LEG STRENGTH PATTERNS OF ATHLETES AS THEY RELATE TO MUSCLE INJURY

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CHAPTER I

INTRODUCTION

A young high school 440 yard dash sensation stepped into the blocks for the finals of the state high school track meet. The gun sounded, the runners were off but a little more than 100 yards down the track the runner was forced to stop with a torn hamstring muscle. Despite the loss of this race the runner went on to compete in college track but with repeated injury to this same muscle group. Due to repeated injury, scar tissue formed and began to contribute to a lack of extensibility and elasticity within the muscle. Because of this scar tissue the runner was eventually unable to achieve full extension and flexion of the injured leg, and was forced to give up what appeared to be a promising athletic career.

Each year numerous athletes are restricted in competition or entirely removed from competition by injuries to the thigh and knee. Such injuries include strains, sprains, and contusions to the thighs, as well as injury to the ligaments and cartilage of the knee, to mention a few. This study is primarily concerned with investigating injuries to the thigh and more specifically injuries that involve muscle tears. It has been stated by Klafs (12, 284) that thigh injuries rank second in the incidence of athletic injuries. He also stated that of all the muscles of the thigh, the knee flexors (commonly called the hamstrings) are most often injured. Some authors have suggested that injuries to the tissues that comprise the thigh and knee are often the result of strength imbalance between the flexor-extensor muscle groups of the knee. This primarily means that the knee extensors are so much stronger than the knee flexors of a single leg that the stronger knee extensors (commonly called quadriceps) in violent contraction may cause injury to the weaker muscle group. This also implies that strength imbalance of the same muscle groups, between the right and left leg may result in injury due to the fact that demands made on the stronger leg may not be able to be met by the weaker leg. This imbalance may be a factor in the cause of muscle "pulls" (this is a colloquialism for muscle strains).

Klein (13, p. 16) after numerous studies in the area of knee injury suggested that in the college football player the flexors should be 60 per cent of the extensor strength. After extensive research, Klein (13, p. 62) concluded that there should be an equal strength development between the right and left leg, not exceeding a ten per cent difference, for avoidance of injury. Klafs (12, p. 39) and Ryan (41, p. 60) both support Klein's observation that the knee flexor strength should be 60 per cent of the extensor strength to prevent muscle strain. Burkett (29, p. 48) concluded from his study of football players and track men that a ten per cent difference in strength between the right and left flexors was a critical level for the prediction of injury to the flexors. More research is necessary to confirm the findings of these authors. If there is evidence that strength imbalance does contribute to injury, emphasis on developing equal strength between the two legs and between the quadriceps and hamstrings will influence training practices for athletes.

Very few experimental studies have been done to determine factors contributing to muscle strains. Burkett's study is one of the few studies completed in this area and this study has limited value due to the small number of subjects tested. Klein has completed extensive research on factors contributing to knee injury and has made some observations concerning the knee flexors and extensors as related to the stability of the knee joint. Most of the studies have been confined to football and track groups, which limits the conclusions that can be drawn concerning injury and the general athletic population.

Since research is not conclusive as to the relationship between strength imbalance of the thigh muscle groups and injury, this study was designed to help answer some of the questions dealing with imbalance and injury.

The Problem

Statement of the Problem

This study was conducted for the purpose of determining the strength relationship between the knee flexor and extensor muscles of 80 athletes and for determining the ratio of the total strength between the left and the right legs. A further purpose was to compare the leg strength patterns among athletes in several sports groups, including baseball, basketball, football, track and field, and wrestling. Finally, an attempt was made to determine the relationship between relative strength of leg muscles and the incidence of muscle strain. More specifically, the purpose of the study was to answer the following questions:

(1) Is there a significant difference between the injured and non-injured groups with respect to strength imbalance between the knee extensors?

(2) Is there a significant difference between injured and non-injured groups with respect to strength imbalance of knee flexors?

(3) Is there a significant difference between injured and non-injured groups with respect to bilateral strength imbalance?

(4) Is there a significant difference between injured and non-injured groups with respect to strength imbalance between the flexors and extensors of the same leg?

(5) Is there a significant difference between the five athletic groups with respect to their flexor-extensor ratios?

(6) Is there a significant difference in the number of injuries occurring to the weak and strong legs?

(7) Is there a significant difference between the combined flexor-extensor strength of a weak injured leg as opposed to a weak non-injured leg?

(8) Is there a significant difference between the combined flexor-extensor strength of a strong injured leg as opposed to a strong non-injured leg?

(9) Is there a significant difference in the flexor-extensor ratio for injured weak legs as compared to non-injured weak legs?

(10) Is there a significant difference in the flexor-extensor ratio for injured strong legs as compared to non-injured strong legs?

(11) Is the dominant leg for all athletes significantly more often the weaker leg?

(12) For the specialized athlete, is the dominant leg significantly more often the weaker leg?

The general concern was that if certain of these comparisons showed a meaningful relationship to thigh and knee injuries, implications for conditioning and rehabilitation programs might be indicated. A further purpose of the study was to make a non-statistical comparison of the results with those obtained by other researchers.

Importance of the Study

If a relationship is established between strength imbalance and leg injury, measurements for imbalance could be conducted as part of the pre-season conditioning program. This perhaps would result in pre-season training to bring about better balance in muscle strengths. If injuries could be prevented rather than time being spent to rehabilitate the athlete during the season, this would indeed be of value to the athlete and coach.

Another benefit that might be derived from this study lies in the area of injury rehabilitation. If a specific strength ratio can be established as "ideal" for the flexor-extensor relationship this would provide a percentage toward which to work in rehabilitation. Such a ratio might even provide an indication of when an athlete should be allowed to return to competition.

Limitations of the Problem

The limitations of this study were:

(1) There are not an equal number of injured and non-injured subjects. The number of injured represents only one-third of the total group.

(2) All subjects were not tested under the same motivational conditions. Because of conflicts in scheduling, a few subjects could not be tested in the presence of their peers.

(3) All athletes were tested within the same two week period; therefore, not all of them were at the same stage of training and some groups were in their post-season. Those in their post-season were for the most part engaged in some type of strenuous physical recreational activity and in many cases they engaged in their varsity sport in their recreational time.

Delimitations of the Problem

The delimitations of this study were:

(1) Only male college varsity or freshman varsity athletes were used in the study.

(2) Only volunteers were used.

(3) Only volunteers from the following sports were used: baseball, basketball, track and field, football, and wrestling.

(4) Only 80 subjects were measured.

Definitions of Terms

The following definitions were adopted for use in this study.

Bilateral Muscle Strength Balance

The total muscle strength (combination of flexors and extensors) of one leg is within 10 per cent of the total strength of the other leg. If the right leg registered 400 pounds total strength and the left leg registered 400 pounds, plus or minus ten per cent, then bilateral muscle strength balance exists.

Bilateral Muscle Strength Imbalance

Imbalance exists if there is unequal strength development of greater than ten percent between the combined leg flexor and extensor strength of the right leg versus the left leg. For example, if the right leg produced 350 pounds of total strength and the left leg produced 500 pounds of total strength, then an imbalance of greater than 10 percent exists. (500-350 = 150/500 = .30 X 100 = 30%.)

Calcium Deposit

Abnormal calcification of soft tissue from traumatic insult, usually from repeated episodes (20, p. 120).

Contusion: Bruise (20, p. 23)

Symptoms: Local pain, stiffness; disability varies with site and extent

Signs: Tenderness; ecchymosis; hematoma formation

Dominant Leg

The preferred leg as determined by the leg that would be used as the kicking leg.

Extensor-Extensor Strength Comparison

This is the source generated by the right knee extensors as compared to the left knee extensors. For example, if the right extensors generated 200 pounds and the left extensors generated only 150 pounds, then the ratio is calculated as: $\frac{200 - 150}{200} = 25\%$. The score represents the percentage difference between the strength of the knee extensors of the two legs.

Flexor-Flexor Comparison

This comparison is arrived at by the same method as that employed for the extensor-extensor comparison, only in this case the knee flexor muscles of each leg are compared.

Flexor-Extensor Ratio

This ratio is a comparison of the strength of the knee flexors and the knee extensors of the same leg. For instance, if the knee extensors of the left leg measured 200 pounds of tension and the knee flexors of the same leg measured 150 pounds of tension, then the ratio is calculated by dividing the extensor strength into the flexor strength and multiplying by 100 to obtain the percentage (150/200 = .75 X 100 = 75%).

Knee Extensors

The Quadriceps femoris muscle is the great extensor of the knee. Its Vastus components cover the anterior, lateral, and medial surfaces of the shaft of the femur, and reach posteriorly to the linea aspera. The Rectus femoris lies in front of the Vastus intermedius and between the Vastus medialis and lateralis and unlike them has a double origin - one head to the anterior inferior spine of the ilium and the other to the posterior superior rim of the acetabulum. These four muscles have a common tendon insertion into the superior border of the patella which in turn, is attached to the tuberosity of the tibia, by the ligamentum patella. Since the Rectus femoris crosses the hip joint as well as the knee joint, it is a flexor of the hip as well as an extensor of the knee (3, p. 266).

Knee Flexors

These muscles are often called the hamstrings. They lie behind the adductor magnus. They are long muscles with their origins on the ischial tuberosity and their insertions in back of the knee joint. The biceps femoris has an extra origin (short head) on the distal portion of the linea aspera of the femur. Its insertion is on the head of the fibula. The semimembranosus inserts on the back of the medial condyle of the tibia, while the long, round tendon of the semitendinosus curves around to the medial side of the knee to insert on the shaft of the tibia close to the sartorius and gracilis. The 'hamstrings' are important extensors of the hip and flexors of the knee and therefore play an important role in walking (3, p. 266).

Sprain (20, p. 99)

Sprains can range anywhere from a minor tearing of the muscle and ligament fibers to a complete tearing of the muscle and ligament. The degrees of sprains are listed below.

Sprains, 1st Degree: Mild Sprain (20, p. 99).

Symptoms: Pain; mild disability.

Signs : Mild point tenderness; no abnormal motion; little or no swelling; minimal hemorrhage; minimal functional loss.

Sprains, 2nd Degree: Moderate Sprain (20, p. 99).

Symptoms: Pain; moderate disability.

Signs : Point tenderness; moderate loss of function; slight to moderate abnormal motion; swelling; localized hemorrhage.

Sprains, 3rd Degree: Severe Sprain (20, p. 100).

Symptoms: Pain, disability.

Signs : Loss of function; marked abnormal motion; possible deformity; tenderness; swelling; hemorrhage.

Strain (20, p. 101)

Strains can range anywhere from an injury to the muscle-tendon tissue with no appreciable hemorrhage and little inflammation of the tissue to a muscle or tendon rupture in which muscle is separated from muscle, or muscle from tendon, or tendon from bone.

Strains, 1st Degree: Mild strain, moderately pulled muscle (20, p. 101).

Symptoms: Local pain, aggravated by movement or tensions of muscle; moderate disability.

Signs : Mild spasm, swelling, ecchymosis; local tenderness; minor loss of function and strength.

Strains, 2nd Degree: Moderate sprain; moderately pulled muscle (20, p. 101).

Symptoms: Local pain, aggravated by movement or tension of muscle; moderate disability.

Signs : Moderate spasm, swelling, ecchymosis; local tenderness; impaired muscle function.

<u>Strains, 3rd Degree</u>: Severe strain; severely pulled muscle (20, p. 101).

Symptoms: Severe pain; disability.

Signs : Severe spasm; swelling, ecchymosis; hematoma; tenderness; loss of muscle function; defect usually palpable.

CHAPTER II

REVIEW OF LITERATURE

Very little has been written on the relationship between strength imbalance of the flexors and extensors of the knee as it relates to muscle injury. This chapter is a review of related literature concerning this specific topic. The review of literature is presented according to the following headings: (1) bilateral muscle strength and muscle injury; (2) flexor-extensor strength ratio and muscle injury; (3) warm-up as related to muscle injury; (4) flexibility as related to injury; (5) posture and activity as related to muscle injury; (6) other factors concerning muscle injury; and (7) literature on cable tension tests and angle measurements.

Bilateral Muscle Strength and Muscle Injury

It has been suggested by several authors that a strength imbalance between the right and left leg predisposes the athlete to a greater chance of thigh and knee injury.

In a study conducted between the years of 1953-58, Dr. Karl K. Klein (13, pp. 61-2) measured the leg strengths of 537 football players. Of the subjects measured, 79.5 per cent sustained knee injury to their weaker side. Within this injured group, the non-injured leg averaged 9.8 per cent stronger than the injured leg. The researcher used a tensiometer to measure strength, but did not state at what angles the measurements were taken. Klein did not report whether the injuries to the subjects occurred before or after testing; therefore, it is not known whether the weak leg was weak because of an injury or because of some other factor. He did point out that strength differences of more than 3-4 per cent became increasingly important in predisposing the player to knee injury. He did not, in this report, cite the statistical significance of this percentage.

Lee Burkett (20, pp. 39-42) conducted research in which he tested the leg strength of the San Diego Chargers football team and selected track athletes from the San Diego area. For these tests, he used the cable tension strength tests designed by Clarke for the measurement of knee flexion and extension. The tests utilized 165 degrees of extension for the knee flexion test and 115 degrees of extension for the knee extension test. Within each of the athletic groups, a control group and experimental group were chosen. The experimental group consisted of athletes who had sustained muscle strains to their knee flexors. The track and field experimental group consisted of athletes who had previously suffered strains to their knee flexors, but who were considered to be rehabilitated. Athletes were considered to be rehabilitated if their performance at the time of testing equaled or surpassed their pre-injury scores. He predicted that six football players would sustain injury to their weak knee flexors. Four of them did sustain injury to their weak knee flexors and one other felt a soreness in his weak knee flexor. The football experimental group was selected after testing, when they sustained knee flexor injuries during the course of the season. Burkett found that those who sustained knee flexor strains had an imbalance of strength between their knee flexors, as well as a greater difference in their flexor-extensor ratios than those who were not injured. He even went so far as to predict which athletes would be injured over the course of the season based on an imbalance of 10 per cent between the knee flexor strengths for right and left legs. Burkett concluded that a reduction of strength imbalance below a 10 per cent critical level would be useful in the reduction of flexor strains. Burkett's adoption of this 10 per cent difference in leg strength results from his 1968 study where 60 per cent of his football injured and 50 per cent of his track injured exceeded this critical level.

Dr. Allan Ryan (41, p. 60), a physician and member of the American College of Sports Medicine, has said that if a difference in the strength of the flexors exists between the right and left leg, that stress which may be moderate for the strong leg may injure the weak one. In an article entitled, "Are You Hamstrung?", Ryan cited Burkett's 1968 study and drew the conclusion that strength imbalance in the legs may lead to knee flexor injury.

Of the authors cited, it is evident that they feel that strength imbalance has a direct relationship to thigh and knee injury. Klein and Burkett were the only ones who specified what constituted an imbalance. Both of them adopted a 10 per cent or more difference between the bilateral strengths as a predictive indication of possible injury.

In other literature, Klafs and Arnheim (12, p. 38), Brueckmann (27, p. 52), and Klein (13, p. 15) have suggested that strengthening of the knee extensors and flexors makes the knee joint stronger and helps to maintain a good level of stability.

Flexor-Extensor Strength Ratio and Muscle Injury

It has been hypothesized by several researchers that the ratio of strength between the knee flexors and extensors in the same leg effects knee joint stability and the incidence of injuries to the thigh musculature.

Based on a number of knee rehabilitation studies, Klein (13, p. 16) concluded that the knee flexors need to be at least 50-60 per cent as strong as the extensors in college varsity athletes. This conclusion came as the result of averaging the flexor-extensor ratios of some 537 football players over a period of four years.

Helen Mendler (39, p. 43), who is a physical therapist, studied the various angles of knee flexion and extension for obtaining measurements of those muscle groups' strengths after injury. During a discussion of rehabilitation techniques she commented that after three months of ambulation the ratio of flexor to extensor strength was 60 per cent. She does not draw any conclusion however, as to whether this particular ratio is the one that should be achieved in muscle rehabilitation.

In the previously cited study by Burkett (29, p. 34), the research indicated a significant difference in the flexor-extensor ratio between injured and non-injured groups. In a comparison of the flexor-extensor ratios for his football sample, Burkett found that 60 per cent of his experimental group was over the 10 per cent "critical level" as compared to 18.74 per cent of his control group. This 60 per cent was statistically significant. The critical level would be interpreted to mean those athletes whose difference in strength between right and left knee flexors exceeded 10 per cent. In his track sample, Burkett found 50 per cent of his experimental group was over the critical level as opposed to 5.55 per cent of his control group. This difference was significant at the .05 level of confidence, also. From this study, Burkett felt that knee flexor injuries could be predicted for those who had more than a 10 per cent difference between the flexor-extensor ratios of their left and right legs. This difference was calculated by determining the flexor-extensor ratio of the left leg as compared to the ratio of the right leg. Although Burkett does compare the ratio of the flexor-extensor strength between right and left legs for injured and non-injured it would seem that his study might have been made stronger by comparing the flexor-extensor ratio <u>within the same</u> leg, between the injured and non-injured groups. This would mean considering each leg separately and not comparing the ratio of one leg to the other. It is interesting that he found a significant comparison, for by averaging the ratios of the two legs there was a greater chance of imbalance in one leg being cancelled by an opposite imbalance in the other leg.

Other authors have expressed opinions on flexor-extensor ratios but did not cite research to substantiate their assumptions. Ryan (41, p. 60) suggested that the flexors should be 60 per cent of the extensor group. Klafs and Arnheim (12, p. 38) believed that the muscular imbalance between the flexors and extensors of the knee was responsible for knee injuries because it reduced the stability of the knee joint. They further suggested that the knee flexor should perform at a level of at least 60 per cent of the extensors. LaPorta (37, p. 30) suggested that muscle strains are caused by sudden uneven contraction of the flexor-extensor groups due to a lack of coordination and imbalance in the muscle groups. Corrective therapist, Zane Grimm (31, p. 45) in a study of exercise techniques for the rehabilitation of the knee after surgery stressed a balance between the flexors and extensors of the knee. He stated that he felt the exercises that employed pulley type, or reciprocal action movements of the biarticular muscles of the thigh would produce the phenomenon of muscle balance. No attempt was made by Grimm, however, to define muscle balance.

The general consensus of the opinions expressed seems to indicate that the muscle strength of the knee flexors should be approximately 60 per cent of that of the knee extensors to decrease the chance of injury.

Warm-up as Related to Muscle Injury

One cause of injury that is frequently mentioned is that of warm-up. On the subject of warm-up as a preventative measure for injury the literature is not conclusive. Opinions as to the value of warm-up are split between those who feel that warm-up is very important for injury prevention and those who feel it has little bearing on injury.

As a result of Tuttle's work on muscle temperature and muscle activity, de Vries (6, p. 19) hypothesized that if the gastrocnemius muscle was allowed to cool down or was never sufficiently warmed-up, the relaxation phase of the muscle could be as much as two to three times slower than the contraction stage. This might result in the slowly relaxing antagonist being driven into its relaxation stage prematurely by a faster contracting agonist. The opposition of forces around the joint might result in muscle injury.

Klafs and Arnheim (12, p. 63) suggested that warm-up be used as a preventative measure. Adequate warm-up they felt prevented muscle strains by raising the general body and deep muscle temperature. They also stated that it increased flexibility of ligaments and collagenous tissues and aided in injury prevention. They did not, however, cite evidence to support their suggestion.

Tremble (42, p. 178) conducted a study involving 22 college sprinters who ran 60 yards a day for 12 weeks. The subjects alternated each day between warm-up and no warm-up. The type of warm-up was not specified. Tremble found no significant difference in performance time between warm-up and no warm-up. Furthermore, he found no significant difference in injury of the thigh between warm-up and no warm-up days.

Over a period of two years, LaPorta (37, p. 31) observed 200 dancers. Of this group, only three sustained injury to their knee flexors. LaPorta concluded that injury was prevented by extensive warm-up, but since he had no control group his study has limited significance.

From his review of literature regarding warm-up and injury, Jensen (32, p. 44) concluded that recent research studies do not provide conclusive evidence that injury can be prevented by proper warm-up nor did he find that it could not.

The writer must agree with Jensen and conclude that warm-up may or may not be a factor in the prevention of muscle injury. Since warm-up has not been shown to be injurious to the athlete it would seem reasonable to continue to use the warm-up as a precautionary measure until further evidence is forthcoming.

Flexibility as Related to Muscle Injury

Closely related to the warm-up controversy is the practice of using stretching exercises as a part of the general warm-up procedure. Very little has been done to determine the relationship between flexibility and injury. The term "good" and "bad" flexibility is not even defined by most authors. Flexibility is defined by Dr. Ruth Lindsey (16, p. 24) in her book on body mechanics as "... a measure of the range of motion in the joints of the body." Extensibility of a muscle is its ability to relax and stretch to its greatest length in that state. Elasticity is the ability of the muscle to return to its original shape after being stretched (25, p. 79). Ligaments do not have the same properties as muscles in that once they are over-stretched they do not return to their original shape. This leaves the joint they surround less stable and is the reason that sprains (stretching of the ligaments) are such a serious injury in athletics. For this reason strong ligaments with readily extensible, elastic muscles and a great deal of flexibility at the joint is desirous for athletes. This flexibility can be increased by passive and active stretching type activities.

Burkett (29, p. 46) administered the Wells sit-and-reach test to each of his football and track subjects. He found no significant difference in flexibility between the subjects who had sustained injury and the ones who had not.

Good flexibility according to Klafs and Arnheim (12, p. 64) increases the athletes ability to avoid injury. They pointed out that greater muscle flexibility permits a greater range of movement and, thus, does not put undue stress on the ligaments.

Joint flexibility is important in sports because it is a possible preventative measure against muscle strains, concluded Matthews (18, p. 71).

In his article on hamstring injuries, Ryan (41, pp. 61-2) suggested that the stretching of the flexors using flexibility type exercises such as the hurdle stretch and seated toe touching may decrease the possibility of muscle injury. He cautioned, however, not to overstretch before subjecting the muscle to maximal contraction. He further suggested that stretching should be done after a workout as opposed to before the workout because stretching prior to the event might cause injury. He felt if the stretching was effective at all it would last more than twenty-four hours. In the same article he suggested that tight knee flexors which do not allow full extension of the knee or flexion of the trunk is another possible cause of knee flexor injury.

As can be readily seen, most of these authors merely stated opinions and gave no research evidence to support them.

Posture and Activity as Related to Muscle Injury

In a study by Klein (33, pp. 42-3) a total of 30 subjects were observed in their natural standing posture without their knowledge. After eight weeks, these subjects were measured for strength of their knee extensors. Klein observed that those who consistently stood on one leg developed one leg stronger than the other. Based on research in the area of knee injury due to unequal leg strength, Klein hypothesized that a leg which is weaker because of a habitual standing posture may predispose the subject to knee injury of the weaker leg. It is interesting to note that he felt that certain types of physical activities have a tendency to influence unbalanced strength development. Some of these activities included baseball pitching, pole vaulting, javelin, shot put, discus, canoeing, and others. One subject in Klein's study, who was a baseball pitcher, bore out this assumption. If unbalanced bilateral strength is affected by habitual standing posture, might it also be possible for the dominant leg to have an affect on strength development?

Unilateral development of the body due to various sports activities creates, according to Klafs and Arnheim (12, pp. 39-40), postural imbalances that cause the body to realign itself in relation to the center of gravity. They felt that deviations of this type could become a primary source of injury.

Concerning injury to the flexors, Goldenberg (30, p. 34) has theorized it is due to a subluxation of the sacro-iliac joint. Due to this malpositioning, the spinal column rotates abnormally on the sacrum, pinching the nerves to the legs. This compression of the nerves can produce muscle contractions that are not in a proper sequence of relaxation and contraction with the agonist. No research was cited by Goldenberg to support this theory.

Ryan (41, p. 61) has suggested that an exaggerated lumbar curve which places the flexors under a constant state of tension may produce flexor strains. He believes this type of problem is common to athletes who develop their hip flexors at the expense of their abdominal muscles.

Charles Lowman (38, p. 15), in an article relating faulty posture to athletic performance, cited the case study of a runner with lordosis. As the runner attempted to lengthen his stride toward the end of a race he felt pain over the posterior two inches of the crest of the ilium. Due to lordosis (hollow back), the lower back muscles were overdeveloped and shortened to the extent that the pelvis could not be tipped back far enough to increase his reach. Therefore, each stride pulled on the shortened back extensors, which in turn jerked on the attachment to the ilium. If what Ryan says is true about an exaggerated lumbar curve placing the knee flexors in a constant state of tension, this particular subject might also be predisposed to knee flexor injury.

Other Factors Concerning Muscle Injury

Several authors suggest other possible causes of thigh injury. Four authors, Klafs and Arnheim (12, p. 254), Dayton (4, p. 263), and Ryan (41, p. 61) all suggest that injury may be due to fatigue, poor form, and poor conditioning. In all cases, no research was cited by the authors to substantiate their claims.

Ryan did explain how poor form effects the chance of injury. He stated that "... an excessive amount of weight on one leg at a critical moment when a strong muscle contraction ..." is needed may add to knee flexor injuries (41, p. 61).

Klein and others have conducted extensive research on the affect of deep knee bends on the stability of the knee joint. Research suggests that exercises involving a bending of the knee past a 90 degree angle of flexion may contribute to injury to the ligaments of the knee and consequent instability of the knee itself.

Cable Tension Tests and Measurement Angles

During World War II, H. Harrison Clarke devised the cable-tension strength tests to determine isometric muscle strength. A table, strap, cable, and cable tensiometer are necessary to administer these tests. Regarding the precision of these tests, Clarke (2, p. 15) states, "... as reflected by objectivity coefficients the tensiometer has the greatest precision for all strength tests." The tensiometer proved to be more consistent than three other devices: the Wakin-Porter Strain Gauge, the

Newman Myometer, and the Spring Scale. The objectivity coefficients for Clarke's (2, p. 13) six strength tests was reported to vary between .90 and .96. These tests have been used by other researchers to measure knee flexion and knee extension strength.

In dealing with cable-tension tests, some confusion is evident in the literature as to how to describe the angle at which the knee is placed for flexion and extension tests. Clarke (2, pp. 31-33) places the knee at an angle of 115 degrees for the extension test and an angle of 165 degrees for the flexion test. The 115 degree angle for knee extension is determined by assuming that when the knee is fully extended, it is at 180 degrees of extension. When the knee is flexed 65 degrees from this anatomical position, it reaches a "115 degree angle of extension." Theoretically, this assumes that the knee is capable of achieving 180 degrees of flexion, which it is not.

For the knee flexion test, the extended knee is once again considered to be at 180 degrees of extension. If the knee is flexed 15 degrees from this anatomical position, it assumes an angle of "165 degrees of extension," the angle used for the knee flexion test. This same point of reference (180 degrees extension) is a starting point used by several physical therapists, Krusen and Kottle (15, p. 53), and Kraus (14, p. 19), for measurement of knee flexion and knee extension.

After testing a variety of angles for knee flexion, Clarke found that 165 degrees of extension gave the best mechanical advantage coupled with the greatest possible muscle length for that advantage. For the knee extension test, Clarke found that 115 degrees of extension provided the greatest mechanical advantage.

Bos and Blosser (26, p. 218) in an electromyographic study of the vastus medialis and lateralis during isometric exercise, found that there was very little difference in action potential between 110 degrees and 170 degrees of extension. Clarke's choice of 165 degrees of extension for the knee extension test, lies within this range.

Helen Mendler (39, p. 43), found in her study of knee flexor and extensor force that the greatest force for knee extension is found at 120 degrees of extension and that the greatest force for knee flexion was found at 170 degrees of extension. These angles come within five degrees of matching the angles stated by Clarke.

Several researchers including Burkett and Klein have used these angles in their studies involving testing of the muscle strength of knee extensors and flexors.

Summary

It would appear, from the review of the literature, that thigh and knee injuries may be due to a number of causative factors. The following summary represents the findings of the research included in the review:

(1) The literature is divided on the subject of the value of warm-up for the prevention of muscle injury.

(2) Research has hinted that bilateral muscle imbalance of the thigh muscle groups may be related to knee injury.

(3) The desirable flexor-extensor strength ratio within the same leg is placed by many as 60 per cent, but some discrepancy concerning the per cent still exists in the literature.

(4) Deviations in posture may bring about leg muscle strains, although this too is inconclusive.

(5) Research on flexibility and its relation to muscle injury is lacking but some writers believe that there is a correlation between a lack of flexibility and muscle injury.

(6) The cable-tension strength tests appear to be most accurate for tests of knee flexion and extension.

As was stated at the first of the chapter, there are very few research studies dealing with muscle strength imbalance and muscle injury. Of those studies available, the literature is not conclusive as to the role of muscle strength in injury. In all but Klein's football study, the samples in the research were small and limited largely to football and track and field athletes. It would seem that more research is necessary using a variety of sports groups as well as samples of the general population. Too many researchers, coaches and trainers have speculated as to the possible causes of injury but have not supported their speculations by controlled research.

CHAPTER III

PROCEDURE

This chapter is designed to cover the actual testing procedures followed in this study. It will include the following topics: (1) the subjects, (2) testing procedures, and (3) statistical procedure.

Sampling Techniques

The primary purpose of this study was to identify any relationship which might exist between leg strength imbalance and injury. Five different athletic groups served as subjects. Subjects volunteered from each of the following varsity teams at Oklahoma State University during the spring semester of 1972: baseball, basketball, football, track and field, and wrestling. These five groups were chosen so that flexor-extensor ratios could be compared for sports requiring a variety of movements and types of conditioning. The 80 subjects were divided into injured and non-injured groups for the purpose of comparison. An injured player was defined as one who had sustained any type of injury to his knee flexors or extensors, or to the knee itself within the last seven years. (For the purposes of this study 25 subjects were classified as injured.)

No attempt was made to eliminate athletes who might tend toward bilateral strength imbalance because of the position they played within their sport, however, note was made of whether the athlete fell into a specialized or non-specialized skill grouping. The majority of the athletes were classed in the non-specialized group because the positions they played in their sports would theoretically have developed equal strength in their right and left legs. The specialized group who might have had unequal development because of their positions, included catchers and pitchers in baseball, jumpers and throwers in track and field, and kickers in football.

The age of the subjects ranged from 18 to 29 years. No effort was made to restrict the study to one race. The study included Negroes, Orientals, American Indians, and Caucasians. All subjects were or had been a member of a varsity or freshman varsity team at Oklahoma State University during the 1971-72 school year. The track and field men and baseball players were still in competition at the time of testing. The football players had just completed their spring football training at the time of testing, but the wrestlers and basketball players had been out of competition for a month. The majority of the subjects who were "out of season" were participating in some type of physical activity such as paddleball, softball, tennis, and others.

The selection of subjects for the study was initiated by an interview with Floyd Gass, the Oklahoma State University Athletic Director. Through him contact was made with the coaches of the previously mentioned varsity sports. Through these coaches, a time was arranged to measure the leg strength of volunteers from each athletic group. In some cases, because of conflicts in schedules, personal contact was made with the athletes to arrange a time for testing. Subjects were selected solely on a volunteer basis. There was no particular emphasis placed on securing athletes who had been injured. In this manner, a total of eighty subjects were secured for testing; twenty-five of these had sustained leg injuries to the thigh or knee, and fifty-five had not sustained injury to either their thigh or knee.

Testing Procedure

As the subjects arrived for measurements, they were given the questionnaire to complete (see Appendix A). The first page was completed by all subjects, while the second and third pages were completed by only those who had sustained injury to the thigh or knee. After the questionnaire was completed by the subject, a measurement was taken of his lower leg length. With the subject in a standing position, the measuring tape was placed at the estimated center of the knee joint on the lateral portion of the leg and stretched down to the center of the lateral maleolus. A mark was then made on each leg, halfway between the knee and the ankle with a skin pencil. This mark was used as a guide for the placement of the canvas strap used in the tensiometer pulling assembly. When the measurement had been completed, the subject was instructed to sit at the end of the Elgin table. He was then positioned for the knee extension test by an assistant. The right leg was given two trials then the left leg was given two trials. The subject was then placed in a prone position for the knee flexor test. Two trials of the right leg flexors were administered, followed by the same for the left leg.

All testing of subjects was done by the investigator with the assistance of two people: one who acted as recorder, and one who assisted in positioning the subjects for the tests.

Instruments

For this study, strength measurements of the knee flexors and knee extensors were made employing the Clarke cable-tension strength tests. Equipment for the tests included a cable tensiometer, a cable-pulling assembly, an angle measuring device, and a testing table.

The tensiometer, is an instrument designed to measure isometric muscle strength. The tensiometer used for this study was manufactured and calibrated by the Pacific Scientific Company of California. A calibration table prepared solely for this instrument was used in preparation of the data.

Force was applied by the subject against an immovable cable. Tension on the cable was registered on the tensiometer by "... measuring the force applied to a riser and causing an offset in the cable stretched taut between two sectors" (2, p. 8). This tension reading was converted into pounds by consulting a calibration chart. For this study a tensiometer (Figure 1) with the capacity to measure as low as 35 pounds and as high as 600 pounds was utilized. A cable 3/32-inch in diameter attached to a canvas strap served as the pulling assembly. A padded Elgin table was used in the testing. A 3/4-inch plywood platform, in which ten, 3-inch "I" bolts were inserted, was placed under the table to provide attachments for the pulling assembly. The purpose of the hooks was to allow for adjustments according to the leg length of the subject. With a variety of hook placements it was possible to control the angle of the leg and at the same time keep the strap pulling at right angles to the leg. The pulling assembly consisted of a 12-inch loop of canvas 2-inches wide, attached to a cable, which in turn was attached to a one foot length of chain. A 2-inch S-hook was used to attach the pulling assembly to the I-bolts in the platform. The chain allowed the pulling assembly to be altered in length according to the leg length of the individual.

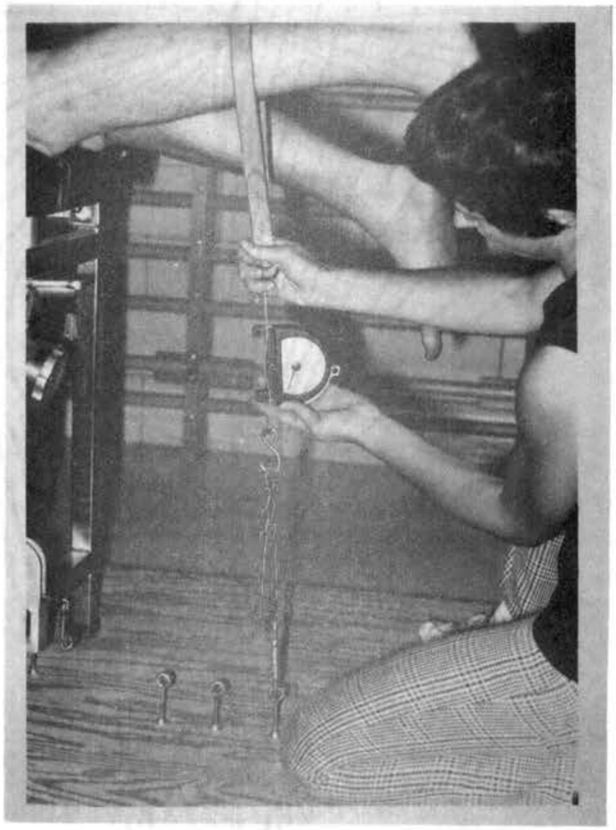

Figure 1. Tensiometer and Pulling Assembly for the Cable-Tension Tests of Knee Extension and Flexion

<u>Flexion-Extension Tests</u>

The following is a description of the tests and test procedures used in the study. Clarke's test descriptions (2, pp. 31-33) for knee flexion and extension were followed closely. No warm-up was allowed preceding the start of testing. For the knee extensor test (Figure 2) the subject was placed in a sitting position with the lower legs hanging off the end of the table with the popliteal space touching the edge of the table. He was then instructed to assume a backward leaning position with the arms extended to the rear for support. The subject was instructed not to flex the arms during the test. The leg on the side being tested was placed at a 115 degree angle of extension. (This assumes that a fully extended leg is at 180 degrees of extension.) The canvas strap was then centered on the skin pencil mark and attached to the platform so the angle of pull was perpendicular to the leg. Lifting of the buttocks was prevented by placing the Elgin stabilizing strap across the upper part of the thighs. The strap was not pulled so tight as to restrict muscle contraction by the knee extensor muscle group. Once the subject was positioned, he was instructed to extend his leg slowly and steadily against the cable until he felt he had reached his maximum effort and then to relax. After the first test was administered to the right leg, approximately 15 seconds of rest was given and then a second trial was given. Following the same procedure the extention test was then administered to the left leg.

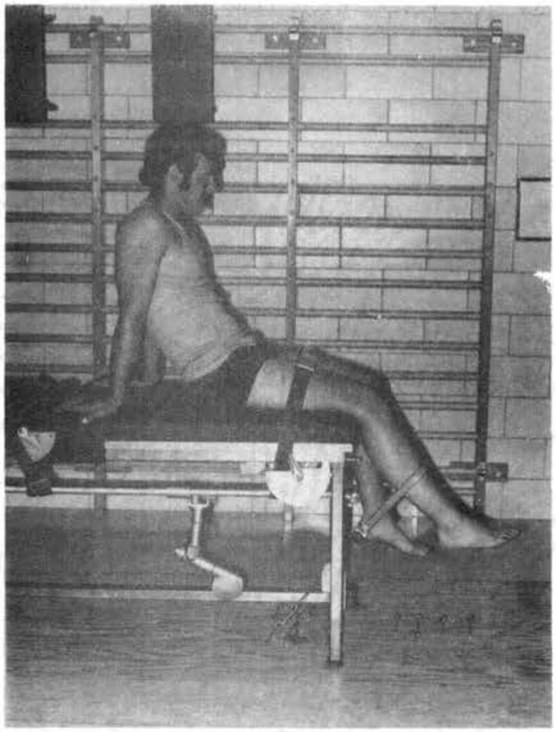

Figure 2. Positioning of the Subject for the Knee Extension Cable-Tension Test

The subject was next placed in a prone position with his patella positioned just at the edge of the table (Figure 3). He was instructed to fold his arms under his head and a strap from the Elgin table was placed across his shoulders to prevent extension of the spine. The leg was placed at a 165 degree angle of extension for this test. (This too assumes that a fully extended leg is at 180 degrees of extension.) The subject was instructed to flex his knee and slowly exert maximum effort against the cable, relaxing after he had reached his maximum. The subjects were told the result of their first trial before they attempted their second trial. It might be noted that the open space in the end of the Elgin table was avoided by offsetting the hooks in the platform to one side.

The highest score for each test was converted into pounds, according to the calibration chart. The data was treated by descriptive and comparative statistical procedures.

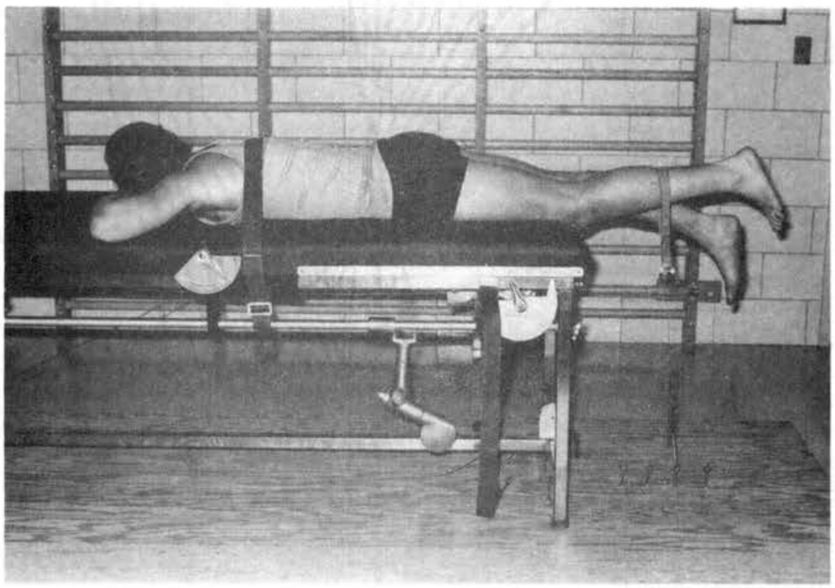

Figure 3. Positioning of the Subject for the Knee Flexion Cable-Tension Test

How Angles Were Determined

Clarke (2, p. 33) stated that an angle of 115 degrees is the best for the maximum measurement of knee extension. In addition, he stated that an angle of 165 degrees is the best for a measurement of flexor strength. Klein (13, pp. 35-36) and Burkett (29, pp. 21-22) also cite these same angles as those which produce the highest strength measurements for these muscle groups. Following the suggestions of these two researchers the author chose to use 165 degrees of extension for the knee flexion test and 115 degrees of extension for the knee extension test.

For this study, a portable posture grid (Figure 4), upon which two pieces of yarn had been stretched was used to control the angles of flexion and extension. One piece of yarn was placed at an 115 degree angle to the vertical plane of the grid. The second piece was placed at an 165 degree angle to the vertical plane of the grid. The strings were placed so that by standing behind the grid the string could be aligned with the longitudinal axis of the lower leg. In this way the angles were determined for both knee flexion and extension.

Motivation

In an attempt to increase motivation, subjects were told the scores of their first trials. A chart was constructed to indicate the top three scores recorded in each athletic group. If a subject exceeded a recorded score, his name and score were placed on the chart in his presence. An additional source of motivation was peer group encouragement. Except in approximately ten cases, peers were present to give encouragement. Peers were not present in these ten cases because these subjects were tested individually due to a conflict with the regular testing schedule. Verbal encouragement by the tester was given to all subjects as they performed the tests. All tests were administered by the author.

Figure 4. Portable Posture Grid Being Used to Determine a 165 Degree Angle of Extension

Questionnaire

The questionnaire was used to obtain information concerning the sport played, how many years played, position played, recreational activities participated in, dominant leg, and athletic conditioning programs. In addition, information dealing with injury was included in the questionnaire. Such questions as the time of the injury, conditions under which it occurred, nature of the injury, and treatment given for it were included (see Appendix A).

Statistical Procedure

The data for this study was reported descriptively and comparatively. The descriptive data consisted of an analysis of means, standard deviations, and maximum and minimum ranges. The raw scores for the knee flexion and extension strength tests are given for each of the five athletic groups in Appendix B. The mean differences between knee extensors, flexors, and bilateral strength are found in Appendixes C, D, and E, respectively. In Appendixes C, D, and E, the left and right leg scores were paired. The difference between these two scores was then converted into a percentage. If an athlete generated 200 pounds in knee extension with his right leg and 150 pounds in extension with his left leg, then the percentage difference would have been computed as follows: $\frac{200-150}{200} = 25\%$. By changing these scores to percentages it was possible to compare scores of weak and strong athletes on a relative scale.

The knee flexor-extensor ratios are recorded for right and left leg in Appendix F. The mean of the combined left and right ratios is also given. The flexor-extensor ratio was computed by dividing the strength of the knee extensors into the strength of the knee flexors of the same leg. Thus, if an athlete generated 200 pounds of strength in the right knee extensors and 160 pounds in the right knee flexors, the ratio would have been computed as follows: $\frac{160}{200} = 80\%$.

Data is also given for the combined strength of the flexors and extensors of the strong leg and for the weak leg. Appendix G includes an indication as to whether injury occurred to the weak or the strong leg, or both. In addition, it indicates which leg was designated as the dominant leg.

The comparative data consisted of t-tests for unpaired samples, analyzing the various strength comparisons. The t-test results were obtained by using a BMDX70 computer program (7, p. 7). This program computed a t-test for pooled variance as well as a t-test for separate variance. In evaluating the t-test results, the F-value for variance was examined and if found significant the t-value for separate variance was reported. If, however, the F-value was not significant the t-test results for pooled variance was reported.

Statistical comparisons were made between and within each of the five athletic groups. A t-test was computed for the differences in means between knee extensors, knee flexors, bilateral muscle strength, and flexion-extension ratios.

Critical ratios were also calculated to determine the proportion of subjects in injured and non-injured groups who were above the 10 per cent level of strength imbalance (29, p. 28). The formula used for computing this critical ratio was as follows:

$$\text{Critical Ratio} = \frac{P_1 - P_2}{\sqrt{p \cdot q \left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

The values for the formula were computed in the following manner:

(1) P_1 and P_2 being the percentage of subjects within the injured and non-injured groups that were above the 10 per cent critical level.

(2) "p" is equal to $\dfrac{\text{Total in Group \#1 over 10\% level} + \text{Total in Group \#2 over 10\% level}}{\text{Total in Group \#1} + \text{Total in Group \#2}}$

(3) "q" is equal to 1.00 - p.

The author is aware that the critical ratio is an inappropriate statistic to use, since the groups in the study were of insufficient size to give validity to this statistic. However, the critical ratio was employed to make possible comparisons of results with Burkett, even though he too used the statistic inappropriately because of his group size.

The criteria for accepting or rejecting a comparison as significant was placed at the .05 level of confidence.

CHAPTER IV

ANALYSIS OF DATA

This chapter contains the results of this study. The data is presented in the following format: (1) knee extensor data; (2) knee flexor data; (3) bilateral muscle strength data; (4) flexor-extensor strength ratio data within groups; (5) flexor-extensor strength ratio data between groups; (6) weak and strong leg comparisons as related to injury; (7) other comparisons; (8) discussion of other issues.

For each comparison, a question will be posed to be answered by the data. Based on the t-tests and the test of critical ratio, conclusions will be drawn and comparisons made with studies of other researchers. Many of the comparisons will be made with Burkett's football and track study or with studies conducted by Klein. It should be noted that any significance in the wrestling group is of limited importance since only one injured wrestler was tested.

For the purpose of this study, the following questions were posed by this study. (If the answer to the question proved to be significant, a "yes" is found after the question; if it did not, a "no" is found after the question.)

(1) Is there a significant difference between the injured and non-injured groups with respect to strength imbalance between the knee extensors? No.

(2) Is there a significant difference between injured and non-injured groups with respect to strength imbalance of the knee flexors? Yes.

(3) Is there a significant difference between injured and non-injured groups with respect to bilateral strength imbalance? Yes.

(4) Is there a significant difference between injured and non-injured groups with respect to strength imbalance between the flexors and extensors of the same leg? No.

(5) Is there a significant difference between the five athletic groups with respect to their flexor-extensor ratios? No.

(6) Is there a significant difference in the number of injuries occurring to the weak and strong legs? Yes.

(7) Is there a significant difference between the combined flexor-extensor strength of a weak injured leg as opposed to a weak non-injured leg? Yes.

(8) Is there a significant difference between the combined flexor-extensor strength of a strong injured leg as opposed to a strong non-injured leg? No.

(9) Is there a significant difference in the flexor-extensor ratio for injured weak legs as compared to non-injured weak legs? No.

(10) Is there a significant difference in the flexor-extensor ratio for injured strong legs as compared to non-injured strong legs? No.

(11) Is the dominant leg for all athletes significantly more often the weaker leg? No.

(12) For the specialized athlete, is the dominant leg significantly more often the weaker leg? No.

It might be noted that raw scores for all subjects can be found in Appendix B.

Statistical Data Results

Knee Extensor Data

In Table I, the means, standard deviations, maximum and minimum scores of the knee extensors for each of the athletic groups are given. Track and field, and wrestling are the only groups that show much differences between the means of the injured group versus the non-injured group for the knee extensor strength. The track and field group registered a difference of approximately nine between the means for the injured and non-injured groups. The basketball group registered a difference of about seven between the means. It might be noted that since there was only one injured wrestler his scores were recorded as an individual with no standard deviation or maximum-minimum range given. His score on this comparison deviates almost 10 per cent from the mean of the non-injured wrestling group, but because he is the only injured wrestler the comparison holds little significance.

TABLE I

DESCRIPTIVE DATA FOR INJURED AND NON-INJURED GROUPS ON STRENGTH IMBALANCE BETWEEN KNEE EXTENSORS

Group	No. in Group	Mean Per Cent of Difference	Standard Deviation	Maximum	Minimum
BASEBALL					
Injured	4	14.7500	14.0801	30.0	0.0
Non-Injured	8	9.2500	6.7981	22.0	3.0
BASKETBALL					
Injured	3	11.6667	8.9629	22.0	6.0
Non-Injured	9	18.2222	10.8487	36.0	7.0
FOOTBALL					
Injured	9	8.1111	9.5844	29.0	0.0
Non-Injured	18	10.6111	9.9832	38.0	0.0
TRACK-FIELD					
Injured	8	12.3750	11.1347	34.0	1.0
Non-Injured	10	21.2000	11.6600	39.0	3.0
WRESTLING					
Injured	1	20.000	-	-	-
Non-Injured	10	10.5000	9.8911	32.0	0.0

The question was asked: Is there a significant difference between the injured and non-injured groups with respect to strength imbalance between the knee extensors? Table II gives the t-ratios that were computed to help answer this question. The t-ratios that were found for each of the five groups were as follows: (1) baseball, 0.94; (2) basketball, -0.94; (3) football, -0.62; (4) track and field, -1.63; and (5) wrestling, 0.92. All of these ratios were below the .05 level of confidence and, therefore, it was necessary to conclude that there was no significant difference between the strength of the left knee extensors and the right knee extensors.

TABLE II

t-TEST OF THE MEAN DIFFERENCE BETWEEN INJURED AND NON-INJURED FOR EACH ATHLETIC GROUP ON STRENGTH IMBALANCE BETWEEN KNEE EXTENSORS

Sample	Mean Per Cent of Difference	t-Ratio	Significant	F-Value	Significant
Baseball	5.50	0.94	No	4.29	No
Basketball	6.56	-0.94	No	1.47	No
Football	2.50	-0.62	No	1.08	No
Track-Field	8.83	-1.63	No	1.10	No
Wrestling	9.50	0.92	No	0.0	No

This same data was then analyzed using the critical ratio formula. This data is recorded in Table III. The purpose of this analysis was to determine if those subjects who possessed an imbalance between knee extensors of greater than 10 per cent were those who sustained injury to their thighs or knees. In this study none of the critical ratios for knee extensors were significant at the .05 level of confidence. Burkett (29, p. 37) did not use a critical ratio on the knee extensors so no comparison was possible. He did, however, find the t-ratios to be significant for his track and field group for this comparison.

TABLE III

THE CRITICAL RATIO FOR STRENGTH DIFFERENCES BETWEEN THE KNEE EXTENSORS FOR INJURED AND NON-INJURED OF ALL ATHLETIC GROUPS

Sample	Per Cent Injured Over Critical Level	Per Cent Non-Injured Over Critical Level	Critical Ratio	Significant
Baseball	50	25	0.866	No
Basketball	33	67	-1.0142	No
Football	33	50	-0.8216	No
Track-Field	50	80	-1.3416	No
Wrestling	100	40	1.1489	No

Knee Flexor Data

The results of the knee flexor strengths can be found on Table IV. Very little difference is seen in the means of the injured and non-injured of each athletic group with the exception of the track and field athlete. In this particular group, there is a difference of almost 10 between the means. The standard deviation from the mean was found in the baseball and track and field groups.

TABLE IV

DESCRIPTIVE DATA FOR INJURED AND NON-INJURED ON STRENGTH IMBALANCE BETWEEN KNEE FLEXORS

Group	No. in Group	Mean Per Cent of Difference	Standard Deviation	Maximum	Minimum
BASEBALL					
Injured	4	16.7500	23.0416	51.0	1.0
Non-Injured	8	15.6250	10.5686	32.0	4.0
BASKETBALL					
Injured	3	10.6667	7.2342	19.0	6.0
Non-Injured	9	7.1111	8.9923	29.0	0.0
FOOTBALL					
Injured	9	9.8889	8.1921	26.0	1.0
Non-Injured	18	9.94444	6.6019	25.0	1.0
TRACK-FIELD					
Injured	8	20.3750	16.3614	47.0	3.0
Non-Injured	10	9.5000	9.9135	29.0	1.0
WRESTLING					
Injured	1	42.0000	-	-	-
Non-Injured	10	14.5000	10.6693	32.0	4.0

With respect to knee flexor imbalance, the following question was posed: Is there a significant difference between injured and non-injured groups with respect to strength imbalance of the knee flexors? This knee flexor comparison is representative of the force generated by the right knee flexor as compared to the left knee flexor. For example, if the right flexors generated 200 pounds and the left flexors generated only 150 pounds, then the ratio is calculated as: $\frac{200-150}{200} = 25\%$. The score represents the percentage difference between the strength of the knee flexors of the two legs.

Table V reports the findings of this study with regard to the t-ratios for the knee flexors. Of the five groups, only the track and field and wrestling groups had t-ratios high enough to prove significant at the .05 level of confidence. The t-ratio for the track and field group was 1.75, with the wrestling group having a t-ratio of 2.46. Burkett found this comparison to be significant for his track and football groups. Since the F-value was significant, the t-test results for separate variances was reported.

TABLE V

t-TEST OF MEAN DIFFERENCES BETWEEN INJURED AND NON-INJURED GROUPS FOR EACH ATHLETIC GROUP ON STRENGTH IMBALANCE BETWEEN KNEE FLEXORS

Sample	Mean Per Cent of Difference	t-Ratio	Significant	F-Value	Significant
Baseball	1.13	0.09	No	4.75	Yes
Basketball	3.56	0.62	No	1.55	No
Football	0.06	-0.02	No	1.54	No
Track-Field	10.88	1.75	Yes	2.72	No
Wrestling	27.50	2.46	Yes	0.0	No

When the data were analyzed using a critical ratio, none of the groups showed a level of significance (Table VI shows this data). Burkett (29, p. 34), however, in his study found significance for both his football and track groups. He concluded that those with strength imbalances of greater than 10 per cent between their knee flexors could be predicted to injure their weak knee flexor.

TABLE VI

THE CRITICAL RATIO FOR STRENGTH DIFFERENCES BETWEEN THE KNEE FLEXORS FOR INJURED AND NON-INJURED OF ALL ATHLETIC GROUPS

Sample	Per Cent Injured Over Critical Level	Per Cent Non-Injured Over Critical Level	Critical Ratio	Significant
Baseball	25	50	-0.8281	No
Basketball	33	11	0.8944	No
Football	33	33	0.0	No
Track-Field	63	30	1.3789	No
Wrestling	100	50	0.9574	No

To test Burkett's hypothesis that a weak knee flexor predisposes an athlete to knee flexor injury, a special comparison was made of those track men receiving only knee flexor injuries. The injured track subjects were compared with the non-injured track subjects. The results of the comparison is shown on Table VII. In order for the data to be significant, it required a t-ratio of 1.771. In this case, the t-ratio was 1.34; therefore, this study did not show a significant relationship between knee flexor strains and strength imbalance between the knee flexors.

TABLE VII

t-TEST OF THE MEAN DIFFERENCE BETWEEN THOSE TRACKMEN SUSTAINING KNEE FLEXOR INJURIES AND NON-INJURED TRACKMEN

Sample	Mean Per Cent of Difference	t-Ratio	Significant	F-Value	Significant
Track-Field	8.5	1.34	No	2.20	No

Bilateral Muscle Strength Data

Bilateral muscle strength is recorded for all groups on Table VIII. Bilateral muscle strength consists of the combined flexor and extensor strength of one leg. The greatest difference in bilateral strength (disregarding the one wrestler) is evident in the baseball group where there is a difference of slightly more than four between the means of the injured and non-injured groups. It is interesting to note that while track and field means for injured and non-injured groups are equal, the standard deviations suggest that there should be a difference in means. This points up the weakness of using mean comparisons.

TABLE VIII

DESCRIPTIVE DATA FOR INJURED AND NON-INJURED GROUPS ON STRENGTH IMBALANCE BETWEEN BILATERAL MUSCLES

Group	No. in Group	Mean Per Cent of Difference	Standard Deviation	Maximum	Minimum
BASEBALL					
Injured	4	14.2500	18.0069	40.0	0.0
Non-Injured	8	9.8750	8.0788	23.0	2.0
BASKETBALL					
Injured	3	10.6667	3.5119	14.0	7.0
Non-Injured	9	9.6667	6.0000	20.0	3.0
FOOTBALL					
Injured	9	6.6667	5.9161	18.0	1.0
Non-Injured	18	8.7778	7.0423	29.0	0.0
TRACK-FIELD					
Injured	8	13.5000	13.5541	38.0	3.0
Non-Injured	10	13.5000	8.1684	29.0	2.0
WRESTLING					
Injured	1	33.0000	-	-	-
Non-Injured	10	9.8000	6.8117	23.0	0.0

Is there a significant difference between injured and non-injured groups with respect to bilateral strength imbalance? The computation necessary to answer this question can be found on Table IX. The wrestling group was the only group to achieve statistical significance. Very little inference can be drawn from this data however, because of the small size (N = 1) of the injured wrestling sample.

TABLE IX

t-TEST OF MEAN DIFFERENCE BETWEEN INJURED AND NON-INJURED FOR EACH ATHLETIC GROUP ON BILATERAL STRENGTH

Sample	Mean Per Cent of Difference	t-Ratio	Significant	F-Value	Significant
Baseball	4.38	0.46	No	4.97	Yes
Basketball	1.00	0.27	No	2.92	No
Football	2.11	-0.77	No	1.42	No
Track-Field	0.00	0.0	No	2.75	No
Wrestling	23.20	3.25	Yes	0.0	No

It might be noted here that the F-value for the baseball group was significant with a 4.97. This indicated that there existed a great deal of variability within that group, when the t-ratio for separate variances was examined, however no significant difference was found at the .05 level of confidence.

Table X gives the critical ratio that was computed for this comparison for each group. The ratios obtained showed no significant differences within the groups. When Burkett (29, p. 34) made these same comparisons he found a significant critical ratio for his track group but not for his football group.

TABLE X

THE CRITICAL RATIO FOR BILATERAL MUSCLE STRENGTH DIFFERENCE FOR INJURED AND NON-INJURED OF ALL ATHLETIC GROUPS

Sample	Per Cent Injured Over Critical Level	Per Cent Non-Injured Over Critical Level	Critical Ratio	Significant
Baseball	50	38	0.4140	No
Basketball	67	33	1.0142	No
Football	33	39	-0.2818	No
Track-Field	25	60	-1.4849	No
Wrestling	100	50	0.9574	No

Flexor-Extensor Strength Ratio Data

Within Groups

Data for flexor-extensor ratios within groups can be found on Table XI. The flexor-extensor ratio is the ratio of the flexor strength to the extensor strength within the same leg, changed to a per cent. Differences in mean flexor-extensor ratios for injured and non-injured basketball and track and field groups are seen to be 14 and 10 per cent, respectively. In the other groups, the injured and non-injured have relatively equal strength ratios. In all but the basketball non-injured group, the means were in the percentage ranges of 80 and 90.

TABLE XI

DESCRIPTIVE DATA FOR INJURED AND NON-INJURED GROUPS ON STRENGTH IMBALANCE BETWEEN FLEXOR-EXTENSOR STRENGTH RATIOS

Group	No. in Group	Mean Per Cent of Difference	Standard Deviation	Maximum	Minimum
BASEBALL					
Injured	4	91.5000	14.2009	102.0	71.0
Non-Injured	8	87.2500	10.6201	102.0	72.0
BASKETBALL					
Injured	3	90.6667	23.5443	115.0	68.0
Non-Injured	9	76.6666	24.5866	135.0	55.0
FOOTBALL					
Injured	9	92.8889	16.9812	123.0	69.0
Non-Injured	18	91.0555	21.3939	152.0	63.0
TRACK-FIELD					
Injured	8	81.3750	23.3724	118.0	40.0
Non-Injured	10	91.5000	24.7756	148.0	66.0
WRESTLING					
Injured	1	123.0000	-	-	-
Non-Injured	10	91.7000	16.8394	120.0	68.0

In dealing with flexor-extensor ratio comparisons, the following question was asked: Is there any significant difference between injured and non-injured groups with respect to strength imbalance between the flexors and extensors of the same leg? As seen in Table XII, none of the comparisons were significant. This may be due in part to the fact that the flexor-extensor ratio of the right leg was averaged with the flexor-extensor ratio of the left leg. In doing so, there is a possibility that strength imbalances may actually be cancelled out. An example of this reasoning might be an athlete who had a very strong right knee extensor and a very weak knee flexor. This would be an imbalance between the muscle groups within his right leg. Then suppose he had a very weak left knee extensor and very strong left knee flexor. Here again, he would have an imbalance between the muscle groups within the same leg. It is conceivable, however that when the ratios of the two legs are averaged the mean difference might be zero. By making the comparison in this manner, sight is lost of the fact that there was a great imbalance of strength within each leg. Burkett (29, p. 38) used this preceding method to make his flexor-extensor comparisons. The present study, in order to make comparisons with Burkett's work duplicated his method of figuring flexor-extensor ratios, but in addition also made a second set of comparisons. For this comparison, all the flexor-extensor ratios of the weak injured legs were compared with the ratios of the weak non-injured legs. The same was done with the strong injured legs and the strong non-injured legs for each athletic group. The results of these comparisons are cited at a later point in this chapter.

TABLE XII

t-TEST OF MEAN DIFFERENCE BETWEEN INJURED AND NON-INJURED FOR EACH ATHLETIC GROUP ON FLEXOR-EXTENSOR STRENGTH RATIOS

Sample	Mean Per Cent of Difference	t-Ratio	Significant	F-Value	Significant
Baseball	4.25	0.59	No	1.79	No
Basketball	14.0	0.86	No	1.09	No
Football	1.833	0.22	No	1.59	No
Track-Field	10.12	-0.88	No	1.12	No
Wrestling	31.30	1.77	No	0.0	No

A critical ratio (Table XIII) was also computed for the flexor-extensor ratios of all athletic groups. The results indicated that none of the five groups showed significant differences for the critical ratio comparison.

TABLE XIII

THE CRITICAL RATIO OF FLEXOR-EXTENSOR RATIOS DIFFERENCES FOR INJURED AND NON-INJURED OF ALL ATHLETIC GROUPS

Sample	Per Cent Injured Over Critical Level	Per Cent Non-Injured Over Critical Level	Critical Ratio	Significant
Baseball	75	63	0.4330	No
Basketball	67	78	-0.3849	No
Football	44	61	-0.8216	No
Track-Field	88	80	0.4243	No
Wrestling	100	70	0.6423	No

Flexor-Extensor Ratios Between Groups

The question was posed: Is there a significant difference between the five athletic groups with respect to their flexor-extensor ratios? The mean of the left and right flexor-extensor ratios for each group was compared with the mean of every other group as seen on Table XIV.

TABLE XIV

t-TEST OF MEAN DIFFERENCES ON FLEXOR-EXTENSOR RATIOS BETWEEN ATHLETIC GROUPS

	Baseball	Football	Track	Basketball	Wrestling
Baseball		0.49	0.22	1.10	-0.92
Football	0.49		-0.71	1.57	0.41
Track	0.22	-0.71		0.76	0.89
Basketball	1.10	1.57	0.76		1.59
Wrestling	-0.92	0.41	0.89	1.59	

(The "athletic group" refers to the combination of injured and non-injured within that group.) None of the t-ratios computed between the groups were found to be significant at the .05 level of confidence. The greatest differences were seen in comparisons between football and basketball (t-ratio of 1.57) and wrestling versus basketball (t-ratio of 1.59). To be significant, a t-ratio of better than 2.08 would have been necessary. These results imply that flexor-extensor ratios seem to develop somewhat equally among the five athletic groups that were tested. One might expect that athletes would develop different ratios because of the sports they participate in, but at least for this study this does not appear to be the case.

Weak and Strong Legs as Related to Incidence of Injury

Several comparisons were computed dealing with the relationship of strong and weak legs to injury. A weak leg was defined as the leg of the subject whose combined flexor-extensor strength was less than the combined flexor-extensor strength of the other leg.

The question asked was: Is there a significant difference in the number of injuries occurring to the weak and strong legs? All eighty subjects were compared and the t-ratio computed (Table XV) showed that injuries to the weaker leg were significantly more frequent. Of the 80 strong legs, 15 per cent of them sustained injury. Out of 80 weak legs, 28.75 per cent of the subjects sustained injury to their weaker leg. The t-ratio computed for this comparison was -1.98 which was significant since only 1.656 was necessary to be significant at the .05 level of confidence. It would seem evident from a study of the data that injury was more prevalent in the weaker leg. This, of course, does not indicate how much weaker the weak leg would need to be to predispose the person to injury. Nor, can one assume that a cause and effect relationship exists. It is possible that a strength imbalance existed before the injury but it is also possible that the strength imbalance is the result of the injury. The author was unable to find any other research in which the weak and strong legs had been designated and compared. (Burkett (29, p. 41) did predict injury to the leg with the weakest knee flexor.)

TABLE XV

t-TEST ON THE INCIDENCE OF INJURY TO WEAKER LEG

Sample	Mean Per Cent of Difference	t-Ratio	Significant	F-Value	Significant
All Athletic Groups	13.75	1.98	Yes	2.00	Yes

Combined Flexor-Extensor Strength For Weak and Strong Legs

The question was asked: Is there a significant difference between the combined flexor-extensor strength of a weak injured leg as opposed to a weak non-injured leg? The mean strength of the injured weak legs was 340.0952 pounds compared to 383.8135 pounds for the non-injured weak legs (see Table XVI). With a t-ratio of 1.97, the difference was significant at the .05 level of confidence. This may mean one of two things, either the weak injured leg possessed less bilateral strength as a result of the injury or it was weaker preceding injury. The same type of comparison was made between the strong injured leg and the strong non-injured leg. The injured strong leg registered a mean strength of 441.5833 pounds while the non-injured strong leg registered a mean of 413.8823 pounds, yielding a t-ratio of 0.66. This t-ratio was not significant at the .05 level of confidence. For both of the previously mentioned comparisons, the F-values were significant, therefore, the t-ratio for separate variance was used. It should be noted that the injured group had greater strength in their strong leg than the non-injured group. This might indicate that the injured group has one muscle group, either flexors or extensor, that are extremely strong and serve to imbalance the strength in the leg still further, hence, resulting in injury.

TABLE XVI

t-TEST OF MEAN PER CENT OF DIFFERENCE BETWEEN COMBINED LEG STRENGTH FOR WEAK INJURED VERSUS NON-INJURED LEGS AND FOR STRONG INJURED VERSUS NON-INJURED LEGS

Sample	Mean Per Cent of Difference Injured Versus Non-Injured	t-Ratio	Significant	F-Value	Significant
Strong Legs	29.7010	0.89	No	2.37	No
Weak Legs	43.7183	-1.97	Yes	1.47	No

Flexor-Extensor Ratios as Related to Weak and Strong Legs

Still another question was posed: Is there a significant difference in the flexor-extensor ratio for injured weak legs as compared to non-injured weak legs? This particular comparison was referred to earlier in the discussion of flexor-extensor ratios with regard to comparisons between and within groups. The flexor-extensor mean ratio for weak injured legs was computed as 87.9524 while the mean ratio for weak non-injured legs was found to be 90.7458 (see Table XVII). The t-ratio was -0.46 which was not significant at the .05 level of confidence. The same comparison was made of the ratios of strong injured legs and strong non-injured legs with mean ratios of 90.3333 and 87.1912, respectively. The t-ratio was found to be 0.45 which was not significant at the .05 level.

TABLE XVII

t-TEST OF MEAN PER CENT OF DIFFERENCE BETWEEN FLEXOR-EXTENSOR RATIOS OF WEAK INJURED VERSUS NON-INJURED LEGS AND STRONG INJURED VERSUS NON-INJURED LEGS

Sample	Mean Per Cent of Difference Injured Versus Non-Injured	t-Ratio	Significant	F-Value	Significant
Strong Legs	3.1421	0.45	No	1.47	No
Weak Legs	2.7934	-0.46	No	1.41	No

Dominant Leg as Related to Strength

Another observation was made even though no t-test was computed for the comparison. The following question was asked: Is the dominant leg for the specialized athlete significantly more often the weaker leg? A frequency count was made of the times that the dominant leg was the stronger leg. The count showed that in 38 cases the dominant leg was also the stronger leg. On the other hand, in 42 cases the dominant leg was the weaker leg. Since the dominant leg was defined as the kicking leg, it would probably not be the supporting leg for kicking, or throwing or jumping. Therefore, the non-dominant leg would be called upon more often to support the body weight. One might theorize that the support leg is under more stress, increasing its strength through the principle of use. Among the subjects in this study, the weaker leg was more often the dominant leg, but only in 52.5 per cent of the cases.

One other observation was made, and this one concerned those athletes designated as "specialized athletes," meaning athletes who would be expected to be developed unilaterally because of the position they played or event in which they participated. Included in this group were four baseball pitchers, one catcher, two football kickers, one long jumper, two shot putters, one discus thrower, and one javelin thrower. In the present study, a frequency count was made to determine the number of times the dominant leg was the stronger leg in specialized athletes. The count showed in six out of eleven cases the dominant leg was stronger. This would seem to indicate that, at least for this specialized group, there was very little relationship between the dominant leg and the weaker leg. Each of these athletes developed unilaterally to some degree but not necessarily in the way that would be anticipated (with the dominant leg necessarily weaker or stronger). It would have been helpful to know if the dominant leg and hand corresponded, and if indeed the throwing hand was most often the one opposite the strong leg. These findings question to some degree the assumption that these specialized athletes develop any differently from other athletes. Contrary to this assumption, Klein (33, p. 43) commented that in his study of standing posture and strength development he found one subject whose unilateral development he attributed to six years as a baseball pitcher.

Other Comparisons and Observations

Flexor-Extensor Ratios

In reviewing the results of this study, several important questions demanded an explanation. The first question concerned the ratio between flexor-extensor strength within the same leg. In this study, most of the flexor-extensor ratios were at least 80 per cent and several were as high as 91 per cent for the athletic groups. Klein (13, p. 61-2) found in his study of 537 college football players that their flexor-extensor ratios averaged near 60 per cent. Dr. Karl K. Klein (in a personal letter written to the author on September 28, 1972) hypothesized that as the ratio approached 1:1 that the incidence of knee injury would be reduced. The discrepancy between this study's flexor-extensor ratios and those obtained by Klein in his football study cannot be explained, but it might be hypothesized that they were due to differences in conditioning procedures.

Critical Ratio

The difference in the critical ratios that Burkett found as compared to critical ratios obtained in this study may be in part due to the fact that Burkett had picked his experimental groups carefully allowing only those who had sustained hamstring injuries to be tested. He was also careful to match his experimental groups and control groups as nearly as possible. In addition he made certain that his subjects had returned to their pre-injury performance levels before testing.

General Comments on Comparisons With Other Studies

This study did not find the same comparisons significant that Burkett found significant except in the case of the knee flexor comparison on which Burkett (29, p. 40) found significance for both his track and football groups. In the present study, the football, baseball, and basketball groups were not found to have a significant difference in knee flexor strength. However, the track and field and wrestling groups were found to have a significant difference for this comparison. Perhaps significance was not found in the football group's measurements because the measurements were completed after injury and rehabilitation, whereas Burkett measured his football experimental group before injury. Since there was only one injured wrestler, the data for the wrestling group did not necessarily reflect a valid comparison. Why there were differences between the data reported by this study and that of Burkett and Klein still remains unanswered but it may be that unidentified variations in the makeup of the groups, small variations in the measuring techniques, as well as such things as training program differences may have influenced the outcome of these studies.

Observations From the Questionnaire

The questionnaire for this study was designed to answer a variety of questions that might have proved pertinent to the study. Several observations were made as a result of the answers on the questionnaire. It was interesting to note that 40 per cent of the injuries occurred within the first three weeks of the playing season and an additional 20 per cent occurred within four to six weeks after the start of the playing season. The question of the amount of warm-up that has been done preceding injury is often asked. In this study 48 per cent of the injuries occurred after 10-15 minutes of warm-up and an additional 43 per cent of the injuries occurred after at least 20 minutes of warm-up. Closely related to warm-up is the temperature of the playing environment. The results of this study indicated that 73 per cent of the injuries occurred during hot or mild temperatures while only 23 per cent occurred in cold temperatures. Recognizing the fact that the warm-up factor had not been controlled preceding injury one can only make the observation that for this study injuries seemed more prevalent near the beginning of a playing season, after at least 10 minutes of warm-up, and in a hot or mild playing environment.

CHAPTER V

SUMMARY, CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

This study was designed to investigate the possible causes of knee and thigh injuries to athletes, particularly injuries to the knee flexors. Two tests including the cable-tension knee extension test and cable-tension knee flexion test were administered to each subject. A questionnaire was also administered to each subject.

A group of 80 subjects composed of athletes from each of the following five varsity teams of Oklahoma State University were used in the study: baseball, basketball, football, track and field, and wrestling.

Twelve questions were posed by the researcher and answered by this study. Four of the answers were significant at the .05 level of confidence. These concerned strength imbalances between the knee flexors for the track and field and wrestling groups, as well as relationships between weak legs and injury to all five groups.

Summary of Statistical Results

The following questions were posed by the researcher. If the answer to the question proved to be significant, a "yes" is found after the question; if it did not, a "no" is found after the question.

(1) Is there a significant difference between the injured and non-injured groups with respect to strength imbalance between the knee extensors? No.

(2) Is there a significant difference between injured and non-injured groups with respect to strength imbalance of knee flexors? Yes.

(3) Is there a significant difference between injured and non-injured groups with respect to bilateral strength imbalance? Yes.

(4) Is there a significant difference between injured and non-injured groups with respect to strength imbalance between the flexors and extensors of the same leg? No.

(5) Is there a significant difference between the five athletic groups with respect to their flexor-extensor ratios? No.

(6) Is there a significant difference in the number of injuries occurring to the weak and strong legs? Yes.

(7) Is there a significant difference between the combined flexor-extensor strength of a weak injured leg as opposed to a weak non-injured leg? Yes.

(8) Is there a significant difference between the combined flexor-extensor strength of a strong injured leg as opposed to a strong non-injured leg? No.

(9) Is there a significant difference in the flexor-extensor ratio for injured weak legs as compared to non-injured weak legs? No.

(10) Is there a significant difference in the flexor-extensor ratio for injured strong legs as compared to non-injured strong legs? No.

(11) Is the dominant leg for all athletes significantly more often the weaker leg? No.

(12) For the specialized athlete, is the dominant leg significantly more often the weaker leg? No.

Conclusions

Based on the results of this study, several conclusions can be drawn:

(1) The track and field injured group had a significant strength imbalance between their left and right knee flexors when compared to the non-injured track and field group. The one injured wrestler also had a significant knee flexor strength imbalance when compared to the non-injured wrestlers.

(2) The wrestling injured group showed significant difference in bilateral strength between right and left legs. (This must be viewed as limited in significance as there was only one wrestler in the injured group.)

(3) Of the injuries sustained to all athletic groups, significantly more of the injuries occurred to the weaker leg of the athletes.

(4) A significant difference was also found between the combined flexor-extensor strength of the weak injured leg as opposed to the weak non-injured leg for all athletic groups.

Implications

In an attempt to isolate specific factors relevant to thigh and knee injuries, but especially muscle strains to the thigh, a series of questions were posed. The evidence seems to indicate that an imbalance in knee flexor strength may be related to thigh muscle strains. If having a marked difference between knee flexors is a significant factor in muscle injury it would seem that, based on measures of strength imbalance between the knee flexors, predictions could be made as to those athletes who might be injured at a later date. Based on this assumption, the author predicts that a significant number of the following track and field athletes will either injure or reinjure the leg with the weak knee flexor: subjects number 53, 54, 55, 57, 58, 59, 61, 63, and 69. (For a key to subject identification number, see Appendix H.) The wrestlers also showed significance for this comparison so it is predicted that a significant number of the subjects numbered 70, 71, 73, 74, 76, and 78 would suffer an injury or reinjury to the leg with the weak knee flexor. Had this study shown a significant difference in the knee flexor strengths for the injured baseball group, one could predict that athletes numbered 4, 5, 6, 9, and 10 would be injured. If the same were true for the football group, it could be predicted that a significant number of the subjects numbered 25, 26, 33, 40, 41, 42, 47, 50, and 51 would be injured. Likewise, in the basketball group it could be predicted that a significant number of the subjects numbered 13, 16, and 20 would be injured.

If a coach or trainer were able to do pre-season tests for flexor strengths and predict which player might be injured, this would allow for preventative type action rather than rehabilitative action. If indeed weak knee flexors is an important factor in muscle injury, it would also indicate to the coach that more time should be spent in exercising the knee flexors. This does not mean to imply, however, to the exclusion of exercise for the knee extensors.

The importance of keeping leg strength equalized is shown by the fact that injury occurred most often to the weaker leg. This would imply that the coach, trainer, or therapist not only needs to be concerned with a weak knee flexor but with weak legs as a whole. Being aware of this factor might lead to the adoption of activities as a part of a training and rehabilitative program that would lead to bilateral strength development.

It, of course, must be recognized that strength imbalance is not the only factor that is responsible for muscle injury. Not everyone who has a strength imbalance will sustain injury to their thigh or knee. Outside forces such as a clip in football, poor coordination, or a wet playing surface may have a great deal of bearing on muscle injury. If, however, some injuries could be eliminated by specialized exercise designed to decrease a strength imbalance, this would be of great significance.

Recommendations

Based on the findings of this study, several recommendations could be made with regard to further study. These recommendations are as follows:

(1) There is need for additional study on the cause of knee flexor and knee extensor injury among a variety of athletic groups.

(2) Additional research should be conducted to determine if the flexor-extensor ratio varies with sex, age and involvement in sports activities. Additional research should be done to determine if there is indeed a "best" flexor-extensor ratio for the avoidance of injury.

(3) A longitudinal study consisting of pre-injury measurements with a follow-up of injuries occurring to this group might produce meaningful insights into strength imbalance and injury.

(4) Since injury to muscles occurs generally during dynamic activity, some thought should be given to the fact that many investigators have found low correlations between isometric strength measurements and dynamic strength measurements. Perhaps dynamic measures would reveal insights into injury causation more accurately than isometric measures.

(5) It is strongly recommended that another researcher follow-up those athletes for whom injury was predicted in this study and see if they were injured at a later time.

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APPENDIX A

QUESTIONNAIRE

QUESTIONNAIRE

Name__________________	Measurement:	Reading	Conversion
Height_____	Right Ext.	(1)_____	_____
Weight_____		(2)_____	_____
Age________	Left Ext.	(1)_____	_____
Leg Dominance_____ (Kicking Leg)		(2)_____	_____
	Right Flex.	(1)_____	_____
		(2)_____	_____
	Left Flex.	(1)_____	_____
		(2)_____	_____

1. Are you currently engaged in a physical fitness program of any type? Cirlce one of the following if yes, circle (9) if not.

   1. Weight lifting 2. Exercises 3. Jogging 4. Flexibility exercises 5. Isometrics 6. Jump Rope 7. Stadium stairs 8. Other 9. None

2. What type of recreational activities do you most often engage in? Circle appropriate response or responses.

   1. Tennis and Paddleball 2. Basketball 3. Football and Soccer 4. Softball and Baseball 5. Track 6. Golf 7. Other 8. None

3. On which varsity team do you participate? Circle one.

   1. Football 2. Basketball 3. Track and Field 4. Wrestling 5. Baseball

4. In what position and/or events do you play in that sport?

5. How many years have you played in this particular sport?

   1. One 2. Two 3. Three 4. Four 5. Five 6. Six 7. Seven

6. If you have played in any other varsity sport in the last seven years indicate which one and the number of years played.

1. Basketball	1 2 3 4 5 6 7	5. Wrestling	1 2 3 4 5 6 7
2. Football	1 2 3 4 5 6 7	6. Swimming	1 2 3 4 5 6 7
3. Baseball	1 2 3 4 5 6 7	7. Tennis	1 2 3 4 5 6 7
4. Track	1 2 3 4 5 6 7	8. Soccer	1 2 3 4 5 6 7
		9. Other	1 2 3 4 5 6 7

7. Describe in a few words what type of training program you are now engaged in that involve leg strengthening.

8. If you have sustained a thigh, knee or lower leg injury within the last four years, please fill out the rest of the questionnaire to the best of your ability and knowledge.

9. Approximate date you injured yourself initially.

   1. 1967 or before 2. 1968 3. 1969 4. 1970 5. 1971 6. 1972

10. If this is an old injury with recurring reinjuries, give the date of the last re-injury.

11. In what week of the season did you injure yourself?

   1. 1-3 weeks 2. 4-6 weeks 3. 7-9 weeks 4. 10-12 weeks
   5. more than 12

12. Time of the day you injured yourself. Circle one.

   1. 8:00-12:00 2. 12:00-3:00 3. 3:00-6:00 4. After 6:00

13. What race or event were you doing when you were injured?

14. Injured in a meet, game, or in practice?

15. Injured at the start, middle, or end of the event.

16. Was the event in which you injured yourself one you participated in most of the time?

17. How much warm-up prior to injury?

   1. None 2. 1-10 minutes 3. 10-15 minutes 4. More than 20

18. If the injury occurred during running, did it occur on a change of direction, a curve, or on a straightaway.

   1. Change of direction 2. Curve 3. Straightaway

19. Approximate temperature when you injured yourself.

    1. Hot 2. Cold 3. Mild 4. Rain 5. Wind

20. Did you injure yourself on your home track or on an opponent's field?

21. Condition of the track or field.

    1. Hard 2. Soft 3. Wet 4. Bumpy 5. Other (specify)

22. Did a physician examine this injury?

23. Did a trainer or coach examine the injury?

24. Circle the treatment, if any, that you were given (you may circle more than one).

    1. Rest (how long) 2. Ultra sound 3. Taped injury
    4. Exercise 5. Whirl pool 6. Heat 7. Cold 8. Surgery
    9. Other

25. Your best performance in the two weeks before the injury (if in track and field).

26. Your best mark for above event one week after returning to competition.

27. If you did not compete or train before of this injury, how long were you out of competition or training?

28. Check the appropriate blanks. Be sure to check at least one blank under each column.

Injured Leg	Injury to:	Type of Injury
___1. Right	___1. Hamstrings	___1. Bruise
___2. Left	___2. Knee	___2. Broken bone and fracture
	___3. Quadriceps	___3. Strain
	___4. Other	___4. Sprain
		___5. Calcium deposit
		___6. Torn cartilage
		___7. Other

APPENDIX B

RAW DATA FOR KNEE FLEXOR AND EXTENSOR STRENGTHS FOR ALL GROUPS

Sample	Subject No.	Right Knee Extensors*	Left Knee Extensors*	Right Knee Flexors*	Left Knee Flexors*
BASEBALL					
Injured	1	245	230	228	245
	2	222	170	180	178
	3	195	195	207	190
	4	214	150	180	88
Non-Injured	5	207	228	145	198
	6	200	155	145	112
	7	180	175	175	161
	8	198	238	220	200
	9	271	288	243	204
	10	243	250	204	298
	11	211	198	173	166
	12	228	248	220	207
BASKETBALL					
Injured	13	387	411	243	300
	14	130	166	163	175
	15	198	214	178	190
Non-Injured	16	200	274	166	185
	17	185	200	180	178
	18	223	255	143	150
	19	195	220	155	153
	20	447	285	168	235
	21	175	195	133	130
	22	145	100	160	160
	23	214	168	116	128
	24	324	298	165	178
FOOTBALL					
Injured	25	233	255	203	274
	26	175	185	130	163
	27	220	195	190	207
	28	195	195	140	130
	29	150	178	155	166
	30	238	235	230	223
	31	250	253	258	271
	32	230	233	166	165
	33	145	204	220	193
Non-Injured	34	198	223	203	188
	35	235	290	214	198
	36	200	245	217	198
	37	195	198	175	193
	38	230	203	163	150
	39	225	217	331	340
	40	233	255	207	267
	41	185	211	150	168
	42	211	220	193	233
	43	214	162	255	245
	44	233	235	214	203

Sample	Subject No.	Right Knee Extensors*	Left Knee Extensors*	Right Knee Flexors*	Left Knee Flexors*
FOOTBALL (Continued)					
	45	285	331	267	243
	46	334	280	198	185
	47	166	166	155	116
	48	220	220	180	178
	49	271	267	188	207
	50	397	248	280	235
	51	235	220	220	188
TRACK AND FIELD					
Injured	52	198	173	188	193
	53	130	128	118	98
	54	143	113	113	60
	55	267	175	334	195
	56	170	145	133	128
	57	185	193	83	68
	58	185	204	160	125
	59	223	220	195	175
Non-Injured	60	238	214	168	185
	61	135	185	120	95
	62	293	214	160	166
	63	148	211	153	214
	64	108	96	82	83
	65	158	96	140	138
	66	120	180	130	135
	67	116	135	180	190
	68	274	334	240	245
	69	255	264	188	233
WRESTLING					
Injured	70	200	250	207	355
Non-Injured	71	260	178	188	166
	72	243	238	160	166
	73	103	125	158	108
	74	238	214	160	214
	75	173	185	145	153
	76	185	185	195	145
	77	145	175	125	133
	78	200	175	180	140
	79	228	214	267	255
	80	190	188	185	203

*Score in Pounds

APPENDIX C

STRENGTH IMBALANCE BETWEEN THE KNEE EXTENSORS

FOR INJURED AND NON-INJURED GROUPS

Sample	Subject Number	Mean % of Diff.
BASEBALL		
Injured	1	6
	2	23
	3	0
	4	30
Non-Injured	5	9
	6	22
	7	3
	8	17
	9	6
	10	3
	11	6
	12	8
BASKETBALL		
Injured	13	6
	14	22
	15	7
Non-Injured	16	27
	17	7
	18	13
	19	11
	20	36
	21	10
	22	31
	23	21
	24	8
FOOTBALL		
Injured	25	9
	26	5
	27	11
	28	0
	29	16
	30	1
	31	1
	32	1
	33	29
Non-Injured	34	11
	35	19
	36	18
	37	2
	38	12
	39	4
	40	9
	41	12
	42	4
	43	24
	44	1
	45	14
	46	16
FOOTBALL (Continued)		
	47	0
	48	0
	49	1
	50	38
	51	6
TRACK-FIELD		
Injured	52	13
	53	2
	54	21
	55	34
	56	15
	57	4
	58	9
	59	1
Non-Injured	60	10
	61	27
	62	27
	63	30
	64	11
	65	39
	66	33
	67	14
	68	18
	69	3
WRESTLING		
Injured	70	20
Non-Injured	71	32
	72	2
	73	18
	74	10
	75	6
	76	0
	77	17
	78	13
	79	6
	80	1

APPENDIX D

STRENGTH IMBALANCE BETWEEN THE KNEE FLEXORS

FOR INJURED AND NON-INJURED GROUPS

Sample	Subject Number	Mean % of Diff.
BASEBALL		
Injured	1	7
	2	1
	3	8
	4	51
Non-Injured	5	27
	6	23
	7	8
	8	9
	9	16
	10	32
	11	4
	12	6
BASKETBALL		
Injured	13	19
	14	7
	15	6
Non-Injured	16	10
	17	1
	18	5
	19	1
	20	29
	21	2
	22	0
	23	9
	24	7
FOOTBALL		
Injured	25	26
	26	20
	27	8
	28	7
	29	7
	30	3
	31	5
	32	1
	33	12
Non-Injured	34	7
	35	7
	36	4
	37	9
	38	8
	39	3
	40	22
	41	11
	42	17
	43	4
	44	5
	45	9
	46	7

Sample	Subject Number	Mean % of Diff.
FOOTBALL (Continued)		
	47	25
	48	1
	49	9
	50	16
	51	15
TRACK-FIELD		
Injured	52	3
	53	17
	54	47
	55	42
	56	4
	57	18
	58	22
	59	10
Non-Injured	60	9
	61	21
	62	4
	63	29
	64	1
	65	1
	66	4
	67	5
	68	2
	69	19
WRESTLING		
Injured	70	42
Non-Injured	71	12
	72	4
	73	32
	74	25
	75	5
	76	26
	77	6
	78	22
	79	4
	80	9

APPENDIX E

BILATERAL MUSCLE STRENGTH IMBALANCE FOR INJURED AND NON-INJURED GROUPS

Sample	Subject Number	Mean % of Diff.
BASEBALL		
Injured	1	0
	2	13
	3	4
	4	40
Non-Injured	5	17
	6	23
	7	5
	8	5
	9	4
	10	18
	11	5
	12	2
BASKETBALL		
Injured	13	11
	14	14
	15	7
Non-Injured	16	20
	17	3
	18	10
	19	6
	20	15
	21	5
	22	15
	23	10
	24	3
FOOTBALL		
Injured	25	18
	26	12
	27	2
	28	3
	29	11
	30	2
	31	3
	32	1
	33	8
Non-Injured	34	2
	35	8
	36	8
	37	5
	38	10
	39	0
	40	16
	41	12
	42	11
	43	13
	44	2
	45	4
	46	13

Sample	Subject Number	Mean % of Diff.
FOOTBALL (Continued)		
	47	12
	48	0
	49	3
	50	29
	51	10
TRACK-FIELD		
Injured	52	5
	53	9
	54	32
	55	38
	56	10
	57	3
	58	5
	59	6
Non-Injured	60	2
	61	9
	62	16
	63	29
	64	6
	65	21
	66	21
	67	9
	68	11
	69	11
WRESTLING		
Injured	70	33
Non-Injured	71	23
	72	0
	73	11
	74	7
	75	6
	76	13
	77	12
	78	17
	79	5
	80	4

APPENDIX F

KNEE FLEXOR-EXTENSOR STRENGTH RATIO FOR INJURED AND NON-INJURED GROUPS

Sample	Subj. No.	Right Leg*	Left Leg	Mean Both
BASEBALL				
Inj.	1	93	107	100
	2	81	105	93
	3	106	97	102
	4	84	59	71
Non-Inj.	5	70	87	78
	6	72	72	72
	7	97	92	95
	8	111	84	98
	9	90	71	80
	10	84	119	102
	11	82	84	83
	12	96	83	90
BASKETBALL				
Inj.	13	63	73	68
	14	125	105	115
	15	90	89	89
	16	83	68	75
Non-Inj.	17	97	89	93
	18	64	59	61
	19	79	70	75
	20	38	82	60
	21	76	67	71
	22	110	160	135
	23	54	76	65
	24	51	60	55
FOOTBALL				
Inj.	25	87	107	97
	26	74	88	81
	27	86	106	96
	28	72	67	69
	29	103	93	98
	30	97	95	96
	31	103	107	105
	32	72	71	71
	33	152	95	123
Non-Inj.	34	103	84	93
	35	91	68	80
	36	103	81	92
	37	90	97	94
	38	71	74	72
	39	147	157	152
	40	89	105	97
	41	81	80	80
	42	91	106	99

Sample	Subj. No.	Right Leg	Left Leg	Mean Both
FOOTBALL (Continued)				
	44	92	86	89
	45	94	73	84
	46	59	66	63
	47	93	70	82
	48	82	81	81
	49	69	78	73
	50	71	95	83
	51	94	85	90
TRACK-FIELD				
Inj.	52	95	112	103
	53	91	77	84
	54	91	77	84
	55	125	111	118
	56	78	88	83
	57	45	35	40
	58	86	61	74
	59	87	80	83
Non-Inj.	60	71	86	79
	61	89	51	70
	62	55	78	66
	63	103	101	102
	64	76	86	81
	65	89	144	116
	66	108	75	92
	67	155	141	148
	68	88	73	80
	68	74	88	81
WRESTLING				
Inj.	70	103	142	123
Non-Inj.	71	72	93	83
	72	66	70	68
	73	153	86	120
	74	67	100	84
	75	84	83	83
76	76	105	78	92
	77	86	76	81
	78	90	80	85
	79	117	119	118
	80	97	108	103

*Score in Per Cent.

APPENDIX G

COMBINED FLEXOR-EXTENSOR STRENGTH OF THE STRONG AND WEAK LEG, PLUS DESIGNATION OF INJURED AND DOMINANT LEG

Sample	Subject Number	Strong Leg	Weak Leg	Injured Leg
BASEBALL				
	1	475	473*	W
	2	402	348	W
	3	402*	385	W
	4	394	238*	W
	5	426	352*	N
	6	345*	267	N
	7	355	336*	N
	8	438	418*	N
	9	514*	492	N
	10	548	447*	N
	11	384*	364	N
	12	455*	448	N
BASKETBALL				
	13	711	630*	S
	14	341	293*	W
	15	404	376*	W
	16	459	366*	N
	17	378	365*	N
	18	405	366*	N
	19	373	350*	N
	20	615*	520	N
	21	325*	308	N
	22	305*	206	N
	23	330*	296	N
	24	489	476*	N
FOOTBALL				
	25	529	436*	W
	26	348	305*	W
	27	410*	402	W
	28	335*	325	B
	29	344	305*	S
	30	468*	458	S
	31	524	508*	S
	32	398	396*	B
	33	397	365*	B
	34	411	401*	N
	35	488	449*	N
	36	443	407*	N
	37	391	370*	N
	38	393	353*	N
	39	557	556*	N
	40	522	440*	N
	41	379	335*	N
	42	453*	404	N
	43	469*	407	N
	44	447*	438	N
	45	574	552*	N

Sample	Subject Number	Strong Leg	Weak Leg	Injured Leg
FOOTBALL (Continued)				
	46	532	465*	N
	47	321*	282	N
	48	400*	398	N
	49	474*	459	N
	50	677*	483	N
	51	455*	408	N
TRACK-FIELD				
	52	386*	366	W
	53	248*	226	W
	54	256*	173	W
	55	601*	370	B
	56	303*	273	B
	57	268*	261	B
	58	345*	329	B
	59	418*	395	W
	60	406*	399	N
	61	280	255*	N
	62	453*	308	N
	63	425	301*	N
	64	190*	179	N
	65	298	234*	N
	66	315	250*	N
	67	325	296*	N
	68	579	514*	N
	69	497	443*	N
WRESTLING				
	70	605*	407	B
	71	448*	344	N
	72	404	403*	N
	73	261*	233	N
	74	428	398*	N
	75	338	318*	N
	76	380*	330	N
	77	308	270*	N
	78	380*	315	N
	79	495*	469	N
	80	391	375	N

* Indicates the dominant leg.
W Indicates injury to the weaker leg.
S Indicates injury to the stronger leg.
B Indicates injury to both legs
N Indicates no injury has occurred.

APPENDIX H

SUBJECT IDENTIFICATION NUMBER AND NAME

Subject Number	Subject Name	Subject Number	Subject Name
1	Reddell, Rusty	48	Dearinger, Tom
2	Bird, Bill	49	Cooper, Gary
3	Cross, Mike	50	Spiller, Glen
4	Tulk, Jim	51	Hardcastle, Don
5	Thompson, Frank	52	Gunther, Larry
6	Sewell, David	53	Rose, Larry
7	Massari, Dan	54	Rakoczy, Frank
8	Meyers, Charlie	55	Marks, Mike
9	Reed, Cleve	56	Cumming, Colin
10	Jacobsen, Jim	57	Martin, Chris
11	Tomkins, Harold	58	English, Geoff
12	Roney, Steve	59	Pell, Gary
13	Hopson, Andy	60	Holderman, John
14	Jeffries, Mike	61	Cole, Mike
15	Fisher, Dave	62	Manke, Mike
16	Roberts, Ray	63	Coulter, Royce
17	Kelly, Mike	64	Boatright, Charles
18	Hund, Tim	65	Halberstadt John
19	Turner, Robert	66	Harter, Reid
20	Duckett, Tom	67	Kurrasch, James
21	Fitzgerald, Kevin	68	Stevens, George
22	Clack, Jerry	69	Bartush, William
23	McCaffrey, Mick	70	Hott, John
24	Uthoff, Steve	71	Gonzales, Bernard
25	Pruss, Uwe	72	Randall, Stephen
26	Rosenthal,	73	Fujita, Yoshiro
27	Vann, Cleveland	74	Jones, Rick
28	Grimes, Mark	75	Jeffries, Sam
29	Barlett, Gary	76	Arneson, Jay
30	Jacobsen, Bert	77	Winnard, Larry
31	Bollenbach, Barry	78	Thrasher, Ron
32	Caraway, Sam	79	Mitchell, Bill
33	Cole, Bobby	80	Ferguson, Randy
34	Abel, Marty		
35	Sparks, John		
36	Smith, Jim		
37	Troutt, Jeff		
38	Toburen, Tom		
39	Devorce, Carl		
40	Looper, Stanley		
41	Briley, Tony		
42	Liddell, Mike		
43	Clapp, Matt		
44	Rivers, Rich		
45	Kilpatrick, Douglas		
46	Kennedy, Mike		
47	Bryan, Bill		

VITA

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Candidate for the Degree of

Master of Science

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