DISUSE ATROPHY OF QUADRICEPS FEMORIS AS A RESULT OF LOWER EXTREMITY IMMOBILIZATION

by

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A Thesis submitted to the Faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirements for the Degree

Master of Science

Department of Physical Medicine and Rehabilitation

1962

This Thesis for the M.S. degree by

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Date July 10, 1962

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Disuse Atrophy of Quadriceps Femoris as a Result of Lower Extremity Immobilization

Thesis directed by Professor Jerome W. Gersten

In order to reduce the time required for rehabilitation of the injured, there is a need to explore the possibilities of a method of reducing strength loss during immobilization of an extremity. A test of the conventional "quad-setting" exercises was inconclusive because the series could not be completed; however, there were indications that this method is relatively ineffective in preventing muscle atrophy. In search of an ideal positional angle for immobilization of the knee, a group of 10 normal subjects exercised one leg using brief isometric contractions at 165° and the other at 120°. Exercise at both angles was equally successful in increasing strength. In a third series, brief maximal isometric exercise of the quadriceps femoris proved to be effective in preventing atrophy of disuse in normal subjects with a lower extremity immobilized in a cast. This method is worthy of a clinical trial on patients with extremities immobilized because of disease or injury.

This abstract of about 150 words is approved as to form and content.
I recommend its publication.

Signed Jerome W. Gersten
Jerome W. Gersten, M.D.

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CHAPTER I

THE PROBLEM

Muscle atrophy as a result of immobilization of an extremity following surgery, disease, or injury has long been a problem of clinical medicine. Early observations of muscle atrophy associated with immobilization were made by Hippocrates(1) and by numerous clinicians down to the present time.

The morbidity from muscle atrophy following immobilization is enormous. As recent as 1922 it was considered normal not to expect the full benefit from surgery for internal derangement of the knee for from two and one half to three years after its performance.(2) Even later, in 1945, a large series of knee injuries in soldiers was reported with a large percentage of poor results.(3) In retrospect, in the light of current knowledge, most of the difficulty with knee effusion and pain could be attributed to quadriceps insufficiency. Even today, using the methods of DeLorme(4), Muller(5), and others, it requires from three to six or eight weeks after short term immobilization to restore the quadriceps to normal strength, starting from the time of termination of immobilization after the initial injury or surgical wound has healed. If this time required for rehabilitation could be reduced, it would be an economic advantage to the patient, both from the standpoint of lessened time of disability and decreased time off the job.

Since it is unlikely that there will be further significant reduction in the time required to reverse muscle atrophy, perhaps more attention should be directed toward prevention of atrophy during immobilization. There are a number of technics currently available that might be considered: (a) optimal position of immobilization; (b) electrical stimulation; (c) cross-education; (d) muscle-setting (isometric, static contraction) exercises. Each of these will be considered briefly. Since quadriceps femoris atrophy is often extreme and very troublesome, this muscle group is a logical choice for investigation.

CHAPTER II

REVIEW OF THE LITERATURE

Optimal position of immobilization. Immobilization of a limb has been shown by numerous investigators to result in atrophy of the affected muscles; however, some lack of agreement exists between the findings of different workers as to the effect upon muscle mass of fixation in different positions. Solandt, Partridge and Hunter(6) observed that immobilization of the hind limb of rats in a position of non-stretch resulted in atrophy almost as rapid as that following denervation. Ralston, Feinstein and Inman(7) found in studies on guinea pigs that immobilization in the shortened position was conducive to atrophy, whereas fixation in the stretched position protected against atrophy of disuse. Eisenhauer and Key(8) found moderate and persistent atrophy in the muscles of cats which had been immobilized in the stretched position, whereas, little consistent effect was found when the muscles were immobilized in shortened and in neutral positions. Summers and Hines(9) found, in studies on cats, that immobilization in either the neutral, shortened or stretched position resulted in atrophy and strength loss of the gastrocnemius and soleus muscles. The extent of atrophy was greatest in muscles immobilized in the shortened and least in the stretched or extended position. Imig, Randall and Hines(10) reported on a study of the effect of immobilization of the muscles of the hind limbs of dogs in shortened and stretched positions and concluded that the atrophy in both positions was equivalent to that during denervation. They believed that the controversial findings among the various investigators are due to the differences in species, the extent to which the immobilization permitted weight bearing, and the extent to which the cast allowed for muscle movement and to which it served to impede blood flow. A portion of their experiment involved measurement of blood flow, which they found to be increased during immobilization and thus is evidence against ischemia contributing to the genesis of atrophy.

As far as could be determined, no quantitative study has been done on humans. However, Ralston, Feinstein and Inman(7), in concluding that stretch protects against atrophy in immobilized muscles, state that this is in agreement with common clinical observation in the human subject.

Electrical stimulation. Much experimental evidence has been accumulated to show that electrical stimulation of denervated muscle can retard its atrophy to a considerable extent if contractions of sufficient vigor and tension can be produced in the muscle.(11, 12) Considerable use has been made of electric stimulation of normally innervated skeletal muscle, particularly in posttraumatic cases. Smart(13) was a leading advocate of this, being of the opinion that it was helpful in restoring muscle tone and in preventing intermuscular, intramuscular and peritendinous adhesions. However, Millard(14), in a controlled study of the merits of voluntary exercise and electric stimulation in which stimulation took the place of one of the exercise sessions in those patients who received it, found no difference in the end results between those who received stimulation and those who did not. The stimulation given was strong enough to extend the knee against the force of gravity. Despite any evidence in its favor, the discomfort to the patient and the necessity of frequent treatment sessions make this method of treatment less feasible than others.

Cross-education. The status of "cross-education" remains in the hypothetical stage, in spite of numerous recent investigations. Support was given to the earlier theory of "cross-exercise" when Hellebrandt, Parrish and Houtz(15), in 1947, found an increase in strength in contralateral non-exercised muscles when the biceps brachii was exercised against increasing loads. They postulated that cross transfer results from widespread synergistic co-contractions of the contralateral musculature. The isometric tensing, or fixation, of the opposite muscles caused by exertion of the exercised muscle group results in increased strength of the "unexercised" muscles. In 1950, Slater-Hammel(16) showed that exercise of one upper extremity produced definite and positive improvement of strength in the contralateral non-exercised upper extremity. That the effect was due to exercise and not to transfer of motor coordination is suggested by the fact that the strength advantage of the experimental group over the controls was lost after two weeks. Muller(17) was unable to demonstrate increase in strength in contralateral unexercised muscles when isometric exercises were used. He attributed the positive findings of Hellebrandt and others to the fact that in dynamic exercises such as they used, there is an increase in cardiorespiratory function which affects the entire body including the non-exercised muscle. He also believed that frequent testing of the unexercised muscle would in itself act as sufficient stimulus to produce an increase in strength.

Rose(18) and associates reported that cross-education occurred in all their normal subjects, but they stated that from the data from six patients it would appear that the cross-education effect is nullified when the extremity is prevented from developing the normal proprioceptive feedback to the central nervous system by immobilization of the part. Later Rose(19) stated that the phenomenon of cross-education appeared to be of no value clinically, Gregg, Mastellone and Gersten(20) studied electromyographic effects of cross-education using skin electrodes. In studies limited to the biceps and triceps, they found that overflow to the unexercised contralateral muscles did not occur during simple non-resistive exercises or during isometric contraction of the biceps brachii. However, with resistance, overflow appeared first in the opposite triceps, and with increasing resistance, activity in the contralateral biceps also appeared. The amplitude was not sufficient to be considered exercise effect.

In 1958, a complete denial of cross-exercise effects was expressed by Kruse and Matthews(21) on the basis of controlled clinical experiments on 120 subjects. Within the last year, an electromyographic evaluation of the cross-exercise effect was done by Panin, Lindenauer, Weiss and Ebel(22) on normal healthy young men. The greatest electromyographic activity was found in the exercised muscles. Potentials of low amplitude and low frequency were found in all non-exercised muscles studied. These potentials were not limited to the contralateral muscles but were widespread throughout all four extremities. The electrical activity appeared to be greatest in those muscles required to stabilize the body while performing exercise. They concluded that the amplitude and frequency of these potentials would indicate that they were of insufficient magnitude to constitute exercise effect.

Muscle-setting exercises. Early in the consideration of the effectiveness of "quadriceps-setting" exercises, a number of unanswered questions arose. How effective are quadriceps-setting exercises, as currently advocated, in retarding atrophy in an immobilized extremity? Is it possible to attain a maximal, or near maximal, isometric contraction in the quadriceps when the extremity is encased in a cast? Is there an ideal positional angle for the knee to be casted from the standpoint of a stronger isometric contraction?

Isometric exercise is not new. Adolph Eugen Fick (1829-1901) is credited with introducing the terms "isometric" and "isotonic".(23) That isometric exercise will retard atrophy and increase strength is now well known.(5, 17, 24, 25, 26) Muller(17), in his studies with isometric exercise, concluded that stimuli from muscle contractions between 20% and 35% of maximal do not induce training yet they are sufficiently strong to prevent atrophy. While exercise above 35% of maximum resulted in an increase in muscle strength, daily exercise using a single six-second contraction of two-thirds maximum was found to be the optimal method of producing increase in muscle strength. He also found that the training effect, at a slower rate of strength increase, is obtained even by one maximal contraction per week. However, this may not hold true when the extremity is casted or otherwise immobilized. A recent study indicates that in the arm brief duration isometric exercise is relatively effective in retarding the loss of strength that occurs during limb immobilization.(27) Whether or not this applies to the lower extremity remains undetermined.

"Quadriceps-setting" exercises have been in use for at least the last half century in attempts to prevent muscle atrophy after knee injury, fracture, or surgery.(28, 29) At the present time the term is in common usage as evidenced by its inclusion in the therapeutic exercise regime of the majority of our Orthopedic and Physical Medicine textbooks. Several investigators have expressed doubt as to the efficacy of muscle-setting exercises(15, 30, 31), but as far as could be determined no quantitative study of this has ever been done.

A study by Houtz, Lebow and Beyer(32) on the effect of posture on the strength of knee flexor and extensor muscles posed another unanswered question. They found that with the subject in the sitting position, the amount of tension developed by the quadriceps femoris with the knee at 165° (180° equals anatomic position) was approximately 25% of the tension developed with the knee at 120°. Williams and Stulzman(33) found similar results in a more comprehensive investigation. Combining these findings with those of Muller(5, 17), one might ask whether it is possible to attain absolute maximum tension only with the knee at 120°, and whether it is possible to achieve a training stimulus (greater than 35% of maximum) with the knee at 165°, even with a maximal effort. This question is pertinent in view of the fact that in a majority of cases the knee is immobilized in a range from a few degrees to perhaps 30 degrees of flexion.

CHAPTER III

THE PURPOSE

The purpose of this investigation was to determine the adequacy of a common method of combating disuse atrophy and to present and test a new concept of brief isometric exercises in subjects immobilized in casts. The experiment was divided according to three objectives:

Section I. To quantitate the effectiveness of the currently prevalent method of using "quadriceps-setting" exercises in retarding muscle atrophy and/or in decreasing the rate of loss of muscle strength in patients with lower extremities immobilized in casts.

Section II. To test the relative effectiveness of isometric training of the quadriceps with the knee angle at 165° and at 120° in normal subjects.

Section III. To determine the effectiveness of brief maximal isometric contractions in preventing quadriceps atrophy and strength loss in normal subjects, with a lower extremity casted with the knee at 165°.

To determine if a maximal isometric contraction of the quadriceps can be obtained with the extremity in a cast.

CHAPTER IV

METHODS

<u>Equipment</u>.

1. Isometric tension was measured with a T-5 cable tensiometer (Pacific Scientific Co., Los Angeles).

2. The Elgin exercise table (Model A-1500, Elgin Exercise Appliance Co., Elgin, Illinois) was used to determine the 10 repetition maximum (10 RM). From a sitting position on the end of the table, the subject was instructed to extend his knee from 90° to 180° against resistance applied to the ankle by a leather cuff placed just above the malleoli. The greatest amount of weight that could be lifted 10 times at a cadence of about 15 times per minute equaled the 10 RM.

In Section I only, the Elgin table was used to determine isometric tension developed by the quadriceps with the knee at 90° and 135° (180° equals full extension). The subject stabilized his trunk and maintained a hip angle of approximately 105° by grasping the table on either side. With the knee at the desired angle, the weight pan was fixed so that any contraction would be isometric. This was done by tightening two pipe clamps three-fourths of an inch in diameter to the vertical guide bars, just above the weight pan, thus preventing any rise of this pan on muscle contraction.(25) The tensiometer was then fastened to the cable (one-eighth inch diameter) from which the weight pan was suspended to record the tension developed during the isometric contraction.

3. A quadriceps exercise table was altered to permit measurement of isometric tension (fig. 1). A specially designed apparatus

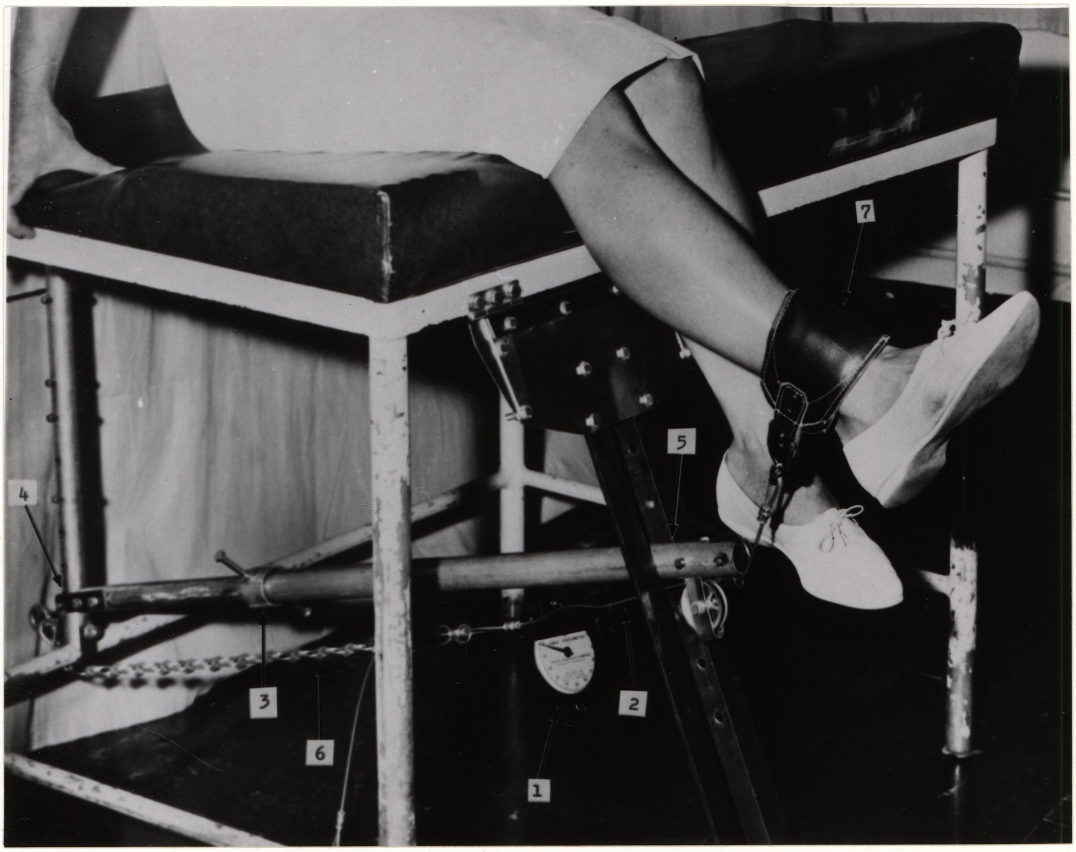

Fig. 1 - Modified Quadriceps Exercise Table

1. T-5 cable tensiometer.
2. 1/8" cable.
3. Telescoping pipes - adjustment for length.
4. Rear adjustment - up or down.
5. Front adjustment - up or down.
6. Chain - adjustment for cable length.
7. Leather ankle cuff - just above the malleoli. The pull of the cable is always perpendicular to the long axis of the lower leg.

was added to permit attachment of a cable and provide for adjustment of the cable angle at the angle to 90° regardless of the positional angle of the knee. The tensiometer was then fastened to the cable (one-eight inch diameter) to record tension.

4. Electrical activity in the contracting quadriceps was determined with a portable transistor amplifier, using skin electrodes. (25, 34) The amplifier unit consisted of a three stage difference amplifier with six transistors, a class B push-pull final stage with two transistors, a 12 ohm two and three-fourths inch speaker, and a 200 d.c. microampere meter.

5. Knee angles were measured with a standard full circle goniometer.

6. Immobilization of the lower extremities of the subjects in Section III was accomplished by the use of Johnson and Johnson quick-setting plaster of paris bandage, using standard orthopedic technics. Padding was placed at the top and bottom and over bony prominences.

Section I

Twenty patients were obtained from the Division of Orthopedic Surgery of Colorado General Hospital who, because of injury or disease of the lower leg, were immobilized in a unilateral long leg cast for periods of 2 weeks to 9 months. Those patients who had received direct injury to the quadriceps muscle were not used in this study. Otherwise, the patients were selected at random over a period of nine months and alternately divided into two groups: Group I and Group II. Ages of the subjects ranged from 12 years to 60 years. The average age was 30.5 years; the median age, 23 years.

Procedure.

1. The normal extremity served as a control for the casted extremity. As soon as possible after the cast was applied and the patient had recovered sufficiently from his trauma and/or surgery, the uninvolved extremity of each patient was tested as follows:

a) Circumferential measurements of the thigh at 2" and 8" above the superior pole of the patella, with the patient in the supine position and the thigh musculature relaxed.

b) Strength testing of the quadriceps femoris on the Elgin table using isometric methods with the knee at 90° and 135° and the 10 repetition maximum (10 RM).

2. The patients in Group I, as the test group, were instructed in quadriceps-setting exercises after the fashion which seemed to be the most prevalent currently. They were taught to do static contractions of the quadriceps in the cast, to hold each contraction for a count of ten, and repeat ten times each waking hour on the hour. After the initial session of instruction, the patients exercised without supervision until the time of cast removal.

3. The patients in Group II served as controls. They received no exercise instruction.

4. Both lower extremities of the patients in both groups were re-tested in the same manner as soon as the casts were removed.

Section II

Ten healthy volunteers, 8 females and 2 males, employees of Colorado General Hospital, were used as subjects. The age range was from 22 to 49 years, with an average age of 32.7 years and a median age between 27 and 30 years.

Procedure.

1. Initial testing of all subjects:
   a) Thigh circumference, as described in Section I.
   b) Strength testing of the quadriceps femoris, bilaterally:
      (1) 10 RM determination, on the Elgin table.
      (2) Isometric tension measurement at 120° and at 165° angle at the knee, using the special quadriceps exercise table (fig. 1). Each subject was permitted a practice pull, then the best of two attempts was recorded.

2. Exercise program. All subjects exercised their quadriceps 5 days a week for 60 days, using one 6 second isometric contraction daily. For each subject, one leg was exercised with the knee at 165° and the contralateral knee at 120°. To avoid any advantage of side dominance, the knee angles were reversed on alternate subjects. For the first 22 days, two-thirds of maximum tension was used as a training stimulus. To accomplish this the subject was asked to contract his quadriceps slowly until the tensiometer recorded two-thirds of his previous maximum, then to "hold" at that point for 6 seconds. After the 22nd day, maximal tension was used for training.

3. Testing. Repeat strength testing was done not oftener than every 10 days to avoid having the test serve as a training stimulus.(17)

Section III

Twenty-two healthy volunteers, 12 females and 10 males, from the general population, were used as subjects. The age range was from 21 to 47 years, with an average age of 28.5 and a median age between 25 and 26 years.

Procedure.

1. Initial testing of all subjects for thigh circumference, 10 RM and isometric tension of the quadriceps was done as described in Section II.

2. Immediately following initial testing, a plaster of paris cast was applied to one lower extremity of each subject with the knee at an angle of 165°. The left leg was used in order to interfere less with automobile driving; however, in 3 subjects who had history of left knee injury, the right leg was casted. The casts were applied from the groin to just above the ankle, permitting full weight bearing throughout the 14 day casting period.

3. Exercise program. The subjects were divided alternately into Group A and Group B. Group A performed a single 6 second maximal isometric contraction of the quadriceps and hamstrings four times daily against the resistance of the cast. Group B did no exercise.

4. Final testing of all subjects was done on the 15th day of casting.

a) Before the cast was removed the peak of the electrical activity of the quadriceps in maximal contraction was measured in microamperes using a portable transistor amplifier. The skin electrodes were placed over the vastus medialis and the vastus lateralis through windows in the cast. The cast was then carefully removed without disturbing the electrodes, and the electrical activity was again recorded with the quadriceps contracting maximally against cable resistance with the knee at 165° (same as cast angle).

b) Prior to final testing all subjects were permitted to flex and extend the knee for 10 minutes in a whirlpool bath with the water at 100° F.

c) All subjects were re-tested as done initially.

CHAPTER V

RESULTS

Section I

A summary of the data from patients who had a lower extremity immobilized in a plaster cast is recorded in Table 1. Unfortunately, for varying reasons, only half of the 20 patients tested initially returned for retesting. Therefore, in addition to the small size of the sample, there is a disproportion between the exercise group and the non-exercise group, both as to the number of subjects and the duration of casting. Accordingly, no attempt was made to compare the two groups statistically. There are several observations that may be worthy of note. Both groups had a high percentage loss of strength by all three test methods. The two patients who were immobilized for 14 and 19 days, respectively, had as much loss of strength as several who were immobilized much longer. There was no apparent correlation between changes in thigh circumference and percent loss of strength.

Section II

Figures 2-4 show graphically the effect of isometric exercise on the function of the quadriceps in normal subjects who exercised for 60 days, one leg with the knee at 120° and the other at 165°. As noted in figure 2, the training effects at 120° and 165° are almost identical, as revealed by isometric testing at 120°. In figure 3, the same effects are noted, as revealed by testing with 10 repetition maximum. However, it may be seen in figure 4, that there are two discrepancies that may

Table 1: Data From Patients Immobilized in Casts

Subject	Thigh Circumference Gain or Loss--inches: 2" Level	Thigh Circumference Gain or Loss--inches: 8" Level	Percent Loss: Isometric Tension 90^{o}	Percent Loss: Isometric Tension 135^{o}	Percent Loss: 10 RM	Duration of Casting--days
Group I (Exercise Group)						
PM	+0.5	-0.5	70	68	67	60
AS	+1.0	+1.0	--*	64	79	181
CO	-1.0	-2.5	90	93	82	138
HA	+0.5	-1.25	38	10	20	122
Mean	+0.25	-0.81	66	59	62	125
Group II (Non-exercise Group)						
MF	+0.75	-0.5	25	46	75	55
JW	+0.5	+0.5	33	22	43	42
DW	+0.75	+1.0	31	38	67	62**
JH	-1.25	-0.5	61	29	81	14
MH	-0.125	-0.125	86	90	92	141
MM	-0.5	+0.25	65	45	85	19
Mean	+0.21	+0.10	50	45	74	56

*Unable to flex to 90^{o}

**No cast--I.M. pin in femur--no PRE for 62 days

Fig. 2-4--Effect of isometric exercise on function of the quadriceps in normal subjects who exercised for 60 days. The ordinate refers to percent improvement in isometric tension (•,o), or in 10 repetition maximum (x); the abscissa refers to time in days. Isometric training at 120° knee angle is represented by solid line (———); at 165° by broken line (------). Isometric testing at 120° is represented by closed circles (•), at 165° by open circles (o), and testing with 10 repetition maximum by crosses (x).

Fig. 2--Testing at 120° knee angle (•) for both training angles: 120° (———), 165° (------).

Fig. 3--Testing with 10 repetition maximum (x) for both training angles: 120° (———), 165° (------).

Fig. 4--Testing at 165° knee angle (o) for both training angles: 120° (———), 165° (------).

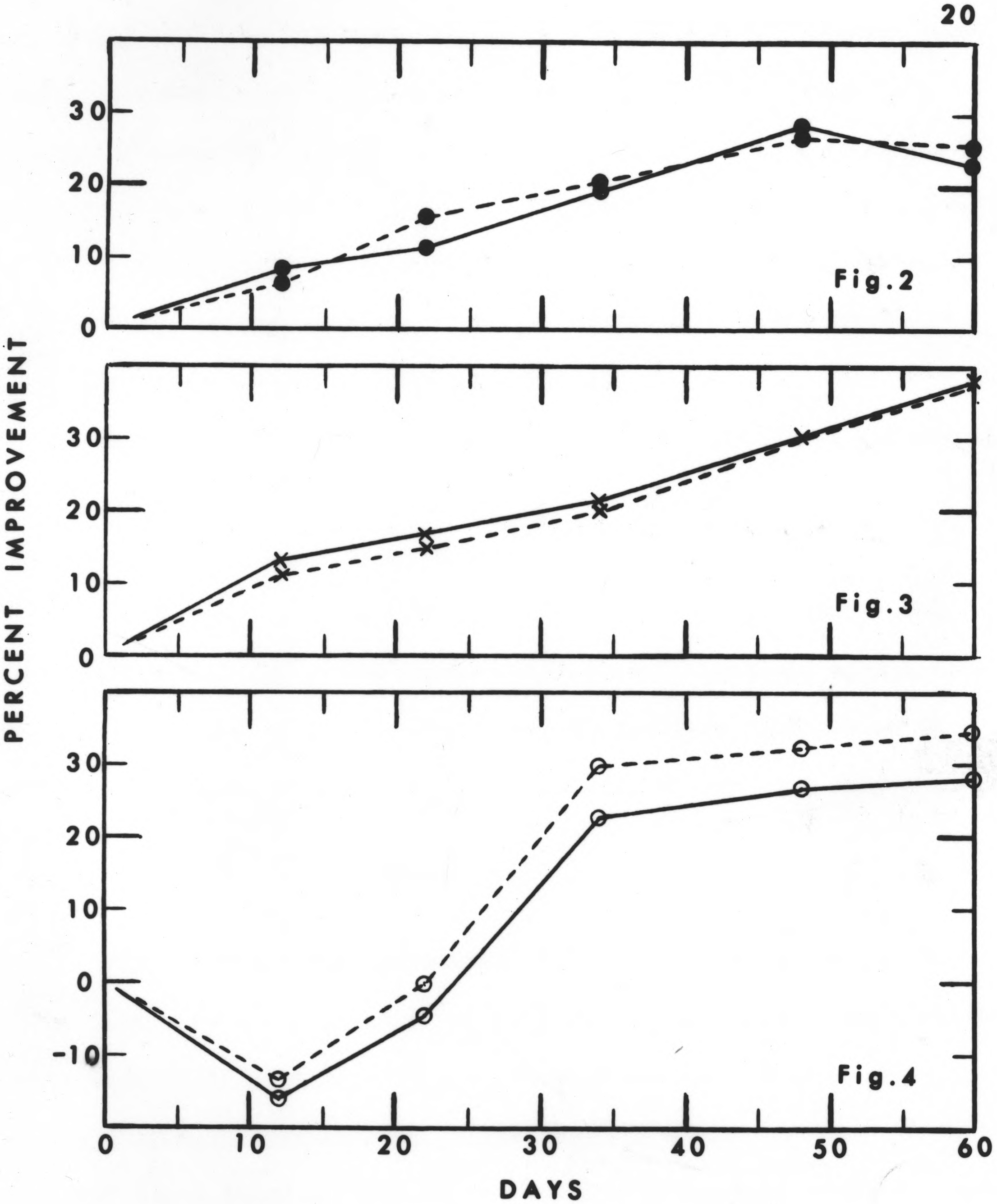
20
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Fig.2
PERCENT IMPROVEMENT
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Fig.3
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Fig.4
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DAYS

require explanation. There is an initial drop in strength followed by a relatively sharp increase which then levels off to a slope equivalent to those in figures 2 and 3. In addition, there is a separation of the two curves with the 165° training curve showing slightly greater percent improvement over the 120° angle. Using the test of significance for paired samples, at each point on the graph there is a significant difference between the two curves ($p < 0.02$).

With the possible exception of figure 4, there is no perceptible change in the curves at day 22 when the training stimulus was changed from two-thirds maximum to maximum tension.

With the possible exception of figure 4, there is no perceptible change in the curves at day 22 when the training stimulus was changed from two-thirds maximum to maximum tension.

The maximal tension produced at 120° was always greater than that produced at 165°. The overall mean maximal tensions of all subjects (both legs) on all test days were as follows: 114 pounds at 120° and 58 pounds at 165°, producing a ratio of approximately 2:1.

Section III

Table 2 shows the accumulated data from normal subjects who had a lower extremity immobilized in a cast for 14 days. The exercise group made a net gain in strength, whereas the non-exercise group lost strength by all three methods of testing. It should be noted that at the 165° angle (same as cast angle and therefore equals training angle) the percent improvement in the exercise group is greater and the percent loss in the non-exercise group is smaller than for either of the other two methods of testing. In the exercise group the 3.1% loss at 120° is not significant ($p = 0.5$); the 16.3% improvement at 165° is

Table 2: Data From Normal Subjects Immobilized in Casts

Subject	Thigh Circumference Gain or Loss--inches		Percent Gain or Loss		
	2" Level	8" Level	Isometric Tension 120°	Isometric Tension 165°	10 RM
Group A (Exercise Group)					
DP	+0.25	-0.25	+ 3	+24	+18
WJ	+1.00	+0.25	- 5	+36	+ 3
GE	0.00	0.00	+11	0	--*
CW	0.00	-0.25	+10	+53	+31
BS**	--	--	--	--	--
GS	+0.13	0.00	-16	+ 6	-10
NB	-0.25	-0.50	0	+ 7	-28
VY	+0.25	-0.50	-26	0	0
LJ	+0.50	0.00	+11	0	+11
DE	+0.25	+0.25	-10	+10	+ 4
BK	+0.50	0.00	- 9	+27	+ 6
Mean	+0.26	-0.01	- 3.1	+16.3	+ 3.5
S.D.	--	--	13.3	19.3	5.5
S.E.	--	--	4.5	6.1	1.9
p Value	--	--	= 0.5	< 0.05	< 0.1
Group B (Non-exercise Group)					
JC	0.00	-0.75	-34	- 9	-32
GI	+0.50	0.00	-11	+13	-14
EC	0.00	-0.75	-31	-18	-14
PF	+0.50	0.00	-19	-23	-38
WK	0.00	-0.50	-29	-32	-64
SF	+0.25	-0.25	-37	+ 3	-29
GD	+0.25	0.00	-37	- 6	-29
JP	+0.25	0.00	-24	- 6	0
CL	0.00	-1.00	-37	-24	-30
KB	+0.25	0.00	-26	-27	-33
SM	0.00	-0.75	-28	- 7	-36
Mean	+0.18	-0.36	-28.4	-12.0	-29.2
S.D.	--	--	8.4	13.7	16.3
S.E.	--	--	2.6	4.3	5.2
p Value	--	--	< 0.001	< 0.02	< 0.001

* Not obtained

** Subject had cast removed at one week--no data significant ($p < 0.05$); the 3.5% improvement with 10 RM is not significant ($p < 0.1$). In the non-exercise group, the percent loss at 120° is highly significant ($p < 0.001$); the percent loss at 165° is significant ($p < 0.02$); the percent loss with 10 RM is highly significant ($p < 0.001$). In the test of significance between the means of percent gain or loss of the exercise group and the non-exercise group, the difference is highly significant with all three methods of testing ($p < 0.001$).

Again, in this series, there is no consistent correlation between changes in thigh circumference and the changes in strength.

The electrical activity of the quadriceps contracting maximally against the resistance of the cast and again against cable resistance was measured in 18 of the subjects in this series. The amount of electrical activity in the cast was recorded as percent of that obtained out of the cast. The range was from 42% to 100%, with a median between 69 and 71% and a mean of 70%. Some of the subjects expressed feelings of discomfort on maximal effort in the cast which probably means that the 70% mean is too low.

CHAPTER VI

DISCUSSION

Section I

It seems possible that the conventional "quad-setting" exercises may not be effective in preventing atrophy of disuse when the extremity is immobilized in plaster. This is the most that can be concluded because of the small sample size and the disproportion between the exercise and the non-exercise groups. Any definite statement will have to await the accumulation of more data.

Section II

The test of the relative effectiveness of isometric training of the quadriceps with the knee angle at 165° and at 120° brought some interesting and surprising results. The greater maximal tension produced at 120° than at 165° was not unexpected since this is in general agreement with the findings of Houtz, Lebow and Beyer(32) and Williams and Stutzman.(33) There is much evidence to indicate that the prime factor responsible for the increase in strength during an exercise program is the tension developed by the contracting muscle.(35-38) Why, then, should the training effect at the 165° angle be the equivalent of, or in one instance better than, that at the 120° angle when the tension developed at 165° is only half that at 120°? Obviously, in this particular situation, there are other factors involved. It should be noted here that the tension referred to in this experiment is that produced externally on a cable attached to the ankle and should not be confused with the actual tension developed within the muscle itself. It is this internal tension that is related to the increase in strength following exercise. Therefore, because of differences in mechanical advantage and in muscle lengths at the two training angles, perhaps the 2:1 tension ratio is smaller when converted to the internal muscle tension. On the other hand, even if the 2:1 ratio holds in this situation, possibly 50% of maximal tension is an adequate training stimulus.(39) Another possibility could be in a statement made many times and in many places to the effect that the vastus medialis acts mainly in the last few degrees of knee extension. Although this has never been quantitatively analyzed, assume for the moment that it is true. This could mean that with the knee at the 120° angle, the vastus medialis may not receive a training stimulus, whereas, at 165° it would. The additional training effect in the vastus medialis at 165° could negate the advantage of the greater amount of tension developed at 120°.

On this assumption, since electrical activity is directly related to muscle tension(40), a preliminary electromyographic study was done on one subject seated on the modified quadriceps table. A long flexible unipolar needle electrode was inserted into the vastus medialis and the electrical activity was observed on the oscilloscope. Isometrically on maximal contraction, there was considerable electrical activity at 120°; however, the activity was somewhat increased at 165°. Isotonically, against gravity resistance, a small amount of electrical activity began at 90° and gradually increased through extension, with a small burst of increased activity through the last 20°.

Although these observations seem to indicate that the vastus medialis has increased activity through the last few degrees of extension of the knee, no conclusions can be drawn from this brief, hardly quantitative study. However, it may serve to point out the need for a quantitative analysis of the roles played by the four components of the quadriceps femoris. The answer to the question of an ideal positional angle for the knee to be immobilized will have to await this investigation.

Another unanswered question is, why was there an initial drop in strength as depicted in figure 4? All of the subjects in this series complained about discomfort in contracting the quadriceps maximally with the knee at 165°, and after the initial testing, all had soreness in the patellar tendon and especially in the patellar retinaculum medially. The soreness persisted for about two weeks. The painful stimulus from the tendon may have inhibited the quadriceps, producing a weaker maximal contraction.

Section III

From the results of this study, it may be concluded that exercise using brief maximal isometric contractions of the quadriceps is successful in preserving muscle strength in normal trained subjects with a lower extremity immobilized in a cast. Another subject for investigation might be to test this method of exercising on clinical patients immobilized because of injury or disease.

The fact that all of the subjects who exercised in the casts either improved or at least maintained their initial strength while casted answers in the affirmative the question of the possibility of achieving a training stimulus with the knee at 165°. In addition, the electromyographic studies indicated that it is possible to achieve a maximal or near maximal contraction in a cast in some subjects. Apparently even those who fell short of this were able to contract strongly enough to achieve a training stimulus.

Another effect of immobilization was observed in this series. All subjects, including those who gained strength as the result of exercise, had a feeling of insecurity at the knee on attempting weight bearing immediately after the cast was removed. There seemed to be an urge to walk with a straight (locked) knee, even though it could be demonstrated by deliberation that the flexed knee was stable. This feeling gradually diminished and disappeared with ambulation during the following two to three days. It is most likely that this phenomenon is due to a temporary sensory deprivation, but the mechanism cannot be satisfactorily explained at this time. It may be hypothecated, however, that this mechanism could account for an apparent strength loss that is greater than the actual loss, through inhibition via the sensory system.

Circumferential measurement of a limb is not a good index of muscle atrophy. Many of the subjects (and patients) who had marked strength loss and obviously deformed muscle topography showed no decrease (or even an increase) in circumference due to subcutaneous edema.

CHAPTER VII

SUMMARY

Section I

1. The four patients who performed the conventional "quad-setting" exercises in the cast lost as much strength as the six patients who did no exercise.

2. Because of the small series and the disproportion between the exercise and non-exercise groups, no definite conclusion can be drawn.

3. More data is needed to properly analyze this problem.

Section II

1. The ten normal subjects who exercised their quadriceps isometrically, one leg with the knee at 165° and the other at 120°, demonstrated significant strength improvement in each leg in each of three methods of strength testing.

2. In all three methods of testing, at 120°, at 165°, and with 10 RM, the percent strength increase was almost identical for each training angle. In the testing at the 165° knee angle, the slight advantage shown by the leg trained at 165° can be accounted for by the fact that daily practice could have produced an increased tolerance to the discomfort of a maximal pull at this angle.

3. It is proposed that a quantitative analysis of the roles played by each of the four components of the quadriceps femoris in extending the knee may provide the answer as to why the 165° training angle is as effective as the 120° angle, considering that the tension ratio is 2:1 in favor of the 120° angle.

Section III

1. The ten normal subjects who performed brief maximal isometric exercises in casts either improved or maintained initial strength, whereas, the eleven subjects who did no exercise consistently lost strength to a significant degree.

2. It may be concluded that brief maximal isometric exercises are successful in preserving muscle strength in normal subjects with a lower extremity immobilized in a cast.

3. A suggested sequel to this experiment is that this method of exercise be given a controlled clinical trial on patients immobilized because of injury or disease.

4. An unexplained temporary loss of proprioception was observed in all subjects.

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