RESTORATION OF MUSCLE POWER BY HEAVY-RESISTANCE EXERCISES

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Exercise is essential in restoring function to muscles, weakened and atrophied as a result of injury and disease. Therapeutically, exercises may be classified according to the quality developed in the exercised muscle,—namely, power, endurance, speed, and coordination. Failure to discriminate between these classes of exercises leads to the employment of the wrong type of exercise to develop the quality needed in the muscle; inevitably the result is poor. Commonly the attempt is made to restore power by exercises to build endurance; this is a mistake.

This paper deals with the redevelopment of muscle power, chiefly in the quadriceps, although some consideration will be given to other muscles.

PRELIMINARY CONSIDERATIONS

Most injuries of the thigh and knee result in atrophy of the quadriceps of varying degree. When the local injury has healed, redevelopment of quadriceps power is the most important factor in restoring normal function to the extremity. The method here presented for developing muscle power by exercise is founded on the principle of heavy-resistance and low-repetition exercises, whereas the generally accepted principle is low-resistance and high-repetition exercises—such as stationary-bicycle riding, lifting light sandbags or other weights through ropes and pulleys, stairclimbing, et cetera—which develop endurance rather than power. The fatigue that results from the latter is not due so much to overcoming resistance, as to the sheer number of repetitions; therefore, such exercise does not develop power. If low resistance is used for a low number of repetitions, no significant increase in either power or endurance results, and the only value lies in increasing slightly the joint motion. On the other hand, in our method we employ heavy resistance that calls forth all the potential strength of the muscle. Since the rate and extent of muscular hypertrophy is usually proportional to the resistance the muscle must overcome, strength returns faster than in the low-resistance exercises. We believe this to be true, because we have seen many patients fail to obtain any appreciable quadriceps hypertrophy during several months of low-resistance exercises; whereas, with the heavy-resistance exercises, we have uniformly recorded rapid hypertrophy (in several instances two to two and a half inches of hypertrophy of the thigh muscles within six to eight weeks). Power is developed in the affected thigh until it equals that in the normal. When the strength of the limbs is approximately equal, then endurance exercises may be begun. Rather than attempt to develop endurance in an atrophied, weakened muscle, it seems more logical to restore muscle strength to normal, and then build endurance by means of low-resistance, high-repetition exercises.

The quadriceps exercise described is particularly valuable, for it develops maximum power without weight-bearing. Since it is a non-weight-bearing exercise, it is especially useful in redeveloping the musculature following meniscectomy, and in unstable knees. In these two conditions, particularly when there is quadriceps atrophy, weight-bearing exercises (such as bicycling, stairclimbing, et cetera) frequently cause swelling and fluid. Except in rare instances, we have seen neither swelling nor fluid on maximum exertion with these non-weight-bearing exercises. In most of our cases, these symptoms have actually completely subsided on exercise. After these patients have succeeded in restoring
normal power to their injured limbs, they are able to do the light weight-bearing exercises mentioned without either symptom developing.

PROGRAM OF EXERCISES

In this program of heavy-resistance exercises, the patient exerts his maximum power only once a week. The maximum quadriceps power for clinical purposes is taken to be the maximum poundage that can be raised to the point of complete extension of the leg, for one repetition. It is recorded in pounds. Once each week the patient exerts the maximum effort of which he is capable for one repetition. On the other days, no weight heavier than that which is maximum for ten repetitions is used. This program of periodic maximum muscular exertion is used even on the most atrophied muscles. Contrary to the popular belief that after injury the quadriceps should never be exercised to its limits, we have never produced chronic muscle sprains or failed to achieve return of muscle power. On the basis of clinical observations in 300 cases in which this program of exercises was used, we firmly believe that even extremely atrophied muscles should exert their maximum effort at regular intervals.

Description of Exercise

The patient is seated on the table with his knees flexed at an angle of 90 degrees, and the boot is strapped on the foot. A folded blanket or pad is placed under the knees. The patient is now in the starting position, as illustrated in Figure 1. The leg is extended as completely as the disability will permit. The leg should be extended and lowered at the same rate. The movements are done smoothly, rhythmically, and without haste, but not so slowly that the mere holding of the weights will tire the patient. Quick or sudden motions while exercising are to be avoided. A momentary pause at the end of each repetition is advocated.

The importance of complete extension with each repetition cannot be overemphasized. The vastus medialis functions chiefly by carrying the leg through the last 15 degrees of extension. The disproportionately rapid atrophy of this muscle following injuries of the lower extremity and prolonged immobilization with resultant inability to completely extend the leg is a familiar clinical picture. Restoration of strength to the vastus medialis is a major problem to orthopaedists and physical therapists. If there is sufficient strength present to carry the leg either partially or completely through the last 15 degrees, the problem is not too great. However, if there is complete inability to extend through the last 15 degrees, the problem calls for more strenuous measures. In these cases it would be im-

Fig. 1
Quadriceps exercise, using one boot.

Fig. 2
Quadriceps exercise, using two boots.
Fig. 3

Fig. 4

Quadriceps-exercise table. The weight stands (A) are to rest the weight upon between sets of exercises.
possible to redevelop vastus medialis power, if the only function of this muscle were extension in the terminal 15 degrees; but the muscle also functions through a much larger range of motion when the leg must overcome a very heavy load. This fact makes it possible to exercise the vastus medialis actively in the available range of extension, thereby building power that will eventually make it possible to completely extend the knee. Sufficient vastus medialis power to produce complete extension can be built by using heavy resistance through the available range of motion. On each repetition, when the patient has reached his maximum extension, he should be taught to expend an extra effort at this point to attain even more extension.

At the beginning of the exercise and until the limbs are approximately equal in strength, only the affected extremity is exercised. Only one boot and a short bar are used, as shown in Figure 1. When the limbs are approximately equal in strength, then they are exercised simultaneously, using two boots attached to a long bar as shown in Figure 2. It is advisable for the patient to use two boots for a while to increase strength in the unaffected extremity, since this extremity becomes considerably weakened from disuse. When both boots are used, the principles of exercise, poundage increase, repetitions, et cetera remain the same as when one boot is used.

Apparatus

Resistance is offered in the form of iron plates, graded from one and a quarter to twenty-five pounds each. These plates are attached to an iron boot by means of a short iron pipe which fits into the boot. This boot is made especially for leg exercises. The iron boots, plates, and bars are shown in Figure 3.

The exercises are performed on a table which should be thirty-six inches high and at least fifty inches wide. The legs and top of the table should be of heavy material and reinforced, since it will be subjected to considerable strain. The edge should be raised two to three inches so that, when the leg is completely extended, the entire limb will be parallel to the floor. The quadriceps-exercise table is shown in Figure 4.

Repetitions and Weight

Fifteen is the maximum number of repetitions ever performed in series, regardless of the amount of weight lifted. Ten or twelve is the number generally performed. The total number of repetitions for an average exercise period varies from seventy to 100,—that is, seven to ten series of exercises with ten repetitions in each.

The Ten-Repetition Maximum (10 R.M.)

The amount of weight lifted by the patient at any single extension during his first week of exercise is determined at the time of his initial workout, as follows: Starting with the weight of the boot (five pounds), and increasing by small amounts (one and a quarter to five pounds), the patient lifts each weight ten repetitions. That weight which requires maximum exertion to perform ten repetitions is thus determined. For the remainder of the week, no weight heavier than this ten-repetition maximum (10 R.M.) is used. Once each week the patient makes an attempt to increase this 10 R.M., and, when this amount is determined, no heavier weight is used during the ensuing week. For example, a patient in his first workout finds that the heaviest weight with which he can perform ten repetitions is twenty pounds. Thus, during his first week, he uses nothing heavier than twenty pounds. At the end of the first week, the 10 R.M. is again determined, and found to have increased to thirty pounds. Then thirty is the maximum poundage used during his second week of exercise, et cetera.

Since seventy to 100 repetitions must be performed in each workout, and each poundage is done ten repetitions, the workout must be begun with a weight considerably less than the 10 R.M., so that when the 10 R.M. has been reached, seventy to 100 repetitions will have been performed. The example given can be continued to illustrate this. The
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At the beginning of the exercise and until the limbs are approximately equal in strength, only the affected extremity is exercised. Only one boot and a short bar are used, as shown in Figure 1. When the limbs are approximately equal in strength, then they are exercised simultaneously, using two boots attached to a long bar as shown in Figure 2. It is advisable for the patient to use two boots for a while to increase strength in the unaffected extremity, since this extremity becomes considerably weakened from disuse. When both boots are used, the principles of exercise, poundage increase, repetitions, et cetera remain the same as when one boot is used.

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10 R.M. for the first week was twenty pounds. By starting with two and a half pounds, plus the weight of the boot, and increasing one and a half pounds after each series of ten repetitions, eighty repetitions will have been performed when twenty pounds is reached.

*The One-Repetition Maximum (1 R.M.)*

As previously stated, once a week the patient exerts his maximum quadriceps power (maximum weight that can be lifted with one repetition, the knee going into complete extension). This one-repetition maximum (1 R.M.) is determined on the same day as the 10 R.M., in the following manner: When the 10 R.M. has been determined, the increases in weight are continued. With each increase beyond the 10 R.M., fewer repetitions can be done until finally that weight which can be extended only for one repetition with maximum exertion is reached. This is recorded weekly as the index of quadriceps power.

As strength returns to the muscle, the weight increases may be five to ten pounds, rather than one and a quarter to two and a half, thus keeping the total number of repetitions for a workout within the range of seventy to 100.

Of course there are many patients who, because of severe quadriceps weakness, have an initial 10 R.M. of less than five pounds. In these cases, the procedure is altered, and we use two or three series of ten repetitions each without any weight, add one and a quarter pounds, and give two or three series more. Then, by increases of one and a quarter pounds, his 10 R.M. is finally determined. (When the patient is unable to begin the exercises with the weight of the boot, five pounds, the smaller weights are attached to the foot by means of a leather strap.)

In these cases where there is incomplete extension due to muscle weakness, the program is further altered. After the patient has performed ten repetitions with the maximum poundage which can be extended to the same degree as when no resistance is being applied, he then continues to increase the poundage at the sacrifice of extension. The poundage increase is continued until the knee can be extended only a few degrees. Exercising in this way through the available range of motion is necessary where muscles are extremely atrophied, in order to build enough power eventually to effect complete extension. This is especially true when the vastus medialis is weak.

*Frequency and Length of Workout Periods*

The patient exercises once a day, five days a week, the workout period usually lasting one-half hour. He is encouraged to rest his leg as much as possible during the two days he does not report for the exercises. Since the exercise periods are short and come only once daily, the patient does not tire of the program, as is often the case when an exercise must be practised hourly or several times a day.

*Data Recorded*

The following measurements are recorded weekly:

1. Range of motion,
   a. Extension,
   b. Flexion,
2. Thigh circumference,
3. Power,
   a. 1 R.M. (one-repetition maximum),
   b. 10 R.M. (ten-repetition maximum).

The weekly determination of the 1 R.M. and the 10 R.M. is made on the same day. For convenience, we designate Friday as the day on which the quadriceps power is determined. There should be a two-day rest following this day of maximum exertion, and this arrangement makes it unnecessary for the patient to exercise over the weekend.

The thigh is measured once a week, at a constant level. Silver nitrate is used to mark
the level, to make sure that every measurement is taken in the same place. Daily observations are made for development of fluid, swelling, pain, et cetera.

The maximum quadriceps power is determined, and thigh measurements of the unaffected extremity are taken, when the exercise program is initiated. Maximum results have been obtained when both extremities are equal in power, circumference, and range of motion.

**Observations**

**Symptoms Developing as a Result of Exercises**

The only symptom that developed as a result of exercise was soreness of the quadriceps muscle. This soreness invariably disappeared within a week. In no instance has swelling or fluid appeared in the knee joint secondary to the strenuous exercises.

**Development of Power in the Existing Range of Motion**

Too often the main stress is placed on increasing motion in the atrophied, weakened limb with a limited range of motion, and very little or no thought is given to developing power. Nicoll states that "range without power is worse than useless, for in its extreme form we have a flail joint." The return of power should accompany return of motion. It is more desirable to have normal power in the existing range of motion than to sacrifice development of power for a wider range of motion. The exercises we advocate are planned so that return of power accompanies return of motion. We believe that range of motion increases more rapidly with increasing muscle power, except when a mechanical factor prevents return of motion.

**Focal Exercises versus Group Exercises**

We are convinced from our observation of patients indulging in group exercises and games, as performed in reconditioning programs, that group exercises for focal muscle redevelopment are unsatisfactory because:

1. The mental factor governing muscle exertion is such an important one in attaining maximum results that the patient must concentrate completely, and actually watch (whenever possible) the muscle being exercised throughout each repetition. Group participation offers too many factors to divert the patient's attention.

2. If a patient is unable to perform the movements as well as others in the group, he may feel his inadequacy to such an extent that he will attempt to cover up his weakness by adopting compensatory trick movements, thus accomplishing the feat with other muscles than the one which he is attempting to redevelop.

3. For the patient who must be prodded along, it is much easier for him to conceal his half-hearted efforts in group exercises.

4. Since there are individual variations in strength, symptoms, and types of injuries, it seems illogical to give exercises to groups of patients with the same repetitions, motions, resistance, and tempo.

**Endurance versus Power**

We feel that in the past one of the shortcomings of the conventional type of physical therapy for redeveloping musculature has been a failure to discriminate between endurance-building and power-building exercises. By "power-building" exercises we mean exercises in which heavy resistance is used for a low number of repetitions. "Endurance-building" exercises are those in which low resistance is used for a large number of repetitions. These are two entirely different types, each one producing its own results, and each being wholly incapable of producing the results obtained by the other. We feel that most current attempts to redevelop musculature are based on exercises which are, in the final analysis, endurance-building and not power-building in nature. We feel it is wrong, for example, to put a patient with an extremity weakened by injury on such endurance-building exercises.
as stair-climbing, walking, bicycling, and similar low-resistance exercises, until the extremities are approximately equal in strength.

A muscle exercised solely on power-building exercises will not have the quality of endurance, whereas a muscle subjected exclusively to endurance-building exercises will not have the quality of power. However, a powerful muscle can be given endurance-building exercises, and attain the quality of endurance; likewise a muscle with great endurance can attain power through the power-building exercises. How illogical it would be for a track man to train for long-distance running events solely by doing knee bends with heavy weights on his shoulder, or a professional weight-lifter to train for heavy lifts solely by running several miles a day!

It seems more logical to restore the weakened extremities to normal strength by power-building exercises and then to exercise for endurance. Endurance is a quality of normal muscle, and therefore should not be sought after until the muscle has returned to normal. We believe it unlikely that endurance can be attained in a markedly atrophied muscle, for we have seen many patients who had been on low-resistance, high-repetition exercises for months, and still complained of rapid tiring of the muscle.

*Physiological Aspects of the Heavy-Resistance Exercises*

It is not the purpose of this paper to discuss neuromuscular or muscle physiology. We are presenting only the clinical observations made on 300 cases in which these exercises have been employed. The splendid response in muscle hypertrophy and power, together with symptomatic relief, seems to vindicate any possible violation of physiological principles. Competent physiologists who have observed these patients and our method of exercise feel fairly certain that the fatigue produced is at the neuromuscular junction, and not of the muscle fiber itself.

The question arises as to whether it is advisable to induce maximum loads on weakened and atrophied muscle fibers. We firmly believe, on the basis of our clinical observations, that even atrophied musculature must be submitted intermittently to maximum loads, in order to obtain maximum hypertrophy. We have treated several cases of fractured femur which had been immobilized from six to fourteen months. The thigh muscles were very hard on palpation, suggesting fibrosis, and lacked power. These responded in four to five weeks, showing an increase in thigh circumference of one to two inches and a remarkable increase in power. They were under maximum loads at regular intervals from the very beginning. It was interesting to observe how quickly these muscles softened and assumed the consistency of normal muscle. This observation throws an interesting light on hypertrophy and return of power in fibrotic muscle.

We believe that, in order to produce in muscle maximum hypertrophy, the heaviest load should be imposed upon the muscle as it approaches complete contraction, and not when the muscle is stretched. It is an accepted physiological principle that the greater the initial stretch or tension on a muscle (length), the greater the contractile power of the muscle. Therefore, when the maximum load is imposed on a stretched muscle, its fibers have the initial advantage rendered by the stretched state, and fewer fibers can overcome the resistance than if the muscle were not stretched. When the muscle fiber is contracted, it does not have this advantage. In order to overcome the resistance, a greater number of fibers are called upon; more fibers are exercised and thus stimulated to hypertrophy. Also, by increasing the load as the muscle reaches the contracted state, a higher degree of coordination of the contracting muscle fibers is obtained, increasing the contractile power of the muscle as a whole. Most of the power-building exercises here described are so arranged that resistance increases as the muscle contracts.

The use of a pulley system for quadriceps redevelopment has the disadvantage that the maximum resistance comes when the muscle is stretched. The pulley system as contrasted with our method is demonstrated in Figures 5-A, 5-B, 5-C, and 5-D. We do not
The pulley system with knee flexed in starting position is shown in Fig. 5-A. There is 25 pounds of resistance on the pulley system, applied to the leg through the rope shown attached to the foot. The long axis of the leg in the starting position is perpendicular to the rope. At this point the resistance consists of the full 25 pounds. However, as the leg extends, the rope comes to lie at a more acute angle to the shaft of the leg, and the amount of resistance to be overcome decreases; so that, when the leg is fully extended (Fig. 5-B), the resistance to be overcome has decreased to only 7½ pounds. In full extension, 23⅓ pounds of the initial 25 pounds of resistance are lost as a compression force in the direction indicated by the arrow, leaving as a resultant of forces, only 7½ pounds of resistance to be (Continued on page 653)
(Continued) overcome by the quadriceps. Thus we see that the pulley system is one of decreasing resistance as the leg goes into extension. Therefore, when that part of extension controlled chiefly by the vastus medialis is reached, the resistance has greatly decreased; thus this muscle is neglected in the strenuous phase of the exercise.

When the resistance is added directly to the foot, the reverse of the above situation exists. In the starting position (Fig. 5-C), the resistance is practically nil; but, as the leg extends, the resistance rapidly increases and is maximum (25 pounds) when the leg is completely extended (Fig. 5-D). There is no compression force as is present in the pulley system. The vastus medialis receives the chief benefit from this exercise.
mean to imply that pulleys are of no value in giving heavy-resistance exercises; on the contrary, they often afford the only means of exercising a certain muscle group. However, for redevelopment of such an important group as the quadriceps, it is felt that the pulley system is inadequate.

**Maintenance of Hypertrophy and Power**

The progress of several patients has been followed for ten months after terminating this program of intensive exercise. Measurement at this time revealed no appreciable loss of muscle size or power, and there was no return of the symptoms previously noted,—such as giving way of the knee or weakness of the extremity. The patient can best maintain the power gained by exercising once or twice a week for fifteen to thirty minutes at a time. It is comparatively easy to maintain the power, once it has been attained.

**Types of Cases in which Exercises are Used**

1. Unstable knees resulting from tears of the cruciate and collateral ligaments.
2. Knees following removal of the menisci—lateral, medial, or both. The program has been used vigorously following total synovectomy of the knee, with good results.
3. Fractured femora.
4. Fractures of the patella.
5. Recurrent dislocation of the patella.
6. Fractures of tibia and fibula where prolonged immobilization has brought about quadriceps atrophy, as well as atrophy in other muscles of the extremity, and limited motion in the knee joint.
7. Knees following chondrectomy for chondromalacia of the patella.
8. Muscle weakness and limitation of joint motion, due to severe soft-tissue wounds and scarring.
9. Removal of foreign bodies from the knee joint.
10. Knees after patellectomy.

The best results have been obtained in cases of unstable knees, meniscectomies, and fractured femora. We believe the exercises are contra-indicated in cases of chondromalacia, in which the disease is accompanied by pain, swelling, and fluid, and where open operation has not been performed.

**DISCUSSION OF CASES**

**Knee Instabilities**

The most dramatic results have been obtained in cases of instability of the knee, of which twelve have been subjected to these exercises. In each the ligamentous injuries were old, and had not responded satisfactorily to previous treatment. Three are presented in detail, and serve to illustrate the progress made in most cases. The instabilities varied in nature: nine with injuries to the anterior cruciate and tibial collateral ligaments; one with injury to the tibial collateral ligament, with marked relaxation; one with injury of the anterior and posterior cruciate and tibial collateral ligaments; and one with injury of the anterior and posterior cruciate and fibular collateral ligaments.

The type of injury did not seem to influence the results, inasmuch as rapid gains and alleviation of symptoms occurred in the extremely loose joints as in the less unstable joints. Four of the twelve were wearing Jones knee cages when they began the exercises. Two patients discarded the braces after fourteen days, one after twenty-one days, and another after twenty-three days. In other words, the average time from beginning the exercises to the time when the patients had enough quadriceps power to safely begin ambulation without the brace was eighteen days. Eight of the twelve were able, after from four to six weeks, to run and play ball, without their braces and without "buckling" of the knee. Nine of the twelve had varying degrees of fluid and swelling when exercises were started; in eight of the nine these symptoms disappeared in one to three weeks. In one patient a
slight amount of swelling persisted. Ten of the patients had pain on exercising and weight-bearing initially; seven lost the pain; three did not.

In all cases, after maximum benefit had been derived from the exercises, the instability persisted unchanged when the quadriceps muscle was relaxed. However, when the quadriceps muscle was contracted, it was impossible to demonstrate any looseness about the joint. A powerful quadriceps renders the knee stable only when it is contracted; but,

Fig. 6
Roentgenographic studies for tear of the tibial collateral ligament, showing positive abduction spread.

Fig. 7
Positive drawer sign for tear of anterior cruciate ligament.
when contracted, offers sufficient stability for ordinary activities and, as demonstrated by some of our cases, even for rather strenuous sports. It is the purpose of the exercises to build the quadriceps muscle to become powerful enough to maintain the stability of the knee, without the full help of the ligaments. Normal quadriceps power is not sufficient for this, so greater-than-normal power must be built in the involved extremity. This explains why we use such extremely heavy resistance in cases of knee instability. In fractured femora, meniscectomy cases, et cetera, where the knee is stable, the purpose is to restore normal power to the injured leg; therefore, redevelopment is not pushed to such an extreme degree.

In none of the twelve cases were there any ill effects from the strenuous program of exercise.

The splendid response of these patients to exercise alone suggests that in certain types of old ligamentous injuries, surgery may not offer more.

An officer sustained an injury of the tibial collateral ligament, following which he was immobilized in a cylindrical plaster cast for seven weeks. After removal of the cast, he received physical therapy for seven weeks before the heavy-resistance exercises were begun. At the time the exercises were begun, he had a marked limp, walked with a cane, complained of pain about the knee, and the knee was slightly swollen. In twenty-one days his knee was completely asymptomatic; he had equal power in both quadriceps muscles; and had gained three-quarters of an inch in circumference of the thigh. His maximum quadriceps power increased from ten to eighty pounds. This patient returned to limited duty with the infantry, with automatic revision to full duty.

A soldier sustained a complete dislocation of the knee when he fell from a four-foot platform. Two weeks after injury, a meniscectomy was performed, and the patient returned to duty, but was unable to continue because of pain on weight-bearing. Five months after the initial injury, another arthrotomy was done, a partial tear of the anterior cruciate ligament being sutured and a fascial flap placed at the site of the tibial collateral ligament. Instability persisted, and eleven months after the initial injury, a third operation was done, at which time a fascial reconstruction of the tibial collateral and anterior cruciate ligaments was undertaken. Again the instability persisted, and the patient was fitted with a Jones knee cage. Three and one-half months after the last operation, the patient undertook the heavy-resistance exercises. At this time there was atrophy of the thigh of two and one-half inches, flexion of 88 degrees, maximum power of two and one-half pounds, and moderate swelling of the knee joint. In fifty-two days of exercise, the patient made the following gains: a power increase of sixty-two and a quarter pounds in the quadriceps, an increase of two inches in circumference, and a gain of 42 degrees in range of motion. By the end of the third week of exercise, he had discarded the knee cage. Pain and swelling rapidly disappeared. The patient was discharged from the Army because of his knee injury, took a job as a truck driver, and his knee has remained asymptomatic.

Another soldier sustained injury to the tibial collateral and anterior cruciate ligaments while skiing. Figure 6 shows the increase in the medial joint space due to injury of the tibial collateral ligament. Figure 7 shows the positive drawer sign for tear of the anterior cruciate ligament. Following the injury, the patient had pain, thickening, and fluid in the knee. For four and one-half months he had conventional physical therapy, without improvement. After this period, a Jones knee cage was worn. Even with the brace, and while walking on level surfaces, he frequently would fall, because of the instability and muscle weakness. After using the knee cage for seven weeks, he undertook the program of heavy-resistance exercises. Two weeks later, his quadriceps power had increased to such an extent that he felt secure enough to give up his knee cage. The symptoms of pain, fluid, and thickening had completely subsided by this time. After one month of the exercises, the patient had gained one and one-half inches in circumference of the quadriceps, with increased power in that muscle of from twenty to eighty pounds, and he could sprint over uneven terrain at full speed without difficulty.

**Meniscectomy Cases**

These patients were given quadriceps-setting exercises for several days preoperatively, and the exercises were resumed as soon after operation as possible, usually in twenty-four to forty-eight hours. Quadriceps setting was continued until the synovitis had largely subsided, and the discomfort from weight-bearing was minimal; this required three to four weeks. They were then started on the heavy-resistance exercises, and, with maximum exertion on these exercises, the synovitis continued to disappear.

Twenty patients have exercised postoperatively by the heavy-resistance method. Seventeen of the twenty had definite synovitis of the knee joint at the time exercise was
began, and in only two of them did the degree of synovitis fail to decrease. In no instance was there exacerbation of synovitis due to the strenuous exercise. No patient was allowed to participate in weight-bearing exercises until the quadriceps power had been restored in the limb operated upon.

The average time required to restore normal power to the affected extremity was nineteen days. Only two of the twenty patients failed to regain normal quadriceps power, and these two developed their quadriceps power to within 80 per cent. of normal. Restoration of normal power and thigh circumference can be expected to occur at a much more rapid rate following meniscectomy than in cases of fractured femur, fractured patella, ligamentous injuries, et cetera, where the period of immobilization is usually more prolonged. It must be stressed that, following meniscectomy, the quadriceps-setting exercises given postoperatively are as important as the heavy-resistance exercises in obtaining good end results.

Restoration of a normal range of motion offered no problem in any of the twenty cases. All patients had normal knee-joint motion on completion of the exercise program. A few had difficulty in obtaining the last 15 or 20 degrees of flexion. These, however, responded rapidly to treatment on the leg-exercising apparatus (Fig. 8).

**WEIGHT-BEARING AND NON-WEIGHT-BEARING QUADRICEPS EXERCISES**

At this point it is appropriate to discuss briefly these two types of exercises. As far as increasing muscle power is concerned, both types have equal possibilities. They differ, however, in the symptoms they produce in knee joints controlled by weak, atrophied muscles.

We believe that the development of pain, thickening, and fluid on weight-bearing exercises in many of the cases of meniscectomy and unstable knees is due largely to the increased laxity in the joint, resulting from quadriceps weakness and atrophy. We have seen many of these patients with marked synovitis in the knee joint, in whom complete alleviation of knee symptoms occurred, when quadriceps power was restored to normal by non-weight-bearing, heavy-resistance exercises. The instability results in repeated strains which produce a traumatic synovitis with fluid, thickening, and pain.

Of the twenty patients who had meniscectomies, seventeen had fluid, swelling, or both, of varying degree, when they began these exercises three or four weeks after the operation. On the exercise regimen outlined here, fifteen of the seventeen showed improvement. Of these fifteen patients, eight became completely asymptomatic, both subjectively and objectively; six retained only an insignificant amount of synovial thickening; and one finished the exercise program with a small amount of fluid still present in the joint. This patient had had a meniscus removed from the same knee prior to Army service, following which there developed a chronic synovitis, with marked thickening and induration of the synovia. Before the exercise program was instituted in meniscectomy cases, exercise in the gymnasium was started three or four weeks postoperatively, in an attempt to redevelop quadriceps power in these patients by the conventional methods—such as stairclimbing and bicycling. On this routine, the hitherto smooth postoperative course of rapidly subsiding synovitis was not only interrupted, but in many cases there was a marked exacerbation of synovitis, which usually subsided as soon as the patient was taken off the weight-bearing exercises. It was then found that, when these same patients were given only non-weight-bearing exercises, synovitis did not recur, and the synovitis, which had previously developed, subsided during the course of exercise. It must be assumed that there is some factor in the weight-bearing exercises that produces synovitis, and that this factor does not exist in the non-weight-bearing exercises. These findings can be explained on the basis of relative knee instability. The quadriceps muscle is as important in maintaining knee stability as are the cruciate and collateral ligaments; and, when this muscle group is atrophied and weak, the maintenance of stability rests almost entirely on the
BEFORE EXERCISE

20 lbs.
20½" Thigh measurements
126° Degree of flexion

AFTER 36 DAYS

60 lbs.
22½" Thigh measurements
135° Degree of flexion

CHART I

BEFORE EXERCISE

5 lbs.
14½" Thigh measurements
60° Degree of flexion

AFTER 36 DAYS

35 lbs.
16" Thigh measurements
104° Degree of flexion

CHART II
ligaments. The ligaments alone cannot maintain as high a degree of stability as when aided by the quadriceps muscle. When, as in cases of meniscectomy, quadriceps power is low, there is abnormal motion in the knee joint. It is this abnormal motion that is indirectly responsible for the development of synovitis in weight-bearing exercises. The twisting, turning, and jarring of the weight-bearing exercises in a relaxed joint probably traumatizes the synovia by nipping and stretching, causing a synovitis; whereas, if the exercises were performed sitting down, the motion in the joint would be in a normal plane, and the knee would not be under the strain of the body weight. Thus instability is preceded as a source of synovial irritation during convalescence.

Fractured Femora

Charts I and II show the gains made by two patients with fracture of the femur, after they had been discharged from general physical therapy. These two represent the average response in twenty cases of fracture of the femur. The gain in circumference for those patients who had obtained flexion of the knee to approximately 90 degrees ranged from one to two inches in the first four weeks of exercise. When flexion was less than a right angle, the gains were not so rapid, since the quadriceps could not be as thoroughly exercised through this limited range. A few patients who worked exceptionally hard increased their thigh measurements by two to two and a half inches in from six to eight weeks.

Frequently, after immobilization, the muscles of the thigh, especially the quadriceps group, are hard in consistency, due to fibrotic changes, which have occurred during the period of inactivity. Immediately after these strenuous exercises have been begun, these same muscles begin to soften, and in a few weeks have regained their normal consistency. This rapid softening of hard fibrotic muscles has been one of the most interesting aspects of this program, and has further substantiated our belief that weakened, fibrotic, atrophic muscles should not be “pampered” because of their subnormal condition, but should be exercised against heavy resistance. In the case of one patient who was immobilized for fourteen months, the thigh muscles of the injured leg showed atrophy of two inches, and had the consistency of hard rubber. After two months of exercise, the thigh had increased one and one-half inches in circumference, and the consistency was that of normal muscle.

Restoration of Motion

Attaining a normal range of knee-joint motion, following immobilization incident to a fracture of the femur, is often a difficult and perplexing problem. After prolonged immobilization, especially in fracture of the lower third (more especially those involving the femoral condyles), there is often a marked limitation of flexion. When some of these patients first begin physical therapy (consisting of heat, massage, and exercises with mild forcing) they often rapidly regain flexion of about 30 to 50 degrees, and then during weeks and months of a similar routine make no further progress. For these cases a leg-exercising apparatus (Fig. 8) has been constructed.

Leg-Exercising Apparatus

This machine was designed to allow the patient to exercise the leg against resistance in a position most conducive to the bending of the leg by such resistance. Because the patient himself is in complete control at all times of the amount of resistance, and can remove and apply resistance as pain and fatigue dictate, he will allow the leg to flex more than if a physical therapist were applying the same amount of resistance by hand. The patient cannot control the pressure or movements of the operator, and will not relax the antagonistic muscles sufficiently to permit the knee to bend to a point of discomfort. However, if he himself can apply the resistance, he will allow the knee to bend to the point of pain, without complaint. In order to attain flexion in stubborn cases, it is necessary to exercise to the point of discomfort, even pain.

The apparatus is used in the following manner: The exercise begins with knees com-
pletely extended (Fig. 9). The pins labeled A are removed, thus freeing the weight, which is then slowly lowered, as the knee is allowed to flex. The downward direction is continued as far as pain or tightness in the joint will permit. The knee is then completely extended; there is a momentary pause, and it is lowered again. The cycle is repeated ten to twenty times. The pins are replaced; the patient rests for a minute or so, and the cycle of ten to twenty repetitions is repeated two or three times.

Twenty patients with fracture of the femur have been given these exercises on this apparatus. All twenty had been discharged from general physical therapy as having attained maximum flexion. By the use of this apparatus, the average gain in flexion was 25 degrees in thirty-two days. However, these figures include eight patients who had fractures about the femoral condyles or who had had prolonged immobilization because of slow union or refracture. They showed an average gain of 21 degrees in forty-two days. Twelve patients with uncomplicated fracture of the middle and upper thirds showed an average gain of 27 degrees in twenty-one days, a considerably more rapid rate of gain than that of the group first mentioned. Two of the

Fig. 8
Leg-exercising apparatus.

Fig. 9
Leg-exercising apparatus being used to regain flexion. The pins (A) fit into the metal guides at different levels, to limit downward motion of the central plate.

Fig. 10
Leg-exercising apparatus, showing use of the pulley system (A) to increase knee-joint extension.
twenty patients were treated by manipulation under anaesthesia in an attempt to increase knee-joint motion; one gained 6 degrees as a result of manipulation; in the other, no increase in flexion could be attained. Both were then placed on this apparatus; the former gained 33 degrees more flexion, the latter 20 degrees. It must be emphasized that the gains in flexion recorded in all twenty cases were made after these patients had received the customary physical therapy for weeks, sometimes months, and had been discharged because no further progress could be made. Constant bending in the form of active heavy-resistance exercises will often produce more flexion than can be accomplished by a single or repeated manipulation. In a few cases, this strenuous flexion of the knee has produced slight swelling of the joint, but in no case has there been effusion. The swelling and soreness which sometimes develop usually subside by the next exercise period.

This apparatus can also be used as a muscle developer with increasing amounts of resistance, after the patient has obtained a good range of motion. When the machine is used for muscle developing alone, the same principle of exercise and method of increasing resistance are used as for the quadriceps exercises. When used for increasing flexion, the amount of weight that can be pushed back into complete extension ten to twenty times with moderate effort is employed.

Three patients who had flexion contractures of the knee rapidly regained complete extension by working on this apparatus. The pulley system (Fig. 10, A) brings pressure to bear immediately above the patella by means of the leather cuff. The pressure is directed towards extension. On each repetition, as the knee reaches its maximum extension, the cuff aids the thigh extensors in effecting further extension. Strenuous quadriceps exercises were also given in these cases.

If the injury was a simple fracture of the patella, or if the lower pole of the patella had been removed, the return of motion, strength, and size was usually rapid. However, if the patella was highly comminuted, or if there developed chondromalacia following fracture, the high-resistance exercises usually caused much pain, and occasionally fluid and swelling, and had to be abandoned.

After the immobilization period following dislocation of the patella, these exercises were begun and a rapid return to normal was noted. By building an exceptionally powerful vastus medialis, it might be possible to prevent redislocation of the patella, when the dislocation was due chiefly to weakness of that muscle.

Two patients had chondrectomies for chondromalacia of the patella; following operation, both patients had moderate synovitis of the knee. In each, the synovitis subsided, and smoothing of the patellofemoral articulation occurred as a result of these exercises.

There were many patients with soft-tissue wounds about the knee and thigh. In these, loss of flexion or extension, due to muscular weakness, scarring, or both, was the usual problem. In many cases, where the loss of active motion was a result of muscular weakness, due to loss of muscle substance, the remaining muscle tissue could be overdeveloped sufficiently to compensate for the lost tissue, thereby restoring almost normal strength to the extremity.

Many patients had a limited range of motion because of scarring about the knee joint. Unless bound hopelessly to bone or other deep structure, these scars in most instances underwent remarkable softening, allowing for normal joint motion. The constant flexing in the leg-exercising apparatus (Fig. 8) was sufficient in many cases to restore flexion to normal. The quadriceps exercise usually rapidly restored enough quadriceps power to make possible complete extension.

Results following removal of foreign bodies from the knee were similar to those in the meniscectomy patients, unless there had been considerable joint damage.

In order to gain full extension following patellectomy, it is essential to have a powerful quadriceps. We have used this program of heavy-resistance exercises in only two of these cases. The patients rapidly obtained complete extension, without development of
synovitis; and quadriceps power was restored to within 90 per cent. of that in the unaffected extremity.

When quadriceps power has increased sufficiently to permit weight-bearing exercises, the patient is given heavy-resistance exercises for the other muscles of the extremity.

**DEVELOPMENT OF OTHER MUSCLES OF BODY BY SAME EXERCISE PRINCIPLE**

The following are some of the other exercises we have used in redeveloping other muscles of the body by the same principle. The type of apparatus, however, varies consid-
crably, and is designed specifically to obtain the desired results. The repetitions, method of weight increase, frequency and length of workout are exactly the same as described for the quadriceps exercises.

I. Lower Extremity
A. Adductor Exercise. This exercise is shown in Figure 11.
B. Abductor Exercise. See Figure 12.
C. Hamstring Exercise. This is an extremely important exercise, and should be diligently performed, especially by patients attempting to regain flexion in stiff knees.
D. Stairclimbing Exercise. This exercise is not used to develop the quadriceps; it is not used at all, until the patient has built nearly full quadriceps power by the use of previously described quadriceps exercise. Resistance is added to a metal yoke, and the patient goes over and back five times with one weight, rests a minute or so, adds more weight, and then repeats. By use of the yoke, the hands are free to grasp the rail (Fig. 13). This exercise was thought necessary because, even though a patient may have good quadriceps power, he may still have some difficulty in stairclimbing, if all the other muscles involved are not proportionately developed. The exercise develops, in the low-repetition, high-resistance manner, all of the muscles involved in stairclimbing.

E. Calf Exercise. The resistance in this exercise is applied by adding weight to the yoke. The use of the yoke permits the hands to remain free, and the patient can use his hands to steady himself, and maintain balance by grasping a bar in front of him. As strength increases, more weight can be added; and, as ankle-joint motion increases, the wooden block can be made higher.
F. Ankle Exercise. The apparatus shown in Figure 14 was devised to exercise the ankle in both dorsiflexion and plantar flexion, in eversion and inversion. Resistance may be added to the hook at A, B, C, or D. The apparatus is also used to help restore ankle-joint motion.

II. Arm and Shoulder

A. Pectoral Exercise. Amazing hypertrophy of the pectoral muscles can be attained in two or three weeks through the practice of this exercise (Fig. 15). Two patients, who sustained machine-gun-bullet wounds through the axilla with resultant damage to the pectoralis major and limitation of abduction because of scar tissue, were able to loosen the scar sufficiently to obtain a complete range of shoulder motion by use of this exercise. In both cases, after a month of exercise, the patients had increased the size of the atrophied pectoralis so that it was larger than the corresponding uninjured muscle.

B. Deltoid Exercise. This is well known.

C. Biceps Exercise. This is an important exercise, as there exists usually an inch or so of atrophy of the arm following immobilization for fracture of the humerus. It is important, not only because it redevelops biceps power, but also because of its value in increasing elbow-joint motion. We believe that exercising for biceps power will do more to restore elbow-joint motion than all efforts to increase motion of that joint while neglecting biceps power. In this we must except instances where there is a mechanical block or where severe irreparable capsular and pericapsular changes have occurred. On each
repetition the patient should make every effort to obtain as much flexion and extension as possible. Triceps exercises should also be used in conjunction with the biceps exercise.

D. Supine Press. See Figure 16 for illustration of the exercise. This is extremely good for loosening up the elbow and shoulder joint.

E. Pulley Exercise. Restoring normal scapulothoracic motion following a fracture of the humerus is often difficult. We have obtained, in most instances, good results through use of this pulley exercise, combined with the pectoral, biceps, and deltoid exercises. It is essential that the pulley be an extremely high one, so that the arm can go into complete abduction (Fig. 17). On each repetition the arm should be allowed to abduct as far as comfort will permit the weights to pull it; then the arm is brought back to the side. There is a momentary pause, and the exercise is repeated. This is done ten times, more weight is added, and it is repeated another ten times, et cetera. An effort should be made to abduct the arm a fraction further on each repetition. This exercise has produced good results, where scapular motion is limited because of fractures of the scapula and large soft-tissue defects. The constant forcing, in the form of active, heavy-resistance exercises, steadily increases the motion of the joint.

F. Parallel Bars. This is a good exercise for the shoulder and arm (Fig. 18). Resistance is added to the weight pan strapped to the back. The width of the bars can also be varied.

G. Arm-Exercising Table. This table is designed to exercise the pronators and supinators of the forearm, and the external (Fig. 19) and internal (Fig. 20) rotators of the shoulder.

III. Trunk

A. Back Exercise. Hyperextension exercises are done on the apparatus shown in Figure 21. This apparatus offers several improvements over the method in general use. The weight pan attached to the back makes possible increases in accurately graded resistance. This cannot be accomplished, as was attempted in the old method, by progressively extending the patient farther over the table edge. Our method does not require an operator to hold the patient's feet. The position of the patient is more stable and comfortable; and, since he is not quite parallel to the floor, it is much easier for him to hyperextend more completely.

B. Abdominal Exercise. By maintaining the knees and hips flexed (Fig. 22).
more of the load falls on the abdominal muscles and less on the iliopsoas muscle. This makes possible development of the abdominal muscles without concurrent development of the iliopsoas. Since the lumbar spine is flexed by the abdominal muscles and extended by the iliopsoas, the selective redevelopment of the abdominals brings about stronger pelvic control, which is of great value in the treatment of certain back ailments. Many patients who have received injuries to the anterior abdominal wall, with resultant loss of muscle tone and tissue, have exercised on this apparatus with considerable improvement. Gradual resistance increases are made by increasing the incline of the board.

Only a few of the exercises actually used have been mentioned. With the equipment illustrated, several hundred different exercises can be worked out. We have shown only a few of those most frequently used, but, in order to conduct exercise programs properly both for range of motion and muscle power, in a great variety of injuries, a therapeutic gymnasium must be equipped with the apparatus described.

THE THERAPEUTIC GYMNASIUM

The therapeutic gymnasium should not be a place of amusement or for keeping fit. It should be a place in which a treatment, prescribed after thorough examination by the medical officer, can be properly given. The gymnasium should be supervised by the medical officer, but it is not necessary that he actually attend the exercises. The gymnasium should be planned and constructed as specifically for its purpose as is the operating room for its purpose. All pieces of exercise apparatus should be designed to produce a desired result in a specific type of case. Accurate notes on the progress of each patient should be made at regular intervals. The patient should work by appointment, and his attendance should be recorded. The appearance of the gymnasium, and the working condition of the equipment are very important, for the patient will maintain much more interest in his exercise if the gymnasium is bright, colorful, well ventilated, and well kept. Equipment in poor condition is not only dangerous, but it also disheartens the patient, and makes it difficult for him to perform his exercises.

It is a good policy to work out several different ways of doing the same exercise. This will prevent the patient’s losing interest from monotony. The greater the variety of exercises, the greater the patient’s interest.

It has been our experience that greater cooperation is achieved, when the patient understands the nature of his injury. Anatomical charts are kept, and are exhibited on the walls, to give him a clear conception of his disability and its location. He also can see what muscles have to be redeveloped or what joints must be loosened up, before he can attain maximum benefits. A chart with the normal ranges of motion for all the joints of the body should be displayed, and the patient should be taught the normal range of the joint upon which he is working. He should become familiar with the measurements of his affected part, the power of that part, and the exact number of degrees of motion present; then, each week, when new measurements are taken, he will know in inches, degrees, and pounds the gains he has made. This will do much toward maintaining the patient’s interest.

The instructor should be efficient, thoroughly familiar with each patient’s disability, know what he is trying to accomplish in that patient and, above all, display interest in the work. A patient cannot be expected to show any more enthusiasm than the one who supervises his exercise.

CONCLUSIONS

1. Low-repetition, high-resistance exercises produce power.
2. High-repetition, low-resistance exercises produce endurance.
3. Each of these two types of exercise is incapable of producing results obtained by the other.
4. Weakened, atrophied muscles should not be subjected to endurance-building exercises, until the muscle power has been restored to normal by power-building exercises.

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3. Restoration of muscle power with return of motion in a limb has been neglected in the past. It is, in most instances, preferable to have a limited range of motion with good power than a normal range of motion with inadequate power.

6. Games and group exercises, as practised in reconditioning programs, are unsatisfactory for producing local muscle development.

7. In order to obtain rapid hypertrophy in weakened, atrophied muscle, the muscle should be subjected to strenuous exercise and, at regular intervals, to the point of maximum exertion.

8. In cases of meniscectomies and unstable knees, quadriiceps power should be obtained by the use of strenuous, non-weight-bearing exercises. Weight-bearing exercises can produce pain, thickening, and fluid in knees, which do not have adequate muscle support.

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