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ABSTRACT

This report by the President's Council on Physical Fitness and Sports examines the effects of various forms of physical exercise on the knee joint which, because of its vulnerability, is especially subject to injury. Discussion centers around the physical characteristics of the joint, commonly used measurements for determining knee stability, muscular and ligament strength. The deep knee bend, an exercise of highly questionable value in conditioning regimens, is criticized on the grounds that it contributes to chronic synovitis, promotes early arthritic onset, and produces gross knee instability. Exercise regimens are proposed and discussed for the treatment and prevention of knee injuries. Practical advice for the development of physical education and athletic programs justifiable from this review of knee joint exercise is given, and includes: (1) Exercises that unduly stretch or damage the ligaments of the knee should be avoided; (2) The deep knee bend should be used sparingly, if at all, in physical education and athletic conditioning, and substitutes should be developed such as bench stepping and weight training routines; (3) In performing knee bends for developing and maintaining the strength and endurance of the quadriceps muscles, a half knee bend is recommended; (4) Progressive resistance exercises of the muscles activating the knee joint should be routinely employed for the prevention of knee injuries and for the rehabilitation of the knee during postinjury or postsurgical rehabilitation. A bibliography of 37 citations is appended. (MB)

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EXERCISE AND THE KNEE JOINT

People of all ages, in and out of school, are making extensive use of conditioning exercises in order to develop and maintain muscular strength and physiological stamina. The sources of these exercises are legion and include popular magazines, health spas, school and college physical education, athletic trainers, cardiologists and other physicians, and professional textbooks and journals. Since the origin of the President's Council on Physical Fitness and Sports 20 years ago, the practice of such exercise has become more and more commonplace.

Just because a particular exercise is frequently found in physical fitness regimens does not assure its quality or qualify it for general use. As indicated by Flint (12): ***"Proper selection must be placed on the principles of joint dynamics, on whether the exercise fulfills its designated purpose, on whether the effort required to perform the movement is proportionate to the demands of the condition at hand and within the limits of the individual's endurance and strength capabilities."*** In her article Flint discusses poorly-designed exercises which do not accomplish claims made for them, together with recommended practices to achieve desired purposes.

Some common exercises proposed and utilized have questionable aspects; depending on how they are performed, some may even have harmful effects. Further, different ways of using the same type exercise may produce different results. Recently, Rasch and Allman (28) reported an incident that dramatizes this situation. At the 1971 meeting of the Advisory Board of the United States Marine Corps Physical Fitness Academy, the physical training program of the Corps was reviewed at some length. During the discussion, one member, an orthopedic physician, remarked: ***"At least 90% of the exercise programs include exercises as detrimental as they are valuable."*** While the orthopedist's view may not be representative of the state of affairs nationally, i.e., outside the Marine Corps program, it does underscore the need to give critical thought to the exercises routinely practiced by individual Americans and to those advocated by physical educators, athletic trainers, corrective therapists, and physicians.

In this issue of the ***Physical Fitness Research Digest***, exercise related to the knee joint will be considered as an area around which considerable controversy exists. For example, the deep knee bend has been designated as a harmful exercise by a number of investigators. Other areas of conflicting views have been the instability of the knee joint as related to knee injuries, especially in football, and the role of exercise in strengthening the muscular and ligamentous structure of the joint in the prevention of such injuries.

The Knee Joint

Although most authorities agree that an unstable knee joint is predisposed to injury, some differences of opinion exist concerning the role of specific structures

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responsible for maintaining a stable knee and the respective effects of exercise upon them. A brief statement only on the salient features of the knee joint is possible here; for structural details, treatises on anatomy should be consulted.

The knee is a hinge joint, held together by ligaments and supported and activated by muscles. The lower end of the femur (thigh bone) and the upper end of the tibia (large leg bone) articulate in much the same manner as would opposing knuckles of the two hands when held together. These bones are spanned in front by a third, the patella, or knee cap. Two similunar cartilages, or minisci, are situated at the head of the tibia. These cartilages deepen the articulation to form a socket between the femur and tibia and to serve as a cushion to absorb shock; they are thick at the edges and thin in the center of the joint. If the knee is subjected to an acute wrench, especially when in a flexed position, one or both of these cartilages may be loosened. The entire joint is enclosed in a membranous sac forming a joint capsule; this sac contains bursae which secrete a lubricating (synovial) fluid during joint movement.

The major binding ligaments are the lateral and medial collaterals on the sides of the knee joint and the anterior and posterior cruciates crisscrossing from front to back within the joint. The collateral ligaments restrict sideward movements of the leg at the knee joint; the cruciate ligaments restrict extension to an alignment with the femur. Thus, the only primary movements possible in a normal knee are flexion until the calf muscles strike the back of the thigh muscles and extension to a straight line of the leg and thigh. A slight rotation and lateral and medial movements of the leg occur when the leg is partially flexed.

While other muscles are involved, three major muscle groups act on the knee, all 2-joint muscles. The gastrocnemius comprises the bulk of the calf of the leg with origins by two heads on the inner and outer condyles of the femur, and with insertion through the Achilles tendon (heel cord) to the calcaneus, or heel, bone. The quadriceps femoris forming the main bulk of the front of the thigh is made up of four parts, as its name implies; origins are on the femur and pelvis and insertion is by a common tendon encompassing the patella and top of the tibia. The hamstrings are the bulky muscles at the back of the thigh with origins on the pelvis and insertions on the heads of the tibia and fibula. Muscles of the hamstring group support both the medial and lateral sides of the knee joint; in addition, they give stability to the posterior aspect of the knee joint and retard knee hyperextension.

According to McCloy (22), a frequently overlooked factor in the structure of the knee joint is that the vastus medialis and the vastus lateralis muscles of the quadriceps group insert not only in the patella, but also in the rectinaculum patellae, associated with the capsular ligaments of the knee and blending posteriorly into the collateral ligaments. Hence, when the quadriceps muscles are strengthened, these ligaments of the knee are given strong support.

Although the largest joint in the body, the knee is the most vulnerable to injury because of its poor bony arrangement. Exercises that unduly stretch or damage the ligaments of the knee should be avoided. The muscles activating movements of the knee joint also aid in stabilizing and protecting it, so should be kept strong. Allman (2) has pointed out that the stretch of a normal ligament is proprioceptive in nature and results in stimulating the contraction of the surrounding musculature, which calls the muscles into a support function of the joint. This muscular action aids in stabilizing the joint and in defending the ligaments against abnormal stress.

A strong musculature binds the joint more firmly together, thus reducing the possibilities of extreme movement.

Because of its vulnerability, the knee joint is especially subject to injury in athletics. Blows to the sides of the knee have been particularly incapacitating to football players; the danger is enhanced when the foot is in firm contact with the ground, as "giving with the blow" is prevented. As examples of the prevalence of knee injuries: In a report of the 1952 season by Hawk (14), such injuries accounted for 30% of man hours lost from injuries in football. In 1966 a report of the National Collegiate Athletic Association (26) showed that more than 23% of all football injuries were to the knees.

Measurement Considerations

The measurements utilized by investigators in studies reported in this *Digest* have been of three types: abduction-adduction, or knee stability; strength of muscles activating the knee; and strength of ligaments of the knee joint. The most common tests of these types are described here.

Knee Stability

Several methods of measuring knee stability have been proposed. Some of the methods utilized radiography and photography as means of evaluating damage from knee injuries. However, two other methods were frequently used in knee stability studies.

Klein's Method (15). At the University of Texas, Klein designed an instrument for testing the medial and lateral stability of the knee. Cuffs made of flexible metal are strapped snugly over the thigh and lower leg with a bearing pivot placed above the knee joint. A machinist dial indicator is attached above the bearing pivot on one side of the apparatus and a pressure plate is mounted on the opposite side so that the plunger of the dial indicator rests against the plate. The tester adducts or abducts the lower leg by applying pressure with one hand at the ankle while securing the knee with the other hand. The amount of deviation of the lower leg at the knee is recorded on the machinist's dial; this distance is converted to angular deviation.

Reliability coefficients for the abduction movements are not given in the reference. In another report, Klein (18) stated: ***"Realizing that the testing procedures used . . . were subjective tests, one has to accept the fact that an experienced tester is capable of demonstrating the evidence of stability or instability of ligaments with relative ease."***

Morehouse's Method (24, 34). At Pennsylvania State University, Morehouse developed a well-conceived instrument to measure the abduction and adduction of the lower leg at the knee joint. The subject is immobilized in sitting position by a backrest with a seat belt around the waist; the thigh on the side being tested is held firmly in place by an orthoplast cuff and vise located at the femoral condyles; a Dillon force gauge regulates the pressure between 40 and 50 pounds to stabilize this position; the knee is in 10 degrees flexion. The force used to produce sideward deviation of the lower leg is 10 kilograms (22 pounds) of free-hanging weight in pans, one on each side of the testing table; abduction and adduction are accomplished by removing the weight in the appropriate pan. The amount of leg movement is determined by two Fairchild linear potentiometers; a Texas FET voltmeter, wired to the potentiometers in a linear additive circuit, records the voltage corresponding to the movement, which is converted into degrees of angulation. The reliability coefficients for the two movements of the right and left legs obtained during the same day ranged between .87 and .91; the coefficients between days were lower, although considered acceptable.

Goldfuss, Morehouse, and LeVeau (13) studied whether "unconscious" muscle activity was present in the quadriceps and hamstring muscles during measures of knee abduction and adduction, and, if present, whether the amount was sufficient to affect the measurement. The subjects were 20 university men. An electromyograph with two surface electrodes placed 1½ inches apart along each muscle was used; knee abduction and adduction were tested with the Morehouse apparatus and method already described. Electromyographic readings were taken for each of the knee movements under four conditions: (a) assumed relaxation, subject asked to relax muscles completely; (b) relaxation, suppressed electromyographic activity by visual feedback as shown on an oscilloscope; (c) weak muscular contraction, pretensed muscles to produce a specified low amplitude on the oscilloscope; and (d) strong muscular contraction, pretensed muscles to produce a designated strong amplitude on the oscilloscope.

Analysis of variance was performed to determine whether mean differences in knee abduction and adduction were significant among the four levels of muscular tension; when significant <u>F</u> ratios were obtained, Tukey's test was applied to decide the significance between pairs of means. Unconscious muscular activity produced by the quadriceps and hamstring muscles had no effect on measures of knee abduction and adduction. Therefore, the authors concluded that it is unnecessary to use electromyographic visual feedback in order to facilitate muscular relaxation for this type of knee evaluation. Induced muscular contraction of these muscles did provide stabilization of the knee joint against abduction and adduction. This result has important implications for the rehabilitation of knees, as it reflects the need to maintain the strength of these muscles during the recovery period of an injured knee joint.

Strength

Two of the methods utilized by investigators to test the strength of the knee flexor and extensor muscles are described.

Clarke's Cable-Tension Tests (10). The aircraft tensiometer is the instrument used in recording muscle strength for the cable-tension tests. This instrument was originally designed to measure the tension of aircraft control cables. Cable tension is determined by measuring the force applied to a riser causing an offset in a cable stretched taut between two sectors. This tension is then converted into pounds on a calibration chart. The instrument was adapted for strength testing: the subject, after being positioned for a specific test, pulls on a light cable; the tension he can apply maximally is recorded on the tensiometer. The position of the subject for the two strength tests are: knee flexion, prone lying with the knee flexed to 165 degrees; knee extension sitting, backward leaning, with the knee at 115 degrees.

Bender's Multiple Angle Testing Method (5). Bender's multiple angle testing method permits measurement of the force developed by muscle groups at right angles to the long axis of the lever arm at any point in the range of joint movement. A dynamometer with limited plunger action is used; this allows very little movement when a strength test is made at a given angle (or point) in the range of movement. The dynamometer with cables and pulleys is mounted on a frame to permit ready adjustment to the angle of force. A new model on which wires and pulleys are eliminated was subsequently developed by the investigator.

Ligament Strength

Tendon and ligament tissues consist of fibroblasts, fibrocytes, ground substances, and fibers. The fibers are predominantly collagenous, although some elastic and vesicular types are present in some ligaments. Tipton and associates (32) have done considerable research on the influence of exercise on the strength of ligaments, using animals as subjects. In making the strength test, the animal is sacrificed and either a bone-ligament or a muscle-tendon-bone preparation is made and force applied. Investigators have found that the usual site of separation when force is applied is in the transitional zone between the ligament or tendon and bone. Thus, the measurement of ligament or tendon "strength" in rats, for example, is usually recorded at this separation point. This point has been variously termed as separation force, failure load, tensile load, and breaking point, although Tipton prefers to call it "junction strength" or "load at separation."

Deep Knee Bends

Potential Dangers

The deep-knee-bend type of exercise, which includes full squats with weights, duck waddle, and Russian bounce, is a leading questionable exercise in physical conditioning regimens. Lowman and Young (21) urge that such exercises be avoided, as they contribute to chronic synovitis by violent compressions of the synovial sac. Further, they indicate that faulty use and activities of the knee provide conditions conducive to the early onset of arthritic changes. When the person is in the full knee bend position, the front portion of the joint is pushed forward and the ligaments and extensor muscles are tensed and stretched. Thus, the entire body weight, plus weights held on the shoulders in weight training squats, is supported on the posterior aspect of the joint.

According to Rasch and Allman (28), opposition to exercises requiring deep knee bends is based largely on the fact that, during the final phase of nonweight bearing flexion of the knee, a small amount of inward rotation of the femur at the tibia occurs. The final seating of the femoral condyles into the contours of the menisci is necessary to complete locking of the knee joint. Klein (18) contends that, when the feet are anchored to the ground by the body weight (and a barbell on the shoulders in weight training), the normal rotation of the femur is prevented. Consequently, the femur forces the tibia into abnormal external rotation, thereby stretching the fibers of the medial and lateral ligaments. Further, the anterior cruciate ligaments are also stretched by the "jacking apart" of the knee joint occurring during full flexion; the femur acts as a lever pivoting on the bunched calf muscles.

As an orthopedist, Ferguson (11) presented several principles of exercise based on his observation of athletes over a number of years. He stressed that most athletic endeavors require a wide range of joint excursions, so exercises that restrict movement are undesirable and those that enhance movement without damaging effects are desirable. The deep knee bend was considered as an exercise that stretches knee ligaments with voluntary and involuntary muscle protection eliminated. He maintained that this exercise has value when used merely to maintain full stretch of the quadriceps and exercising the knee joint and is done no more than 10 times. However, when large numbers (expressed by the author as "several hundred") are done, the exercise produces abnormal mobility of the knee medially, laterally, and anteroposteriorly. The resultant gross instability may cause loss of speed and agility.

As a consequence of these considerations, in 1962 the National Federation of State High School Athletic Associations and the Committee on the Medical Aspects of Sports of the American Medical Association (3) condemned the use of the deep-knee-bend type of exercise in the conditioning of athletes. While agreeing with this position, Rasch (27, p. 20) indicated that he had never known a man with damaged knees which were attributed to doing full squats with weights during his 40 years of interest in weight training.

Possibly an overlooked factor in the use of the full squat in weight training is that adequate advantage of the amount of weight that may be lifted is not realized. The amount of weight must be adjusted to the weakest point in the range of the joint movement. In leg lift testing with a dynamometer and with a belt holding the lifting bar to the hips, the strongest position is with the knees nearly straight (7); not nearly as much weight can be lifted when the knees are in a full bend position. Consequently, a heavy weight lifted with the knees fully bent would be relatively light weight through most of the range of movement. A deep squat performer will readily recognize that the greatest effort to rise with a given weight is at the starting position, which rationally supports this contention.

Studies Involving the Deep Knee Bend

Klein (16, 18, 19) and Klein and Hall (20) summarized studies by Klein and others pertaining to the effects on the knee joint of deep squat exercises. Over a period of years Klein and associates conducted extensive studies of such exercises, utilizing anatomical analysis, knee dissections of cadavers, knee injuries occurring in athletics, and the knee instability of football players, weightlifters, and paratroopers as contrasted with control subjects from University of Texas physical education classes. Findings that may be gleaned from these studies follow.

a. Approximately 35-40% of knee cases resulting from athletic injuries demonstrated ligament instability in the involved knee joint. The highest percentage was to the medial ligament, resulting in ligament stretching or medial cartilege tearing or both. This suggests that injuries are caused from a blow or force applied to the outside of the leg as in football blocking.

b. Knee dissections were made on 64 cadavers in order to determine amounts of ligament stretching in standing and in deep squat positions. The mean stretches were 7-8% and 12% for the medial and lateral ligaments, respectively. These results indicate that the lateral has greater involvement than the medial ligament when the deep squat exercise is performed. However, both ligaments are exposed to "abnormal" stretch effects, according to the investigator.

c. Two groups of men were contrasted for ligament instability, (A) 128 competitive weightlifters at the 1959 Pan-American games and from three Texas universities; all subjects included deep squat exercises in their training and competition; and (B) 386 university students from beginning weight training, basketball, and gymnastics classes; none of these men had ever done squat exercises with weights. Significance of differences between groups was tested by application of chi-square. Results may be summarized as follows:

(1) The instability finding from the dissection study, i.e., the lateral is subjected to greater stress than the medial ligament in performing deep squats, was verified. There were 19.4% more right lateral ligaments unstable than right medial ligaments; for the left knee, the percentage was 12.0.

(2) Comparing the two groups, A and B, the deep squatters had 46% and 58% greater instability in the right and left knees, respectively. By ligaments, the squatters had 67% and 57% greater lateral ligament instability and 16% and 25% greater anterior cruciate ligament instability of the right and left knees, respectively. The deep squat group had 61% greater instability in two or more ligaments of both knees. The control group (university students) had 44% more subjects with no ligament instability.

d. A study of 95 paratroopers, who used squat jumps in training, showed a high incidence of knee joint instability. The lateral and medial ligaments showed by far the greatest instability of both knees.

At Pennsylvania State University, Ward (34) studied the effect of performing squat jumps on the stability of the knee joint. Two groups of 25-27 men were formed by equating them according to the amount of knee abduction of the right leg. The experimental group performed 80 squat jumps a day, three days a week, for seven weeks, as well as participating in regular handball classes. The control group participated only in handball. Squat jumps were started from the deep knee position, one foot slightly forward of the other, hands clasped on top of head; the subject jumped high enough to clear the floor, reversed the forward-backward position of the feet and returned to the deep knee bend position. The deviations of the right and left medial and lateral knee ligaments were tested before and after the experimental period for both groups by use of Morehouse's test. The following results were obtained: (a) no significant differences between groups on all pre- and posttest means; (b) abduction of the right knee increased significantly for both groups; and (c) adduction of the right knee of the control group and the left knee of the experimental group decreased significantly. The effect of the handball activity in this experiment is not known; the investigator recommended that the study be repeated with handball omitted from the experimental group and with a control group that does not participate in any vigorous activity.

Knee Injuries

Ligament Imbalance

Marshall (23) measured the knee stability and maintained injury records on 25 football players at the University of Wisconsin. On the basis of a discrimination analysis technique, he concluded that it was impossible to predict susceptibility or proneness to knee injury from preseason evaluations of knee stability and/or muscular strength.

Muscular Imbalance

Klein and Hall (23, p. 9) related the muscular strength of the thigh muscles to knee injuries of 537 football players in 16 colleges and universities; the tests were made early in the preseason training period. Of 437 players with no knee injuries during the season, the average strength of the right thigh muscles was 4.7% stronger than for those of the left thigh. Of the players receiving knee injuries, 79.5% were to the left knee; of this group, the muscles of the noninjured side were 7.9% stronger than those of the injured side (this difference represents 54 pounds of strength). Eight different factors were recorded by the colleges at the time injuries occurred as being possible causes; of these eight, the only one common to all reports was strength imbalance between right and left thigh muscles.

Bender and associates (4) studied the strength imbalances related to the knee injuries of entering cadets at the United States Military Academy. They reported that individuals who had knee flexion and knee extension strength differences greater than 10% between limbs, and also those in the lower quarter strengthwise, were more likely to suffer noncontact knee injuries than were those who possessed balanced strength levels. Further, cadets who had previous knee injuries were more likely to reinjure the joint than were those who had not been injured before.

Racial Differences in Knee Structure

Utilizing data from sources in England, Germany, Australia, Japan and the United States, Klein (17) compared anatomical differences in the structure of the knee joint between Caucasian and Oriental racial groups. Quoting from Amoko, differences were given between Japanese and Europeans as shown in Table I. Klein noted that the incidence of knee injuries from participating in the martial arts of judo, karate, kung fu, and aikido is high for United States and European participants, while this problem is minor among Asiatics. He suggested that the difference in such injuries between the racial groups may well be attributed to the differences shown in internal knee structures.

Table I

Knee Structure Differences Between Japanese and Europeans

Knee Structure	Japanese	Europeans
Popliteal tendon	wide, strong	small
Transverse ligament	existence is rare	common
Meniscofemoral ligament	strong	not strong
Discoid meniscus	frequent - lateral	uncommon
Medial meniscus (mobility)	wide range	small range
Lateral meniscus (mobility)	limited range in knee flexion	wide range

Exercise and Ligament Strength

Listing 71 references, including 10 of their own, Tipton and associates (33) presented a research review on the influence of physical activity on ligament strength. The measurement of ligament strength of animals has been presented. Some relevant observations that may be drawn from this review follow.

a. Junction strength must be interpreted with regard to the ligament tested and to differences in age, sex, body weight, endocrine status, and the physical activity level of the animals. To reduce the variability between groups, junction strength should be expressed as a body weight ratio. This ratio is fairly constant over a wide range of body weight in rats and dogs.

b. In male and female rats, junction strength and ligament weight are highly correlated (around .90) until the animals are 135 days old. As they become older, this relationship declines.

c. The junction strength of bone-ligament preparations is increased with exercise training and decreased with immobilization.

d. Junction strength is influenced by the presence of certain hormones. However, in hypophysectomized rats, junction strength is increased by exercise training and decreased by immobilization.

e. The weight/length ratios of ligaments are higher in exercised rats and lower in those immobilized.

Some studies that demonstrate the value of exercise in the strengthening of knee ligaments are given below as a supplement to the above review.

By random placement, Adams (1) formed four groups of 30 female rats each in order to study the effect of exercise upon ligament strength. For five weeks the rats participated as follows: Group I, restricted to small cages; Group II, restricted to large cages and free to roam at will; Group III, exercised in drum with even surface, 15 minutes a day, five days a week; Group IV, same as Group III, except drum surface was uneven. Medial ligament strength was determined as the amount of weight required for the exercised ligament to tear from its bony attachment. The difference in ligament strength between Groups I and II, both groups being mostly sedentary, was not significant, although the ligaments of those in the larger cage were stronger. The Groups III and IV rats in the exercise drums had much stronger ligaments than did those confined to their cages. Also, the rats exercising in drums with uneven surfaces had stronger ligaments than did those in the smooth-surface drums (t = 3.00).

A similar study was done by Zuckerman and Stull (36), who randomly divided 47 male rats into four groups, each of which was assigned to a different experimental treatment for nine weeks. The respective treatments were: Group I, sedentary, restricted to small cages; Group II, spontaneous exercise, permitted to exercise at will in a drum attached to the cage; Group III, swimming, permitted spontaneous activity in addition to swimming in a tank with progressive overload for 15 minutes per day, five days a week; Group IV, running, same as Group III, except progressive running on a treadmill was substituted for progressive swimming. The usual ligament-bone separation method was applied to the right rear medial and the left rear lateral ligaments. Both ligaments of the rats participating in swimming and running were stronger than those in the sedentary and spontaneous exercise programs. The differences between the running and swimming groups and between the sedentary and spontaneous exercise groups were not significant.

In a later study Zuckerman and Stull (37) randomly assigned 93 male rats to 10 groups. Some groups were trained by swimming in a tank 15 minutes per day, five days a week with a weight equal to 2% of their body weight attached to their tails as an overload; spontaneous running on exercise wheels attached to their cages was permitted some rats; other animals, serving as controls, were housed in cages which did not permit appreciable exercise. Some animals were sacrificed at the end of eight weeks and others at the end of 16 weeks; strength of the medial ligament of the knee was determined by the usual ligament-bone separation method. Ligament strength was greater for the rats that exercised than for the sedentary rats. Detraining for eight weeks did not significantly alter the ligamentous separation force which had been acquired through training.

Tipton, Schild, and Tomanek (31) divided rats into the following four groups: control, repeated exercise (trained), trained and untrained, tenectomy, and immobilized. The training was on a motor driven treadmill in accordance with procedures that had repeatedly been shown to be effective in producing trained states. No animal was trained less than six weeks nor more than 12 weeks; the majority trained for 10 weeks; the detraining in one group was for four weeks. Ligament strength was tested as the separation force of the medial collateral ligament; also determined were separation-force-to-body-weight ratios and ligamentous elongation. The findings showed that a single exercise bout had no appreciable influence on separation force. Repeated periods of exercise did significantly strengthen knee ligaments; this effect persisted after four weeks of inactivity. Ligaments from tenectomized and immobilized rats had separation force values lower than the controls; however, statistical significance was found for the immobilized group only. Trained rats had more elongation for a given force than did untrained animals.

Rash and associates (29) formed four groups of 15 male albino rats each; the groups were respectively assigned to exercise, leg stretching, immobilization, and control. The exercise group ran in an exercise drum for 15 minutes twice daily at .5 mph for 10 days and 1 mph during a second 10 days. Rats in the stretched group were subjected to repetitive passive stretching by suspending seven ounces of lead weight from the right hind leg for one minute, followed by a release of one minute; this procedure was repeated for 10 minutes, twice daily; an ounce of weight was added at the beginning of each subsequent week of the study. At the end of four weeks, no significant difference was found in separation force among the four groups.

Tipton and associates (73, p. 169) applied an exercise schedule to rats which consisted of repeated "sprints" of two minutes duration up a 20% grade with rest periods of 30 seconds between sprints; the total time was progressively increased until the rats were exercising for two hours a day. The results showed no improvement in ligament-bone separation strength of the medial collateral ligament at the tibial junction, even though the weight and weight-length ratio were markedly increased. This finding demonstrated that ligament weight and junction strength do not exhibit concomitant changes in response to this type of exercise training. The investigators indicated that their results not only reinforced the "specificity of exercise" concept but also suggested that changes in junction strength are dependent on the type of exercise performed and not solely on the amount of time devoted to exercising.

Exercise and Treatment of Knee Injuries

Klein (16) placed 38 college men assigned to knee reconditioning classes on an exercise program designed to improve joint stability. The subjects had had knee injuries but had not undergone knee surgery. The exercise regimen consisted of three sets of 10 repetitions of exercises (10-RM), each set separated by one minute of rest; weight loads were progressively adapted to the tolerance of the individual; exercises were conducted three times a week for six weeks. The medial ligament exercise was conducted while standing with the knee in tension and 90 degrees of flexion; the knee was adducted toward the mid-line of the body; tension was kept at the knee joint throughout the exercise sequence of 10 repetitions by use of pulley weights attached to a sling located around the ankle. Lateral ligament exercises were done in the reverse manner, with the movements being away from the mid-line of the body. For each subject, exercises were applied to the injured knee only. Knee abduction and adduction were tested by Klein's method. No change was recorded for the stability of the ligaments of the uninjured knee. For the injured side, the medial ligaments significantly increased in tension ($t = 2.95$), while the lateral ligament nearly did so ($t = 1.90$).

Sparks (30) formed three subgroups of 10 college men who had had knee injuries from each of two categories (six groups, 60 subjects). The two categories comprised those who had not had knee surgery and those who had had knee surgery. One group in each category served as a control, so did not participate in an exercise regimen. The other four groups performed prescribed exercises twice each week for 15 weeks; one group in each category used the Elgin Exercise Unit and the other did single-boot exercises. Each experimental group did six progressive resistance exercises designed to strengthen the muscles activating the knee joint: three sets of 10 repetitions of each exercise. Strength was measured by Bender's method for 90, 125, 135 and 175 degrees of knee extension and 20 degrees of knee flexion. Data were treated by analysis of variance; the New Duncan Multiple Range Test was applied to determine significance among paired means when significant F ratios were obtained. Generally, the progressive resistance exercises produced gains of the knee extensor and knee flexor muscles which were significant compared with the control groups. The Elgin exercise system was superior to the single-boot method.

Exercise and Prevention of Knee Injuries

Some Comments

Several investigators have stated that strong well-developed quadriceps muscles are the first line of defense against strains to the knee, and it is only when this first line breaks down that strain on the knee ligaments comes into play. However, it seems only sensible to advocate exercise regimens that strengthen all muscles activating the knee joint for best results in preventing knee injuries.

In discussing several types of procedures which would help prevent knee injuries, McCloy (22) cited as evidence the practice followed by early Harvard University football teams. These players were subjected to an exercise routine designed to strengthen the quadriceps muscles. As a result, knee injuries were seldom encountered while this practice was in effect. Further, McCloy claimed that persistent, proper exercises for strengthening the muscles involved with the knee may avoid three-fourths of knee injuries ordinarily occurring in football and basketball.

West Point Study

From the 1962 entering class at the United States Military Academy, Bender and associates (4) selected plebes who had a 15% or greater difference in strength between limbs at knee extension 90 or 160 degrees and at knee flexion 135 or 180 degrees, or who could not lift 50% of their body weight at 90 degrees knee extension. Control and experimental groups of 117 and 120 subjects, respectively, were formed, divided as equally as possible in height, weight and strength. Both groups participated in the regular physical education program at the Academy. In addition, the experimental group participated in an isometric exercise program designed to strengthen the muscles which aid in the stabilization of the knee joint. Contrasts were made between the groups in noncontact injuries to the knee.

Both groups increased in strength at the four knee flexion and extension positions of both legs. However, the experimental group had significantly greater gains than did the control group at three of the four strength positions. The control group had 17 noncontact knee injuries (14%) during the period of the study, while the isometric group had only eight (7%). For the 569 cadets not in the experimental and control groups, 35 (6.1%) received noncontact knee injuries while participating in the Academy program; of this number 21 plebes (60%) had a 10% strength imbalance between the two knees.

These investigators may have made a very significant differentiation between contact and noncontact injuries. They considered noncontact injuries to be related to muscular weakness. The contact injury, on the other hand, was thought to be due more to chance, i.e., the chance that the participant was in a position where he received a blow to the knees. For example, in some football positions, blocking or tackling by opponents at the knees is more apt to occur than in other positions.

Other Pertinent Studies and Observations

Morehouse (24, 25) administered abduction and adduction measures by his method to the knees of 64 Pennsylvania State University football players before and after their participation in 20 days of spring football practice. The practice session activities with approximate time devoted to each were: conditioning drills, 20%; skills of blocking, passing, receiving passes, and special defensive and offensive skills, 15%; offensive and defensive team drills, 25%; and dummy and controlled scrimmages, 40%. Some differences in knee abduction and adduction occurred: decreases were found in amounts of abduction of the left knee and adduction of the right knee, thus showing improved joint stability; right knee abduction and left knee adduction also showed decreases, but the amounts were not significant.

Campbell (6) assessed the strength of the elbow flexor and knee extensor muscles of four college football players (two backfield and two linemen) at four times during spring practice: before practice, two weeks into practice, last week of practice, and one week after practice. Arm strength was maintained throughout the spring practice with a significantly higher level at the end than at the outset. On the contrary, leg strength was not maintained during the period; however, knee flexor strength was significantly higher one week after practice than for the previous tests. The investigator suggested that the reduction in strength of the knee may be a contributing factor to knee injuries received in football participation.

As an orthopedic surgeon who had treated many knee injuries in Army hospitals during World War II and of athletes in civilian life, West (35) expressed the conviction that athletics, even of the most strenuous variety, do not produce muscular strength to the same degree as do focal progressive resistance exercises. He indicated that this has been shown repeatedly in quadriceps strength development of football and track athletes, stating that even the fastest and most powerful of linemen after several years of football have been able to increase quadriceps strength from 50 to 100% in six to eight weeks of progressive resistance exercise. He stated: *"This fact is important, particularly in treating unstable knees where greater than normal power is essential to compensate for instability due to ligamentous injury. Even if the patient was able to resume his previous activity for a while without difficulty, he would not develop the supernormal level of strength essential for prevention of knee injury that in all likelihood would occur."*

Although not related specifically to exercise for strengthening the muscles supporting and activating the knee joint, the January 1974 ***Physical Fitness Research Digest*** (8) was devoted to the development of muscular strength and endurance. This statement may be consulted for application of activities, procedures, and practices found effective for this purpose. Another ***Digest***, January 1973 (9) may also be found helpful, as it reviews research related to a better understanding of muscular strength.

Summary

Inasmuch as the knee joint is especially vulnerable to damage and injury through athletics and physical education activities, this ***Physical Fitness Research Digest*** is devoted to considerations of exercise involving this joint. Summarizing statements follow.

a. The knee is a hinge joint, held together by ligaments, the lateral and medial collaterals, and the anterior and posterior cruciates. Three large muscle groups support and also activate movements of this joint, the gastrocnemius, quadriceps, and hamstrings. The stretch of a normal ligament is proprioceptive, stimulating contractions of the surrounding musculature. The knee movements are confined mostly to flexion and extension; slight rotation and lateral and medial movements of the lower leg occur when it is partially flexed.

b. Because of its vulnerability, the knee joint is especially subject to injury in athletics. Blows to the sides of the knees have been particularly incapacitating to football players; the danger is enhanced when the blow occurs when the foot is in firm contact with the ground.

c. Three types of measurements of knee functions have been utilized in the research reported herein: knee stability, as determined by degrees of abduction and adduction of the lower leg; strength of the muscles activating movements; and strength of ligaments. The first two types of tests were performed on human subjects; for the third type, ligamentous strength, the subjects were animals, mostly rats. In this latter regard, our investigator cautioned against transferring results from rats to man, as differences in responses may be present; evidence of such differences, however, was not presented.

d. The deep-knee-bend type of exercise, which includes the full squat in weight training, the duck waddle, and the Russian bounce, is a leading questionable exercise in physical conditioning regimens. The deep knee bend has been condemned by the National Federation of High School Athletic Associations and the Committee on the Medical Aspects of Sports of the American Medical Association. At least one leading orthopedist (21) has associated faulty use of the knees with chronic synovitis and with predosposition to the early onset of arthritic changes.

e. When the person is in the full knee bend position, the front portion of the joint is pushed forward and the extensor muscles are stretched; the entire body weight is supported on the posterior aspect of the joint. The final seating of the femoral condyles into the contours of the menisci is prevented.

f. Many members of various groups that routinely practice some form of deep knee bend in conditioning regimens have unstable knees. These groups include football athletes, competitive weightlifters, and paratroopers.

g. However, one study (34) revealed that knee instability did not occur from performing 80 squat jumps a day, three days a week for seven weeks. An orthopedist (11) has observed that the deep knee bend has value when used merely to maintain full stretch of the quadriceps and excursion of the knee joint when done no more than ten times; he contended that instability of the knee is likely to result when large numbers of deep knee bends are performed.

h. Imbalance in the strength of muscles activating the two knees is a contributing factor to the noncontact knee injuries of football players. Further, individuals weak in strength of these muscles are more likely to suffer such injuries.

i. Differences in ligamentous structure of knee joints may be a factor in the prevalence of knee injuries between races. In one report (17), Japanese as compared to Europeans had significant differences in knee ligaments and had a much lower incidence of knee injuries in judo, karate and other martial arts.

j. Ligament strength of animals, as evaluated by the force required to separate knee ligaments from their bony attachments, can be increased through exercise training and decreased through immobilization. The types of exercise mostly used in relevant research are endurance running in an exercise drum or on a treadmill, and endurance swimming in a tank. In one study (33), repeated "sprints" of two minutes duration interspersed with 30-second rests, progressively increased to two hours a day, did not significantly improve ligament-bone separation strength. These investigators suggested that increase in junction strength may be dependent on the type of exercise performed and not merely on the amount of time devoted to exercising.

k. Progressive resistance exercises have been used successfully to improve knee joint stability and the strength of muscles activating the knee joints of individuals recovering from knee injuries and knee surgery.

l. Progressive resistance exercise has also proven valuable in the development of strength for the prevention of knee injuries. Such exercise is needed as a supplement to the regular routines of sports practices, as athletic training per se does not produce muscular strength to the same degree as does specific strengthening exercises for this purpose.

m. The application of progressive resistance exercises for the prevention of knee injuries is especially needed when the participant has a muscular imbalance between the two knees or when the individual is muscularly weak when compared with other players.

n. Investigators in one study (4) differentiated between noncontact and contact injuries to the knees. The noncontact injury was thought to be due more to muscular weaknesses; the contact injury, more to chance, the chance that the participant was in a position to receive a blow to his knees. This differentiation may well be important in future studies of knee stability and muscular imbalance as related to knee injuries.

Implications

Implications for practice in physical education and athletics that seem justified from this research review of exercise involving the knee joint follow.

a. Exercises that unduly stretch or damage the ligaments of the knee should be avoided. Further, the muscles activating movements of the knee should be kept strong. A strong musculature binds the joint more firmly.

b. The deep knee bend should be used sparingly if at all in physical education and athletic conditioning. Perhaps its major value is to maintain full stretch of the quadriceps and full excursion of the knee joint. However, substitutes for these purposes may well be employed. Such substitutes are bench stepping, weight training routines, and modified forms of the knee bend.

c. In performing knee bends for developing and maintaining the strength and endurance of the quadriceps muscles, a half knee bend is recommended, just deep enough for the thighs to be parallel with the ground. One authority (22) suggested that one way to control the degree the knee is bent is to squat or bend until the subject touches a bench in a sit position.

d. An argument against deep squats in weight training regimens is that the load must be adjusted to the weakest point in the range of movement of the knee joint, which is the full squat position. Thus, the load for the muscles is maximal only at this position and becomes progressively easier to lift as the knees straighten.

e. Progressive resistance exercises of the muscles activating the knee joint should be routinely employed for the prevention of knee injuries and for the rehabilitation of the knee during postinjury or postsurgical rehabilitation.

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