the weight stacks to remove the eccentric component of the exercises. Since the same equipment was used for all three groups, it was necessary to assure that the concentric component was not altered by these modifications. The relatively small resistance added by the hydraulic cylinder was, therefore, counterweighted.

Two needle biopsies, after the method of Bergstrom, of the right side vastus lateralis, were taken from all subjects before the beginning of heavy training. Two more biopsies were taken from adjacent sites at the end of 20 weeks of training, and again after 30 days of detraining.

RESULTS

STRENGTH AND METABOLIC RESPONSES TO TRAINING

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The concentric/eccentric training group, CON/ECC, increased leg press strength more than the concentric only, CON, training group ($P<0.05$) when the testing exercise was performed with both concentric and eccentric actions. The relative group increases were 26% and 8%.

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When the testing was only in the concentric mode, the CON/ECC group improved 22%, the CON group 12%. Detraining for one month resulted in modest changes in strength, but group CON/ECC was still stronger than before training while group CON was not. (In both cases $P<0.05$.)

The energy cost for a given training session using the supine leg press exercise was approximately 75 kcal for both groups. This occurred in spite of the fact that group CON/ECC performed almost twice the total work as group CON; 4358 ± 288 kg·m versus 2551 ± 192 kg·m mean + SE. The modest additional energy cost of adding eccentric muscle actions to the training program and the benefit of a large increase in the load acted against, probably reflects the high efficiency of performing this type of muscle action.

MUSCLE FIBER TYPE HISTOCHEMICAL CHANGES WITH TRAINING

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A marked decrease in type 2b fibers, to approximately 1%, was found post-training in both groups CON/ECC and CON, ($P<0.05$).

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At the same time the percent of type 2a fibers was increased to a level very nearly equal to the percent loss of type 2b. This occurred to a similar relative extent in both groups, ($P<0.05$). After one month of detraining, type 2b fibers were beginning to return in group CON. This was not the case in group CON/ECC.

Because the type 2b percentage was extremely low both post-training and detraining, valid and reliable cross sectional area and capillary count data could not be determined on this fiber type at these times. Accordingly, the area and capillary data are reported for type 1 fibers and all type 2 fibers.

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Group CON showed evidence of hypertrophy post-training for type 2 fibers (15% increase, $P<0.05$) but not Type 1 fibers (<10% increase, $P>0.05$). After one month of detraining the cross sectional area of both fiber types was only 5% larger than before training ($P>0.05$).

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Group CON/ECC showed stronger evidence of hypertrophy. The cross sectional area of type 1 and type 2 fibers was 11% and 30% larger, respectively, post-training. Moreover, they were still 12% and 21% larger, respectively, after one month of detraining. These results indicate the addition of eccentric muscle actions to resistance training resulted in greater hypertrophy of mainly type 2 fibers, which was maintained to a greater extent after cessation of training.

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This is supported by the fact that the ratio of the cross sectional area of type 2 to type 1 fibers was increased ($P<0.05$) both post-training and detraining for group CON/ECC, but not group CON.

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The number of capillaries around type 1 and type 2 fibers was increased 18% and 25%, respectively, for group CON/ECC post-training, and 29% and 32% after detraining. ($P<0.05$ in both cases.)

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Group CON showed similar increases for type 1 and type 2 fibers post-training (30% and 36%) and detraining (32% and 40%, $P<0.05$ in all cases).

(Slide #16)

As a result of these responses and the modest hypertrophy shown by group CON, the number of capillaries per unit area of type 1 and type 2 fibers was increased post-training and detraining more for this group than for CON/ECC.

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Group CON/ECC showed a similar response for type 1 fibers after detraining. The substantial hypertrophy of the type 2 fibers in this group, however, offset the neoformation of capillaries such that the capillarity per unit area of the type 2 fibers did not change with training or detraining for group CON/ECC. The proliferation of capillaries with resistance training has not generally been reported. It may be that the supine nature of the leg press exercise used in this study placed a greater stress on the peripheral circulation than conventional resistance training in the upright posture. This requires further verification and should be pursued since the supine posture imposes cardiovascular stresses more analogous to null gravity than upright exercise. Nevertheless, the data indicate this type of training can cause substantial hypertrophy without compromising the capillary supply of muscle.

Data from the experimental group that performed twice the number of concentric only exercises, group CON/CON, have not been presented here. Some tissues have not been completely evaluated. We can, however, safely make certain general statements from the data that are available. The time required for completion of an exercise session was nearly twice that required for group CON/ECC, and the energy cost for a given training session was nearly doubled. In spite of this, the gains in strength were clearly less than those of group CON/ECC, though greater than group CON.

SUMMARY

We interpret these data as convincing evidence that the eccentric component of heavy resistance training is required along with the concentric for the most effective increase in strength and muscle fiber size in the least time. We also conclude that such heavy exercise of any such muscle group need not consume inordinately long periods of time, and is quite satisfactorily effective when performed on 72 hour centers.

If I may extrapolate from our present data to the environment of the microgravity habitat, it seems reasonable to conclude that the long periods of time devoted to attempts at maintaining muscle strength and mass might be shortened. Further, based on these data and other work from our laboratories by Convertino and others, daily exercise for two hours or more may be unnecessary for the maintenance of aerobic capacity. If more effective muscle maintenance can be performed in less time and with less than daily impact on the crew duty schedule, and if a single bout of maximal aerobic exercise on 5 or 7 day centers can maintain cardiopulmonary capacity, then expensive non productive crew time can be significantly reduced.

The negative effect of these findings, as stated earlier, may be in the creation of hardware that can be used in microgravity to provide the balanced concentric/eccentric resistance for all the major muscle groups. Ideally, such a device should be isolated in regards to any vibration produced. For the currently planned space station, equipment with electromagnetic or electrohydraulic requirements could result in severe limits on the time available for use. A purely mechanical device that can be adequately calibrated for long periods, should be nearly ideal. We have assembled a candidate devise in our laboratory at Kennedy Space Center, based on a commercially available mechanical load cell. A testing program is currently in progress.

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CONCLUSION

In order to gain enough confidence in these presented data to bring about a major influence on planning of future space missions, methodologies similar to those described must be applied to an extended hypokinetic, hypodynamic model, such as bedrest. An unlikely alternative would, of course, be an extended, well controlled trial in the actual space environment. Whichever method is eventually pursued, it is obvious that the problems of muscle wasting, and the most effective and productive use of crew time must be given a higher priority as our several space agencies move toward a serious manned space exploration initiative.

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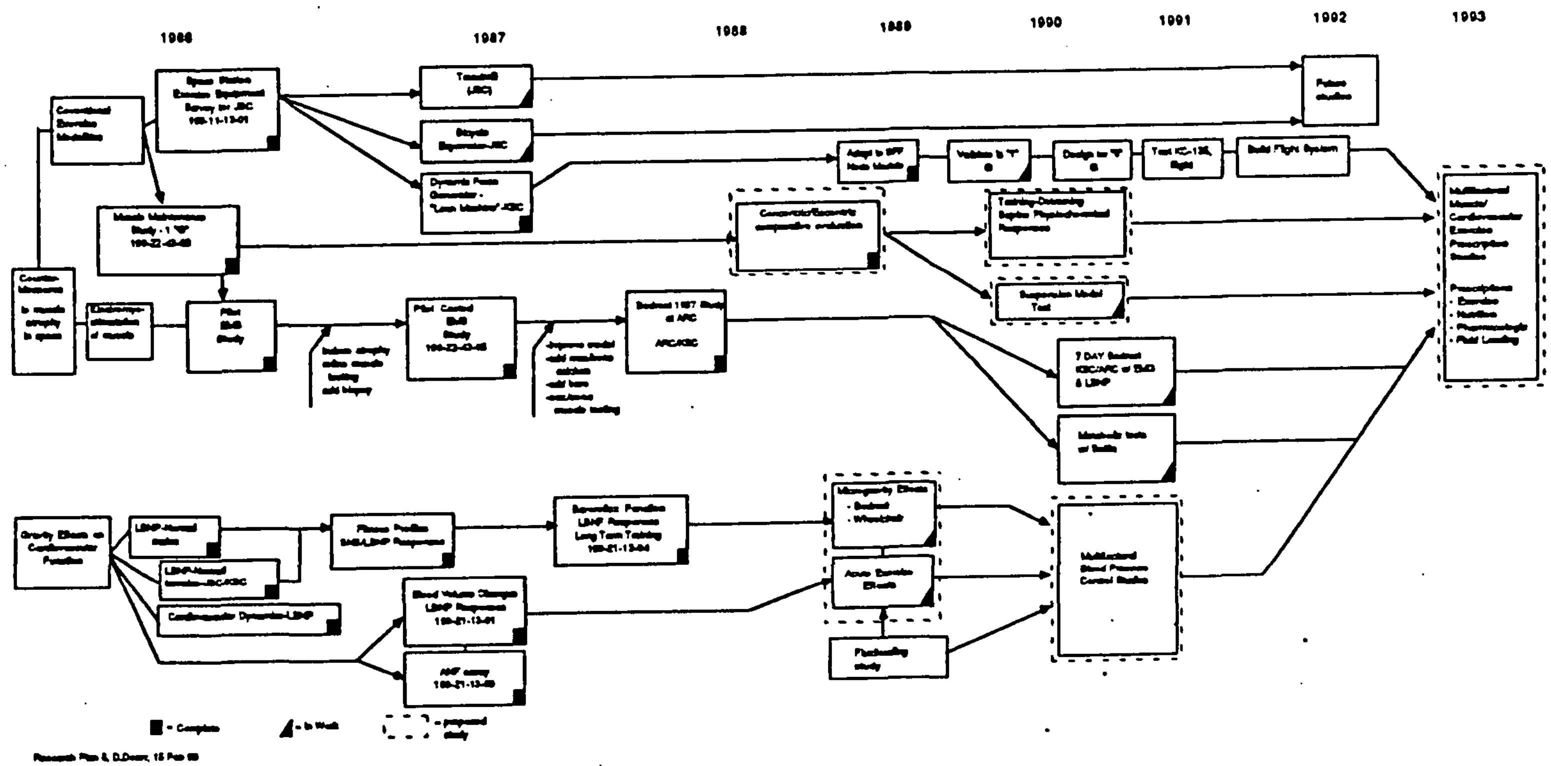
KSC BIOMEDICAL OFFICE HUMAN RESEARCH PLAN



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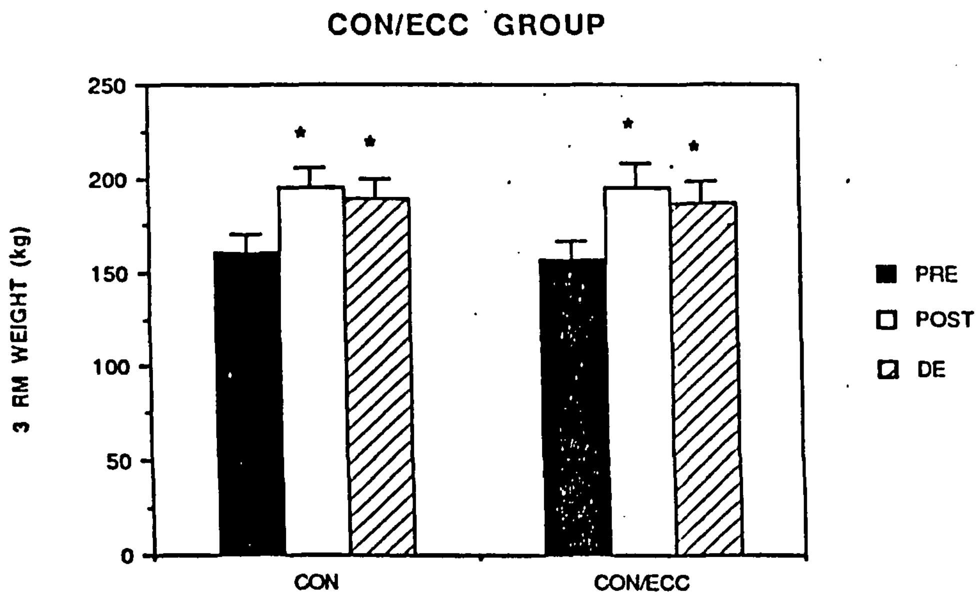
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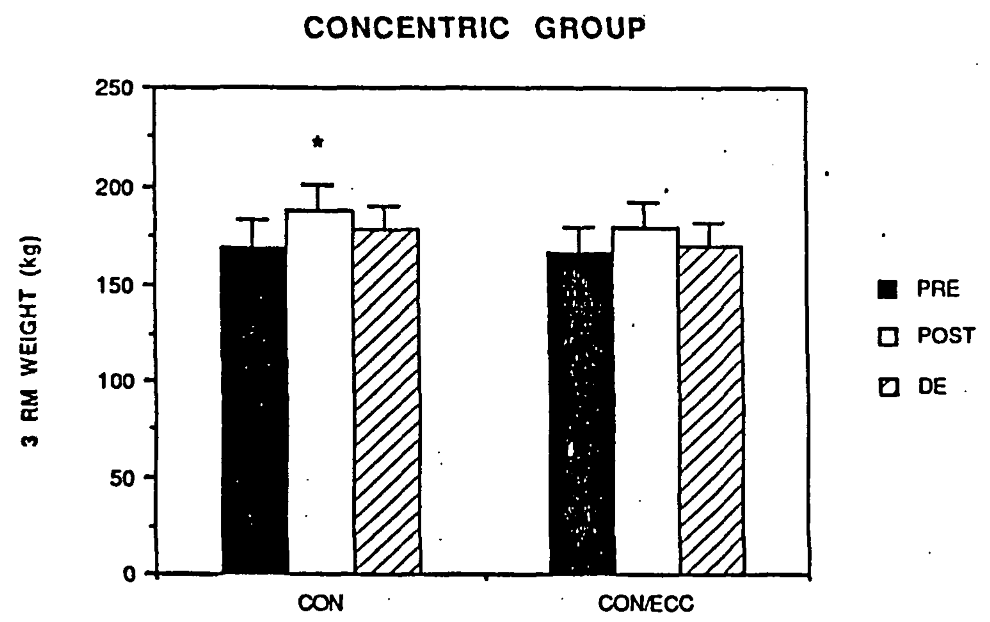
3 RM WEIGHT (kg)
250
200
150
100
50
0
CON
CON/ECC
PRE
POST
DE


CONCENTRIC GROUP
250
200
150
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50
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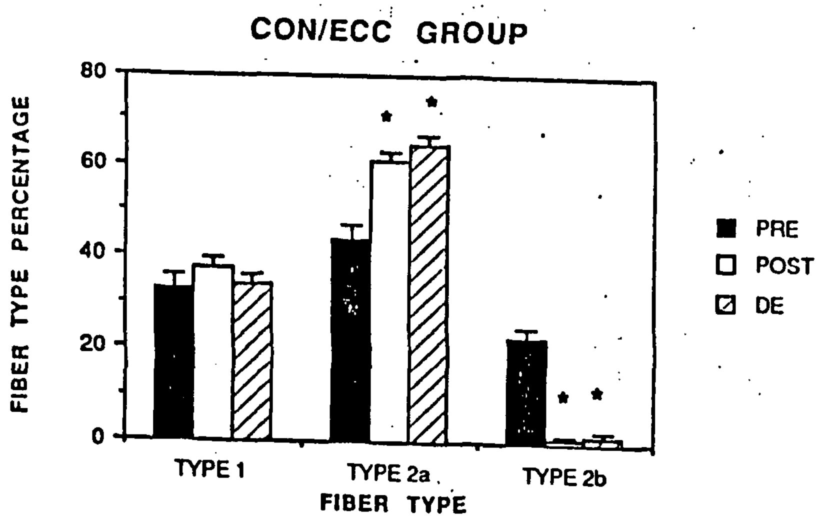
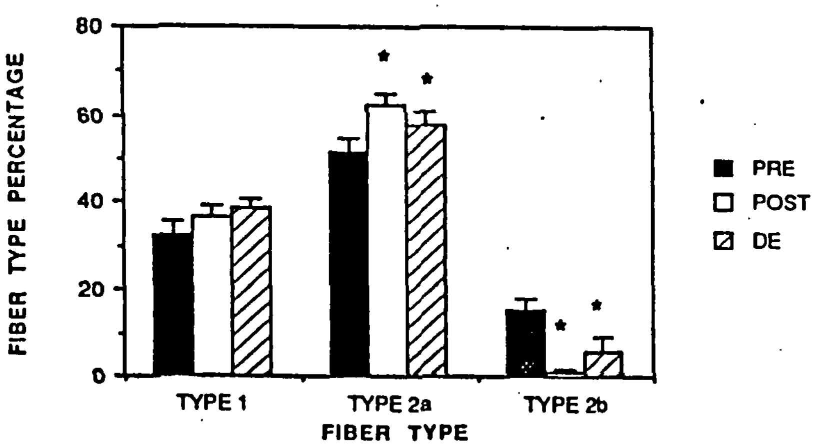
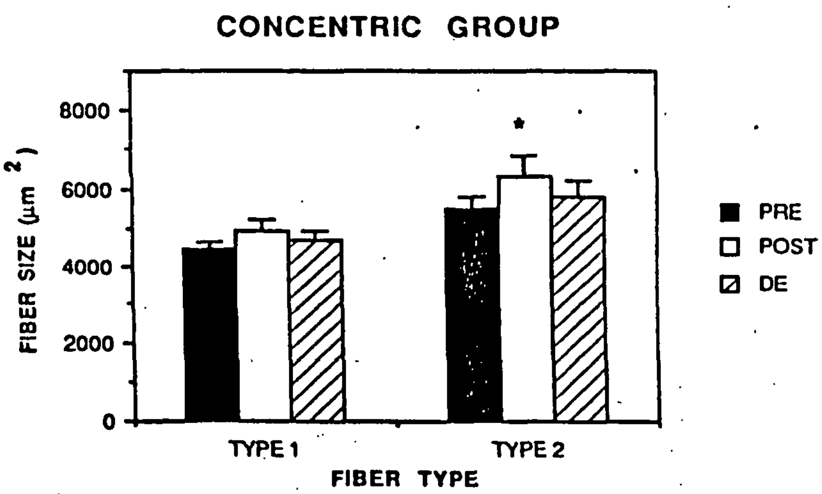
3 RM WEIGHT (kg)
*
CON
CON/ECC
PRE
POST
DE


CON/ECC GROUP
80
60
40
20
0
FIBER TYPE PERCENTAGE
TYPE 1
TYPE 2a
TYPE 2b
FIBER TYPE
PRE
POST
DE

CONCENTRIC GROUP




CONCENTRIC GROUP
FIBER SIZE (µm 2)
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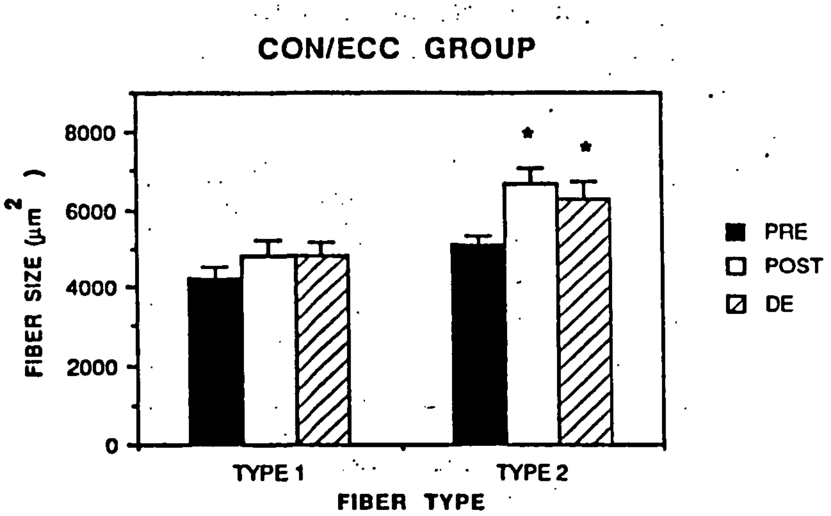
6000
4000
2000
0
*
TYPE 1
TYPE 2
FIBER TYPE
PRE
POST
DE


CON/ECC GROUP
8000
6000
4000
2000
0
FIBER SIZE (µm2)
TYPE 1
TYPE 2
FIBER TYPE
PRE
POST
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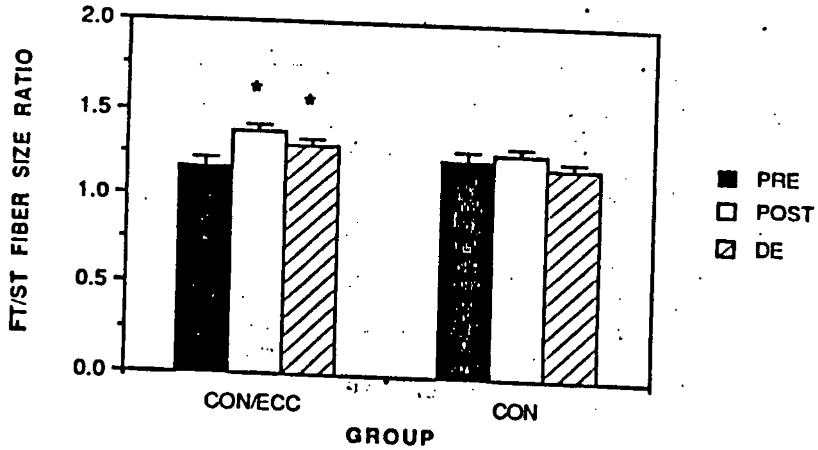
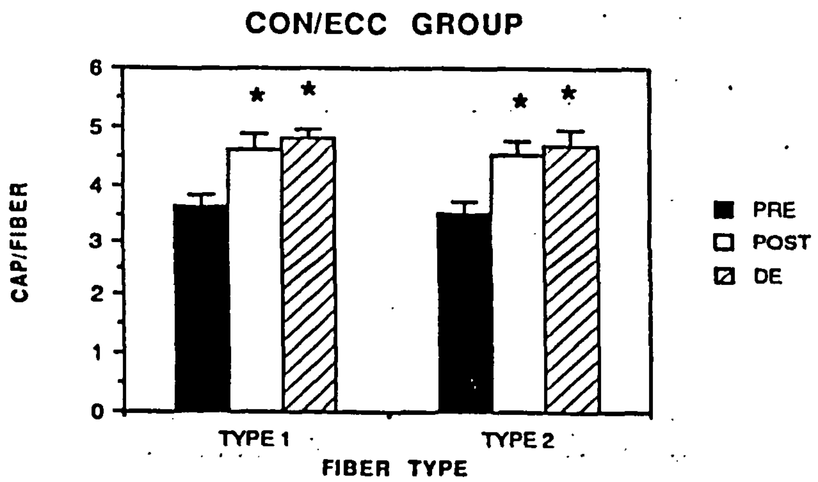


2.0
1.5
1.0
0.5
0.0
FT/ST FIBER SIZE RATIO
*
*
CON/ECC
CON
GROUP
PRE
POST
DE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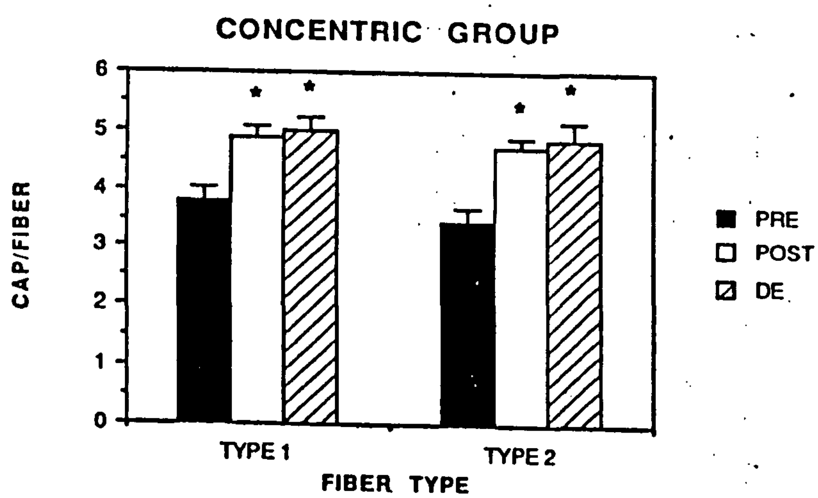
CAP/FIBER
0
1
2
3
4
5
6
TYPE 1
TYPE 2
FIBER TYPE
PRE
POST
DE


CONCENTRIC GROUP
CAP/FIBER
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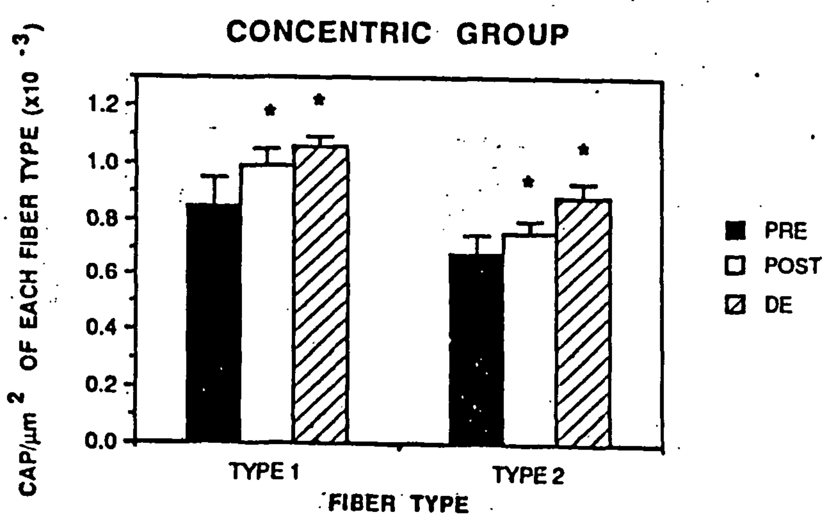
1
2
3
4
5
6
*
*
*
*
TYPE 1
TYPE 2
FIBER TYPE
PRE
POST
DE



CONCENTRIC GROUP
CAP/μm 2 OF EACH FIBER TYPE (x10 -3)
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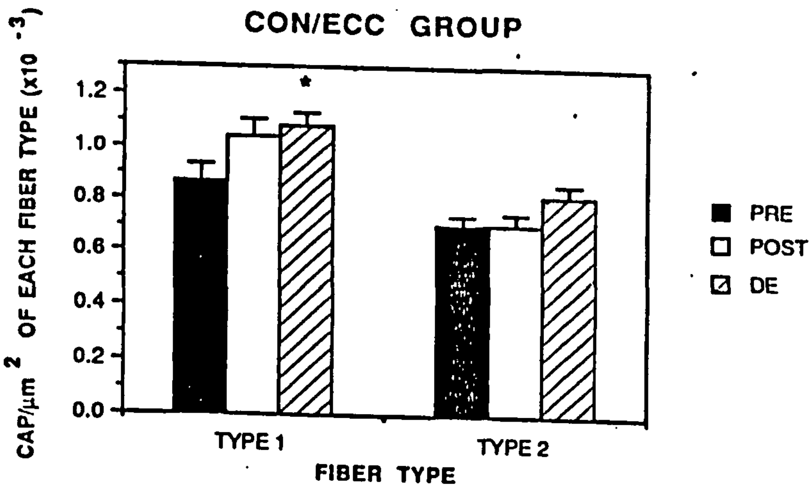
1.0
0.8
0.6
0.4
0.2
0.0
TYPE 1
TYPE 2
FIBER TYPE
PRE
POST
DE



CON/ECC GROUP
CAP/µm 2 OF EACH FIBER TYPE (x10 -3)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
*
TYPE 1
TYPE 2
FIBER TYPE
PRE
POST
DE