



Genu valgum : can observable or symptomatic changes occur with an exercise protocol in collegiate women?

by Jaime Erin McCafferty

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Health and Human Development

Montana State University

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Abstract:

Genu valgum, or “knock-knees”, is a structural deformity that results in knee adduction. Genu valgum and increased quadriceps (Q) angle are synonymous and lead to an increase in lower extremity injuries and painful symptoms. Women typically have larger Q angles than men, and are therefore at an increased risk for injury. There is no known exercise protocol to correct the genu valgum deformity. The primary goal of this study was to implement an exercise protocol in collegiate women who have genu valgum and measure changes. The secondary goal was to decrease symptomatic afflictions associated with genu valgum.

Eleven collegiate women volunteered to participate in the study and were divided into either a treatment (n=6) or control (n=5) group. The treatment group participated in a six-week exercise protocol meant to strengthen the hip flexors, internal and external rotators, hip abductors and adductors, and knee flexors and extensors. Lower extremity digital photographs were taken of the subjects prior to the study and following each week of treatment. Tibial Femoral Angle (TFA) and Q angle were the variables measured from the photographs. Strength measures of the targeted muscles were taken prior to the study, following week three, and at the conclusion using a Manual Muscle Tester (MMT). Subjective data was documented in the form of Visual Analog Scales (VAS).

The results of the study noted decrease in the treatment group Q angle, with more change occurring in the right leg. The TFA also improved in the treatment group, and more change was present in the right leg as well. Strength increased in the subjects performing the exercise protocol, and those who completed the protocol reported a decrease in symptoms.

In conclusion, it is reasonable to expect that a longer exercise protocol would yield greater changes in Q angle and TFA in collegiate women with genu valgum. It is likely that the strength gain experienced by the subjects was the factor in the decrease of Q angle, TFA, and symptoms. Therefore, this protocol proved to be a beginning step to correcting the appearance of genu valgum and decreasing associated symptoms in collegiate women.

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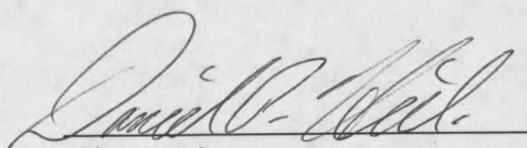
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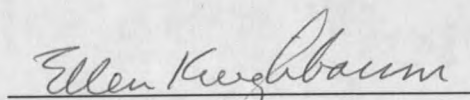
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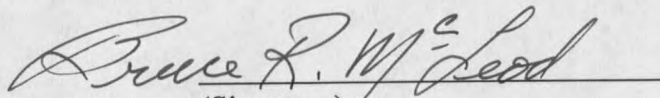
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TABLE OF CONTENTS

1. INTRODUCTION.....	1
Statement of the Problem.....	1
Primary Hypothesis.....	4
Secondary Hypothesis.....	4
Assumptions	5
Limitations	5
Delimitations	6
Operational Definitions	6
2. LITERATURE REVIEW	7
Problems Associated with GenuValgum.....	7
Quadriceps (Q) Angle and Genu Valgum.....	12
Treatment Recommendations.....	20
Surgical Procedures.....	21
Conclusion.....	28
3. METHODS	29
Subjects.....	29
Procedures.....	29
Instrumentation.....	32
Statistical Analysis	34
4. RESULTS	35
Subject Characteristics.....	35
Analysis of Quadriceps (Q) Angle Data.....	35
Analysis of Tibial Femoral Angle (TFA) Data	39
Analysis of Strength Measurement Data.....	40
Analysis of Subjective Visual Analog Scale (VAS) Data	42
Reliability Data	48
5. DISCUSSION	51
Introduction.....	51
Exercise Protocol Justification	51
Quadriceps (Q) Angle.....	52
Tibial Femoral Angle	54

Reliability Data	55
Strength Measures	56
Visual Analog Scales (VAS)	57
Subject Characteristics	57
Subject Comments	59
Further Discussion	61
6. CONCLUSION	64
GLOSSARY	66
REFERENCES CITED	69
APPENDICES	73
APPENDIX A: SIGNS AND SYMPTOMS QUESTIONNAIRES	74
APPENDIX B: EXERCISE PROTOCOL	89

LIST OF FIGURES

Figure	Page
1. Anatomical and Mechanical Axes of the Lower Extremity	2
2. "Squinting" Patella	9
3. Anatomy of the Knee Joint	11
4. Anatomical Landmarks for Establishing the Quadriceps (Q) Angle.....	15
5. The Complementary Physeal-Shaft (CPS) Angle (A) and The Tibial-Femoral Angle (TFA) (B).....	22
6. The model is demonstrating Adduction (A) and Abduction (B).....	92
7. The model is demonstrating the Active Bridge exercise.....	93
8. The model is demonstrating the Active Cobra exercise	94
9. The model is demonstrating the Assisted Hip Lift exercise	95
10. The model is demonstrating Cat (A) and Dog (B).....	96
11. The model is demonstrating the Counter Stretch exercise	97
12. The model is demonstrating the Crocodile Twist: Start Position (A) and the Crocodile Twist: End Position (B).....	98
13. The model is demonstrating the Double – Double exercise.....	99
14. The model is demonstrating the Double – Switch exercise	100
15. The model is demonstrating the Foot Circles / Point Flex exercise	101
16. The model is demonstrating the Hand – Leg Opposite Blocked exercise	102
17. The model is demonstrating the Hand – Leg Opposite Glide exercise.....	103
18. The model is demonstrating the Hip Crossover exercise.....	104

19. The model is demonstrating the Isolated Hip Flexor Lifts: Start Position (A) and the Isolated Hip Flexor Lifts: End Position (B) exercise	105
20. The model is demonstrating the Kneeling Counter Stretch exercise.....	106
21. The model is demonstrating the Kneeling Groin Stretch exercise.....	107
22. The model is demonstrating the Modified Runners Stretch.....	108
22. The model is demonstrating Pelvic Tilts.....	109
23. The model is demonstrating the Progressive Supine Groin exercise.....	110
24. The model is demonstrating Pullovers: Start Position (A) and Pullovers: End Position (B).....	111
25. The model is demonstrating Reverse Presses	112
26. The model is demonstrating the Sitting Adductor Press	113
27. The model is demonstrating the Sitting Floor exercise.....	114
28. The model is demonstrating the Sitting Floor Twist exercise.....	115
29. The model is demonstrating Sitting Heel Raises	116
30. The model is demonstrating the Squat exercise	117
31. The model is demonstrating the Static Back exercise	118
32. The model is demonstrating the Static Wall exercise	119
33. The model is demonstrating Static Wall Femur Rotations: Start Position (A) and Static Wall Femur Rotations: End Position (B).....	120
34. The model is demonstrating the Supine Gastroc/Hamstring Stretch: Start Position (A) and the Supine Gastroc Hamstring Stretch: End Position (B)	121
35. The model is demonstrating the Supine Groin Stretch.....	122
36. The model is demonstrating the Upper Spinal Floor Twist exercise.....	123

37. The model is demonstrating the Wall Drop exercise.....	124
38. The model is demonstrating the Wall Sit exercise.....	125

LIST OF TABLES

Table	Page
1. Demographic Data for the Control (n=4) and Treatment Group (n=6)	36
2. ANOVA table results for the Quadriceps Angle (QA) and Tibial Femoral Angle (TFA).....	37
3. Quadriceps Angle (QA) and Tibial Femoral Angle (TFA) Means and Standard Errors (Mean $\pm$ SE) reported for the control and treatment groups.	38
4. ANOVA table results for Strength Measure data	43
5. Strength Measure Means and Standard Errors (Mean $\pm$ SE) reported for the control and treatment groups.....	44
6. Right and left leg strength measure means and standard deviations (Mean $\pm$ SD) reported for the control and treatment groups.....	45
7. <u>Pre-Testing</u> Subjective Visual Analog Scale (VAS) Means and Standard Deviations	46
8. <u>Week Six</u> Subjective Visual Analog Scale (VAS) Means and Standard Deviations	47
9. Summary reliability data for Quadriceps (Q) Angle	49
10. Summary reliability data for Tibial Femoral Angle (TFA)	50
11. Exercise Menu for subjects classified with Internal Knees.....	90
12. Exercise Menu for subjects classified with External Knees.....	91

ABSTRACT

Genu valgum, or "knock-knees", is a structural deformity that results in knee adduction. Genu valgum and increased quadriceps (Q) angle are synonymous and lead to an increase in lower extremity injuries and painful symptoms. Women typically have larger Q angles than men, and are therefore at an increased risk for injury. There is no known exercise protocol to correct the genu valgum deformity. The primary goal of this study was to implement an exercise protocol in collegiate women who have genu valgum and measure changes. The secondary goal was to decrease symptomatic afflictions associated with genu valgum.

Eleven collegiate women volunteered to participate in the study and were divided into either a treatment (n=6) or control (n=5) group. The treatment group participated in a six-week exercise protocol meant to strengthen the hip flexors, internal and external rotators, hip abductors and adductors, and knee flexors and extensors. Lower extremity digital photographs were taken of the subjects prior to the study and following each week of treatment. Tibial Femoral Angle (TFA) and Q angle were the variables measured from the photographs. Strength measures of the targeted muscles were taken prior to the study, following week three, and at the conclusion using a Manual Muscle Tester (MMT). Subjective data was documented in the form of Visual Analog Scales (VAS).

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INTRODUCTION

Statement of the Problem

One of the most common deformities in the knee joint is genu valgum, and has been cited to be more common among women (Hoppenfeld, 1976 & Livingston, 1998). Genu valgum, or “knock-knees” is defined as a structural abnormality of the alignment of the femur on the tibia (Hoppenfeld, 1976). It is characterized by lateral rotation of the femurs, hyperextension of the knees, and pronation of the feet, and all of these factors contribute to adduction of the knees (Kendall, McCreary, & Provance, 1993) (Figure 1).

A correlation between genu valgum and an increased quadriceps (Q) angle has been observed. In addition to an increased Q angle, flat feet, patellofemoral pain, thigh and hip muscular weakness, medial joint stress, medial joint instability, and an increased risk for anterior cruciate ligament (ACL) injuries have been discussed in conjunction with genu valgum (Starkey & Ryan, 1996 and Arnheim & Prentice, 2000). Byl, Cole, and Livingston (2000) stated their investigation supported the common observation that women, on average, have larger Q angles than men do. Lathinghouse and Trimble (2000) also stated that women have consistently been found to have larger Q angles than men, and are more often affected by patellofemoral problems. The National Collegiate Athletic Association (NCAA) reported data indicating collegiate women basketball players were four times more likely to sustain an ACL injury than their male counterparts (Moeller & Lamb, 1997).

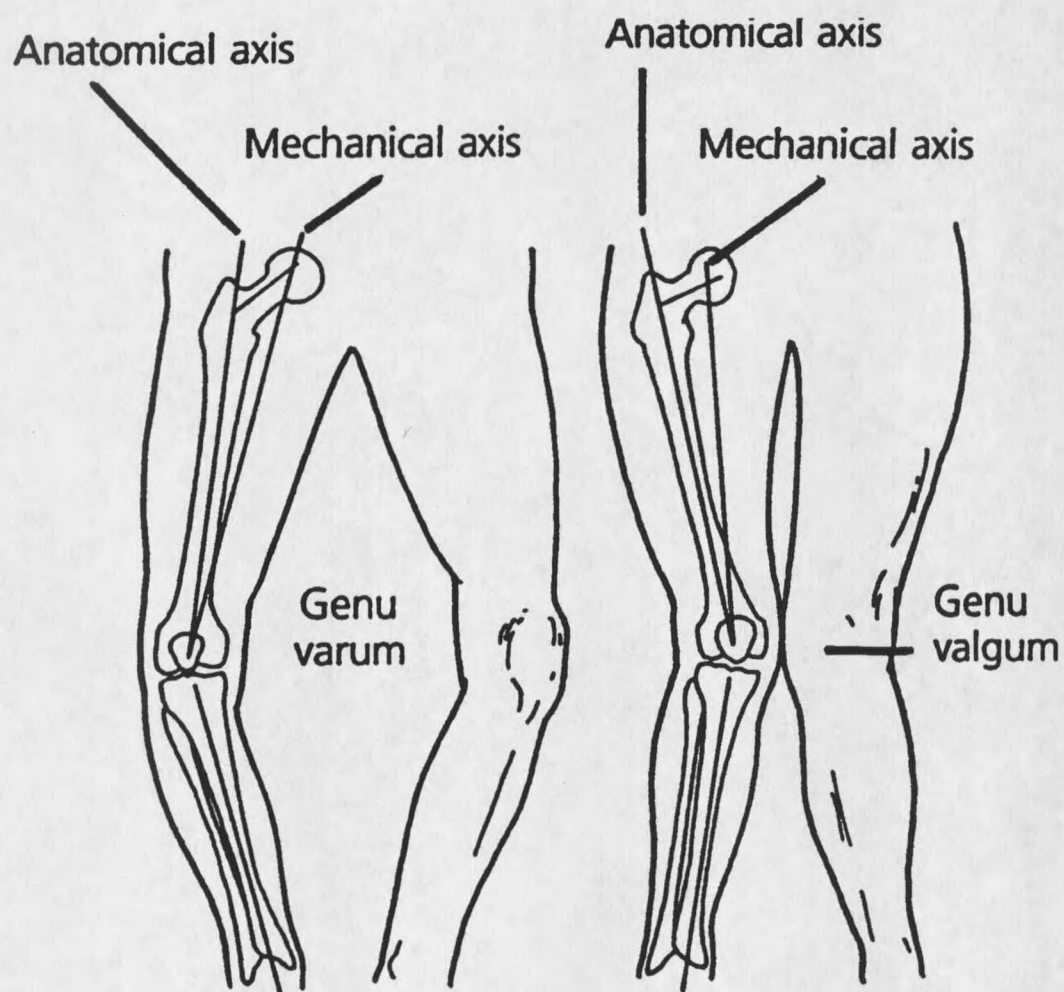


Figure 1. Anatomical and Mechanical Axes of the Lower Extremity.

Current treatment for the genu valgum deformity ranges from physical therapy to surgery. It is the purpose of this study to explore a physical therapy program to correct genu valgum in collegiate women, and it is believed by the researcher that a six week individualized exercise program will decrease the visual appearance of genu valgum in the subjects studied. The exercise program will consist of exercises concentrating on strengthening hip flexors, hip abductors and adductors, hip internal and external rotators, hamstring muscle group, and quadriceps muscle group. Within the reviewed literature, it is stated that muscular weakness may be present in people with genu valgum (Kendall et al., 1993). Weakness of the medial hamstring muscles leads to a decrease in stability of the medial knee joint, and because of this weakness, a genu valgum position of the knee is allowed and tendency for lateral rotation of the leg on the femur is present (Kendall et al., 1993). Kreighbaum and Barthels (1996) stated that strengthening should take place in order to correct this malalignment. On the premise that exercise should be implemented to correct the genu valgum deformity, a study should be conducted to determine whether exercises could provide an anatomical change in the deformity. The physical therapy option for treating genu valgum should be researched in order to arrive at an alternative to surgery, which may have complications, unsuccessful results, and can be costly. All other treatments, excluding surgery, do not attempt to change the biomechanics of genu valgum, but to provide symptomatic relief. It is the intent of this study to determine if exercise can correct the anatomical deformity of genu valgum. Any symptomatic relief that occurs as a result of the exercise protocol is secondary to the purpose of the study.

Primary Hypothesis

It is hypothesized that the group of subjects who perform the exercise protocol (treatment group) will have a decrease in the anatomical appearance of genu valgum, whereas the control group will have no change in the appearance of genu valgum.

$$H_0: \Delta M_C = \Delta M_T = 0$$

$$H_A: \Delta M_C = 0, \text{Pre } M_T > \text{Post } M_T$$

The notations of M_C and M_T are the mean population values for the appearance of genu valgum in the control and treatment groups, respectively. A decrease in anatomical appearance correlates with a decrease in the quadriceps (Q) angle measurement and an increase in the tibial femoral angle (TFA). The TFA will be closer to 180° than the baseline measurement.

Secondary Hypothesis

It is hypothesized that there may, in fact, be no change in symptoms of genu valgum in the treatment group following the treatment protocol.

$$H_0: \Delta M_{SC} = \Delta M_{ST} = 0$$

$$H_A: \Delta M_{SC} = 0, \text{Pre } M_{ST} > \text{Post } M_{ST}$$

The notations of M_{SC} and M_{ST} are the mean population values for the symptoms of genu valgum in the control and treatment groups, respectively. It is possible that symptoms of genu valgum may be alleviated without a decrease in the degree of deformity. Symptoms of genu valgum generally include pain of the hip, medial and lateral

knee, lower legs, ankles, and feet. The visual analog scales (VAS) in the signs and symptoms questionnaires will address symptomatic relief that may result from the treatment for genu valgum. The VAS measurements will be used to gain subjective information indicating any change in symptomatic problems associated with genu valgum.

Assumptions

It is assumed that all subjects will adhere to the guidelines of the study and will comply with the protocols set by the researcher. Also, an assumption is made regarding genu valgum. It is assumed that every day activities do not affect the degree of deformity, but do have an impact by increasing symptoms.

Limitations

This study is dependent on those who volunteer for the study, and this may result in difficulties gaining an adequate number of subjects. The degree of genu valgum is expected to vary within the subjects, and it is also expected that differences will be present in signs, symptoms, and fitness habits. All subjects will not be identical. The design of the study implements a short duration of intervention. It is acknowledged that this short duration may only yield minor results.

Delimitations

The method of gaining the subjects is not a true random sample, since it only draws upon people who volunteer from Montana State University in Bozeman, Montana. The findings of this study can only be applied to collegiate women.

Operational Definitions

- Control Group:* A group of subjects who will not participate in the exercise protocol.
- Genu valgum:* Knock-knees; a deformity of the knee where the femur and tibia are angled inward.
- Quadriceps (Q) angle:* An angle formed by the intersection of a line from the anterior superior iliac spine to the midpatella and another line from midpatella to the tibial tuberosity; an angle of 15° or less is considered normal (Booher & Thibodeau, 1994).
- Tibial femoral angle (TFA):* The angle formed by the anterior view of the tibial shaft and the femoral shaft where the average alignment is 180-195°.
- Treatment Group:* A group of subjects who will participate in the exercise protocol.
- Visual analog scale (VAS):* a subjective measure of symptoms associated with genu valgum.

LITERATURE REVIEW

Problems Associated with Genu Valgum

Genu valgum, commonly referred to as “knock-knees”, is a structural abnormality that is noted by the alignment of the femur on the tibia. Knock-knees and bowlegs (genu varum) are two of the most common deformities of the knee joint (Hoppenfeld, 1976). Knock-knees result from a combination of factors including lateral rotation of the femurs, hyperextension of the knees, and pronation of the feet. Also, the axis of the knee joint runs oblique to the coronal plane, so combining the axis of the knee joint with hyperextension leads to adduction at the knees, a common trait associated with genu valgum (Kendall, McCreary, & Provance, 1993). Imagine that a line passing through the femoral and tibial shafts ranges from 180-195° in average alignment. An angle less than 180° is considered genu valgum (Starkey & Ryan, 1996). Genu valgum may be observed without diagnostic imaging, although arthritic changes may be noted in roentgenograms. Hoppenfeld (1976) stated that the valgus angle is usually more pronounced in females.

An increase in compressive forces on the lateral tibiofemoral articulating surfaces occurs as a side effect of genu valgum, along with tensile forces on the medial tibiofemoral ligaments (Starkey & Ryan, 1996). Lateral tracking of the patella, compressive forces of the lateral facet, and stretching of the medial patellar restraints also occur with genu valgum (Starkey & Ryan, 1996). Arnheim and Prentice (2000) stated that pronated feet, chronic tension on medial ligaments of the knee, abnormal

compression of the lateral knee, and abnormal tightness of the iliotibial band are commonly associated with genu valgum. Hip external rotator weakness was also noted in people with genu valgum (Arnheim & Prentice, 2000). Weakness of the medial hamstring muscles, the semitendinosus and semimembranosus, leads to a decrease in stability of the medial joint line of the knee (Kendall et al., 1993). This weakness permits a knock-knee position and a tendency toward lateral rotation of the leg on the femur. Shortness of the tensor fasciae latae muscle can be associated with genu valgum as well (Kendall et al., 1993). In an attempt to correct this malalignment, the muscles that stabilize the knee from abduction, the quadriceps in particular, should be strengthened (Kreighbaum & Barthels, 1996).

The angle of inclination is the angular relationship of the femoral head and the femoral shaft, and can be determined roughly by observing the correlation between the femur and the tibia. A decrease in the angle of inclination, coxa vara, may lead to genu valgum or "squinting" patella. "Squinting" patella occurs secondary to an internal rotation of the lower extremity and is noted by medially positioned patellae on the femur. The patellae appear to be looking at one another while the feet are pointed straight ahead (Starkey & Ryan, 1996) (Figure 2).

One of the problems associated with genu valgum is increased tension on the medial ligaments of the knee (Shahane & Bickerstaff, 1997). The medial collateral ligament (MCL) of the knee consists of two parts, with the more superficial portion being the primary inhibitor of external tibial torsion and tibial abduction. This portion

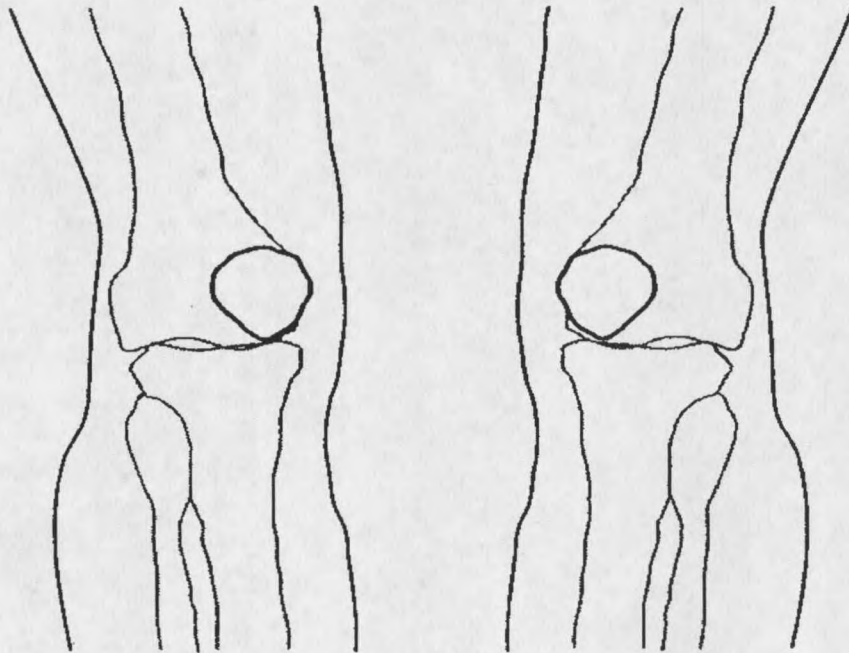


Figure 2. "Squinting" Patella.

of the MCL is strongest from 15-90° of flexion. The deep portion is much weaker and smaller, however, it serves to attach the medial meniscus to the femur and tibia.

Excessive genu valgum is likely to impose considerable strain on the proximal femoral attachment of the MCL (Shahane & Bickerstaff, 1997).

Genu valgum is said to be an anatomic risk factor for anterior cruciate ligament (ACL) injuries as well (Griffin et al., 2000). Hip varus, foot pronation, and hip rotation are also said to be a possible anatomic risk factor for ACL injuries. The correlation

between ACL injuries and genu valgum has not been fully explored, but is currently under examination (Griffin et al., 2000). In order to visualize the increased stress that femoral rotation can place on the ACL, refer to Figure 3, which presents the anatomy of the knee joint.

Genu valgum is a risk factor for developing patellofemoral pain because the alignment of the tibia on the femur predisposes the patella for malalignment and patellar tracking abnormalities (American Academy of Orthopedic Surgeons, 1991). Genu valgum is said to increase the valgus sector of the knee, therefore increasing the risk for patellar subluxations or dislocations (AAOS, 1991). Also, patellofemoral pain can be associated with pes planus (flat feet), which usually occurs simultaneously with genu valgum. The patellofemoral syndrome is a generalized term and refers to a group of conditions that produce pain beneath or surrounding the patella. Any factor within the knee that disrupts normal patellar tracking can result in inflammation and pain to the undersurface of the patella. Malalignment of the patellofemoral joint may contribute to the development or the severity of pain (Tomsich, Nitz, Threlkeld, & Shapiro, 1996). Since an individual with genu valgum has a tendency towards having excessive pronation of the feet, or "fallen arches", it is likely that heel spurs may begin to form and cause pain. A heel spur is defined as a bony projection on the sole (plantar) region of the calcaneous, or heel bone (Feeny, 1997). The excess bone that is formed when making this bony projection is most likely the result of painful tearing of the plantar fascia on the plantar aspect of the foot.

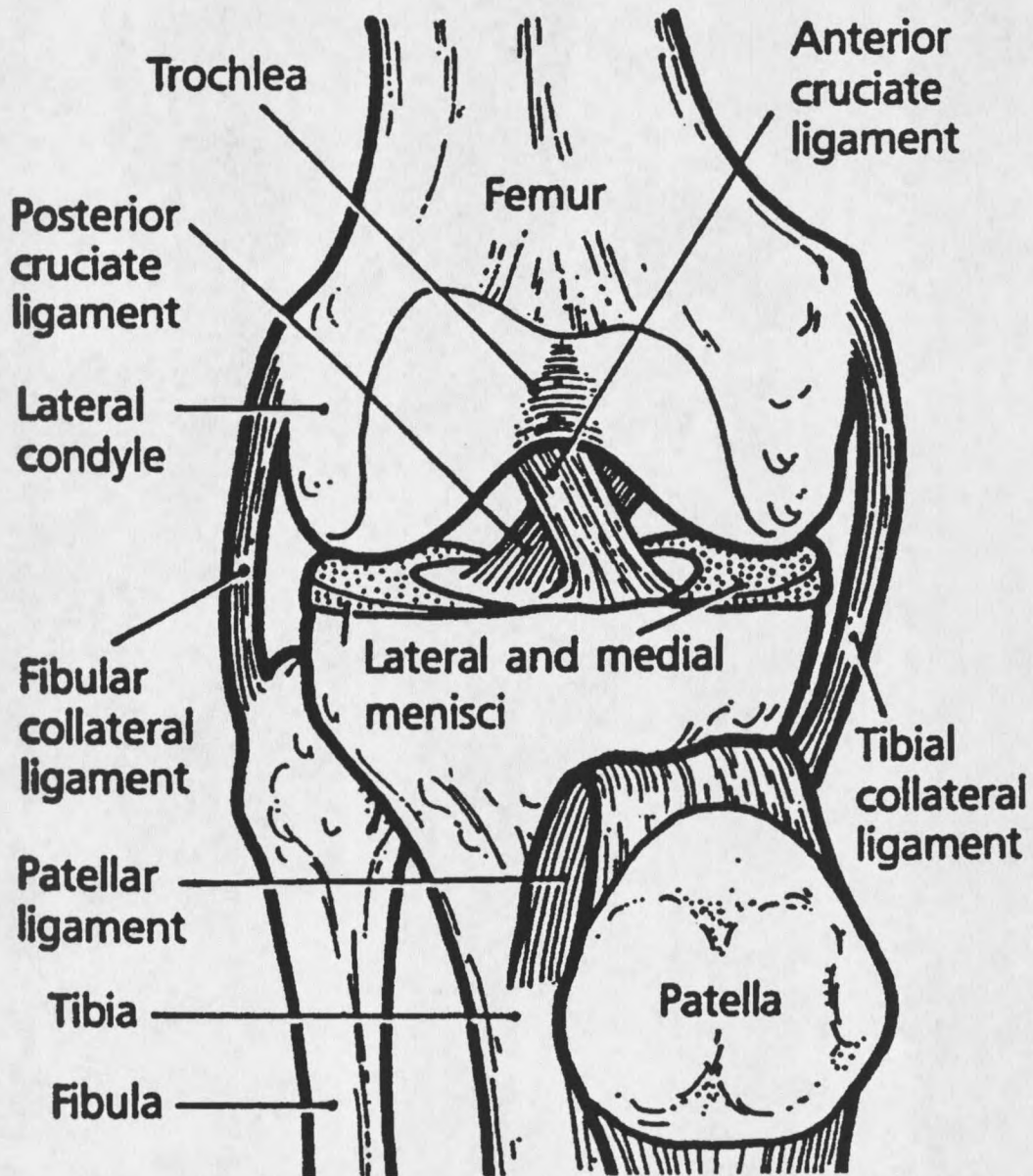


Figure 3. Anatomy of the Knee Joint.

Quadriceps (Q) Angle and Genu Valgum

Liss and Liss (2000), physicians from the Physical Medicine and Rehabilitation Center in Pennsylvania, wrote an informative article regarding patellofemoral pain and the quadriceps (Q) angle. These physicians stated that genu valgum is included within what is known as the malicious malalignment syndrome. The malicious malalignment syndrome is characterized by excessive internal rotation of the hips, genu valgus, pes planus, and an increased Q angle (Liss & Liss, 2000). The Q angle is the angle between a line drawn through the tibia and a line drawn through the anterior superior iliac spine (ASIS) and the patella (Liss & Liss, 2000). An increased Q angle of more than 19° increases the risk of patellofemoral pain, and this increased angle puts additional stress on the knees during the motions of flexion and extension resulting in increased symptoms because of disruption to normal tracking mechanisms (Liss & Liss, 2000).

The present treatment for patellofemoral pain has been strengthening of the quadriceps muscles, which will decrease the initial stress placed on the patella and thus reducing pressure behind the patella and improving patellar tracking. Liss and Liss (2000) stated this method is still controversial. In most studies, simple isometric strengthening results in reduction or elimination of symptoms in 70-80% of patients (Liss & Liss, 2000). Along with exercises, taping of the patella to reduce mechanical problems with patellar tracking has also been implemented (Liss & Liss, 2000). Although this technique can be justified biomechanically, more studies need to be conducted to confirm the actual benefit (Liss & Liss, 2000).

Since the issue of performing quadriceps exercises is still controversial, Boucher, King, Lefebvre, and Pepin (1992) conducted a study to determine whether terminal extension rehabilitation of the vastus medialis was appropriate, and to try to dissociate neuromuscular and mechanical mechanisms that underlie patellofemoral pain syndrome. The vastus medialis oblique (VMO) is the quadriceps muscle that has mainly been focused on in the rehabilitation of patellofemoral pain (Boucher et al., 1992). Traditionally, it is believed that the VMO is the most active in the final degrees of extension (terminal extension) of the knee. Symptoms of patellofemoral pain include diffuse knee pain, loss of motion, swelling, a sensation of instability, and pain with or without activity. Boucher et al. (1992) studied 18 female subjects and placed them into two groups based upon the knee Q angle and a diagnosis of patellofemoral pain syndromes from a physician. The control group was asymptomatic and had a normal Q angle. The other group was diagnosed with patellofemoral pain syndrome and had an increased Q angle. All were tested for isometric knee extension at 90°, 30°, and 15° of knee flexion. Electromyography (EMG) was utilized to test muscle activity of the long fibers and the oblique fibers of the vastus medialis. All other quadriceps muscles were noted between groups or between the three angles mentioned earlier. Therefore, the authors suggested that all the vasti measured were consistently active throughout the entire studied range of motion. Boucher et al. (1992) came to the conclusion that the neural drive was not affected with the patellofemoral patients. However, when the five patients that had the largest Q angles were compared, they had a significantly smaller vastus medialis oblique: vastus lateralis ratio. The researchers also revealed that the

patients with patellofemoral syndrome had a less active vastus medialis relative to the vastus lateralis as showed by the EMG's. In reference to biomechanical problems, Boucher et al. (1992) said a knee or ankle malalignment could put the vastus medialis in such a mechanical position that its contribution would be minimized. If the mechanical alignment is allowed to deteriorate further, it could result in increased symptoms. Thus, it was concluded that rehabilitation strategies should include a mechanical management and a functional or neuromuscular management (Boucher et al., 1992).

Livingston (1998) wrote a paper to present a review of the current literature on the quadriceps (Q) angle. Livingston (1998) defined the Q angle by drawing an imaginary line from the anterior superior iliac spine to the center of the patella and from the center of the patella to the middle of the anterior tibial tuberosity (Figure 4). These landmarks are easily palpable and have been the landmarks used in all measurement procedures. However, the methods of measuring the Q angle have not been standardized (Livingston, 1998). A Q angle greater than 15-20° is thought to contribute to knee extensor dysfunction and patellofemoral pain. An increased Q angle is defined as an anatomic risk factor ranging from 0.2° to 1.3°, when the measurements were taken from a supine to a standing position.

In regards to the differences between the male and female Q angle, overwhelming evidence existed that indicated young adult women have a greater mean Q angle than males. The difference between men and women ranged from 2.7°-5.8° in the supine position and 3.4°-4.9° in the standing position (Livingston, 1998). Livingston (1998)

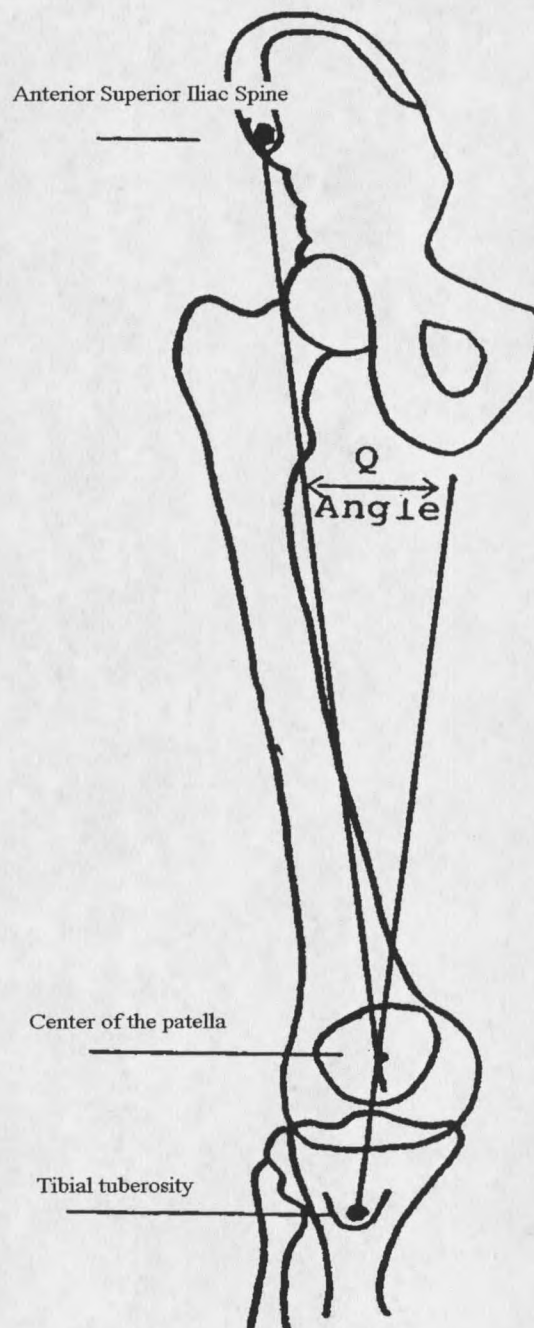


Figure 4. Anatomical Landmarks for Establishing the Quadriceps (Q) Angle.

concluded that on average, women have a Q angle 2.0° - 8.5° greater than men, and no studies were located that stated young men had a larger Q angle than young adult women. There is very little evidence within the reviewed literature that suggested that a Q angle in excess of 15 - 20° caused conditions of the extensor mechanism or patellofemoral joint by itself (Livingston, 1998).

The purpose of the study conducted by Woodland and Francis (1992) was to determine the average mean Q angles for college-aged men and women. They also wanted to compare the differences in Q angle measurements in supine and standing positions. Measurements of 269 men and 257 women were taken with a modified goniometer in both the standing and supine positions. Woodland and Francis (1992) stated that a high Q angle is clinically relevant because of an increase risk for chondromalacia and patellar tracking dysfunction. Most clinicians measure Q angle in the supine position, with measurements taken in the standing position as their second choice (Woodland & Francis, 1992). The mean Q angle for all subjects in both positions was 14.7° (7 - 27° range) with a standard deviation of 3.2° . Defining an abnormally high Q angle in subjects is somewhat subjective, but the abnormally high measures of greater than 20° for women was used because this is what has been reported in the literature (Woodland & Francis, 1992). The difference between the standing and supine measurement positions in both men and women was relatively small. In women, the difference was 1.2° , while in men, the difference was 0.9° with the higher values occurring in the standing position (Woodland & Francis, 1992). Woodland and Francis

(1992) stated that the difference found between standing and supine measurements are so small that it could be of no practical importance, and that the differences are most likely due to weightbearing factors and the presence of foot pronation or supination in the individuals tested. These factors were not investigated during their study. In further support of the findings of Woodland and Francis (1992), Shambaugh, Klein, and Herbert (1991) studied the structural measures of the lower extremity and injury correlation in male basketball players. They found a significant relationship between the Q angle measures in the players who were injured and those who did not sustain an injury throughout the course of their season. All measures in the injured subjects had larger Q angles than the average, or the subjects who did not sustain injuries. The non-injured Q angle values were (Mean $\pm$ SD) $10 \pm 2.5^\circ$ in the right leg and $9.7 \pm 2.4^\circ$ in the left leg. This was determined as the average value for men in this study. The injured subjects had Q angle values of (Mean $\pm$ SD) $14.1 \pm 3.5^\circ$ in the right leg and $12.6 \pm 3.3^\circ$ in the left leg (Shambaugh, Klein, & Herbert, 1991).

Abnormal tracking of the patella is the most commonly accepted cause of patellofemoral joint pain (Lathinghouse & Trimble, 2000). Lateral subluxation of the patella can be predicted by the measurement of the Q angle, which represents the resultant force of the quadriceps femoris muscle group on the patella (Lathinghouse & Trimble, 2000). An increased Q angle creates a lateral pull on the patella which, in turn, places the patella at a greater risk for lateral displacement during firing of the quadriceps muscle group. The magnitude and the tendency for lateral displacement is believed to

increase as the Q angle increases (Lathinghouse & Trimble, 2000). Average values for the Q angle in women is said to be between 14° and 17° . The increased Q angle in females may be attributed to an increased pelvic width, shorter femur length, or femoral neck anteversion (Lathinghouse & Trimble, 2000). Lathinghouse and Trimble (2000) conducted a study in regards to Q angle and quadriceps activation, and the purpose was threefold. First, the researchers wanted to confirm that a change in Q angle occurred with isometric quadriceps activation (IQA). Second, to determine if the decrease in the Q angle with IQA is related to the magnitude of the Q angle at rest, and third, to discover if an intense bout of exercise utilizing the quadriceps affects the Q angle measurement during IQA. The results for the first purpose was that the Q angle does, in fact, decrease with IQA. This finding was in agreement with a study conducted by Guerra, Arnold, and Gajdosik (1994). In answer to the second purpose of the study, it was found that the amount of decrease with IQA increases as the magnitude of the Q angle in relaxed standing position increases. Lathinghouse and Trimble (2000) thus concluded that an excessive Q angle may predispose women to greater lateral displacement of the patella during intense exercise in which the quadriceps muscle group is stressed.

The purpose of the study conducted by Byl, Cole, and Livingston (2000) was to discover what determines the magnitude of the quadriceps angle. Greater valgus orientation of the knee has been said to be a predisposing factor for increased Q angles, and therefore, the study was to examine the relationship between bilateral measurements of the Q angle and selected skeletal (pelvic breadth and femur length) measures. At the conclusion of the study, Byl et al. (2000) stated that there appeared to be little evidence to

support the often cited assumption that women have larger Q angles than men because of wider pelvises and shorter femurs. The shorter femur explanation is perhaps more appealing because women do tend to have shorter femurs than men do on average (Byl et al., 2000). The results of this study supported a previous study by Hahn and Foldspang (1997) that stated the Q angle magnitude is related to the strength of the quadriceps muscle group; the stronger the quadriceps, the smaller the Q angle.

Hypertrophy of the quadriceps muscle group can contribute to a reduction in the Q angle and recent observation displayed lower Q angle values in the stronger, dominant lower limb which lead to increased quadriceps strength (Beidert & Gruhl, 1997). Powers (1998) reported that although quadriceps strengthening produces successful clinical results in the treatment of patellofemoral pain, the mechanism by which symptoms are reduced and functional ability is improved has not been established. It is possible that small reductions in lower limb alignment, brought about by quadriceps training programs might help alleviate patellofemoral pain. However, this theory has not been fully investigated (Powers, 1998).

Cowen et al. (1996) conducted a study on the risk of overuse injuries among male infantry trainees. It was found that 41% of those who were defined as having genu valgum had occurrences of overuse injuries compared with 22% of trainees who had asymptomatic knees. Overuse injuries encompasses injuries that occur over a period of time and are chronic. Examples of an overuse injury would be patellar tendonitis or lower leg stress fractures. The key finding of this study was that anatomic variants of the

lower extremity (genu valgum, increased Q angle) were associated with elevated risk of some types of overuse injury. The trainees with genu valgum experienced more overuse injuries and those with an increased Q angle were more prone to stress fractures (Cowen et al., 1996).

Heiderscheit, Hamill, and Van Emmerik (1999) stated that alignment of the lower extremity has often been implicated as a potential cause of running injury. An increased Q angle was suggested to produce excessive foot pronation or rearfoot eversion. This could then cause disruption in patellofemoral tracking and lead to a pain syndrome (Heiderscheit et al., 1999). The purpose of this study was to examine the influence of the Q angle on the variability of lower extremity segment coordination during running. The subjects were divided into a low Q angle group (LQ) and a high Q angle group (HQ), and all subjects were healthy. It was discovered that the variability in the lower extremity of the LQ and the HQ would indicate that the Q angle magnitude had an influence on running kinematics. Since this study utilized healthy subjects, the authors noted that coordination differences may be present between subjects with and without lower extremity pathologies.

Treatment Recommendations

Treatment recommendations for genu valgum have included restriction of activities, anti-inflammatory medications, physical therapy, orthotics, epiphysiodesis, and osteotomy (Stevens, Maguire, Dales, & Robins, 1999). Simply implementing shoe

corrections has usually treated knock-knee conditions ranging from the mild to moderate. Bracing or even surgery may be required for the more severe conditions (Kendall et al., 1993). Lysholm, Nordin, and Ekstrand (1984) stated that bracing may give some symptomatic relief, but bracing is ineffective for changing the knee alignment or stabilizing the patellofemoral joint. Sports participation increased the symptoms of genu valgum, and physical therapy, including stretching and strengthening exercises, did not have a lasting effect on these symptoms either (Stevens, et al., 1999). The history of adolescent genu valgum is not benign, and spontaneous improvement in the condition is unlikely to occur. The symptoms associated with genu valgum may predispose degenerative problems in the anterior and lateral compartments of the knee after maturity (Stevens et al., 1999). Since surgery has been decided as an option for treating genu valgum, it is important to investigate the procedures that are being utilized. The success rate and the satisfaction of the patient following their operation also need to be addressed.

Surgical Procedures

The purpose of the study conducted by McCarthy, Kim, and Eilert (1998) was to compare results of operative treatment versus nonoperative treatment of posttraumatic genu valgum. All of the patients in the study were diagnosed with genu valgum following a proximal tibial fracture, and the tibial fracture occurred before the age of ten years. A nonoperative group was formed to serve as the control group. The operative group composed of patients who underwent an operative procedure (osteotomy) to attempt to correct posttraumatic genu valgum. The degree of genu valgum was measured

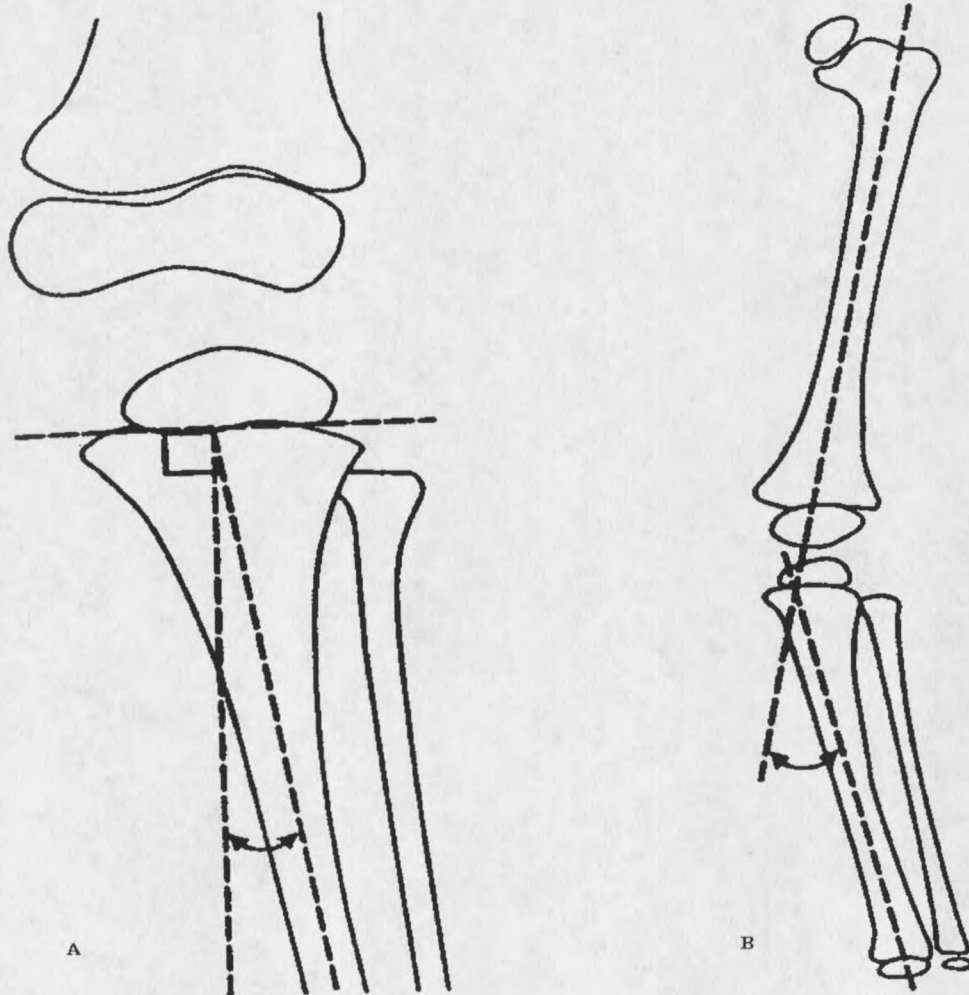


Figure 5. The Complementary Physeal-Shaft (CPS) Angle (A) and The Tibial-Femoral Angle (TFA) (B).

by the complementary physal-shaft (CPS) angle and by the tibial femoral angle (TFA). The CPS angle is the angle formed between a line drawn along the axis of the tibia and a line perpendicular to the proximal tibial physis (Figure 5A). The TFA is the angle formed by a line drawn along the long axis of the tibia and a line drawn along the long axis of the femur (Figure 5B) (McCarthy et al., 1998). However, Balthazar and Pappas (1984) opposed operative treatment for posttraumatic genu valgum. They reviewed nine cases of posttraumatic genu valgum and came to the conclusion that all of them had either a reoccurrence of the deformity or a poor outcome (Balthazar & Pappas, 1984). McCarthy et al. (1998) arrived at similar conclusions. They found that the operative group had slight improvement in the complementary physal-shaft (CPS) angle compared to the nonoperative group, and they found absolutely no difference in the tibial-femoral angle (TFA). Therefore, nonoperative treatment and observation provided as good an outcome as operative treatment of posttraumatic genu valgum.

Edgerton, Mariani, and Morrey (1993) conducted a follow up study of 23 patients that received a femoral varus osteotomy, another surgical procedure utilized in treating genu valgum. The painful genu valgum presented in this study was attributed to osteoarthritis in all of the patients. The follow up of operative procedures occurred from five to eleven years following operation and the surgeries took place from 1978 until 1984. Complications arose in 63% of the cases. Nonunion of the surgery took place in 25% of the cases and a loss of correction happened in 21%. In the follow up evaluations conducted by the authors, 13% of the knees had been converted to a total knee replacement. However, subjectively, 75% of the patients were satisfied with or believed

they benefited from the procedure (Edgerton et al., 1993). In the roetgenografic evaluations of the study, the mean tibial femoral angle, or the anatomical axis, was measured at 18° valgus before surgery and 1° valgus post operation. A total of fourteen knees were corrected surgically to a tibial femoral angle of 0° or varus. Only 60% of the knees left in some degree of valgum had satisfactory results (Edgerton et al., 1993). Another finding of the study was that those subjects with a 20° valgus (12 subjects), only seven of twelve (58%) were satisfied with the results of the surgery. In conclusion, the authors stated that many complications did occur, but were mostly due to the fact that staple fixation was a dominant mode of fixation used at their institution of medicine at the time the study was conducted.

According to Edgerton et al. (1993), the usage of staples in a femoral osteotomy is inappropriate. They suggested a stronger, more stable method, such as blade plates, compression plates, and side screws. Finkelstein, Gross, and Davis (1996) stated that when an osteotomy is to be performed on a knee with valgus deformity, a varus osteotomy is the procedure of choice. This group of researchers previously reported results of varus osteotomy of the distal part of the femur in people with osteoarthritis associated with genu valgum (Finkelstein, Gross, & Davis, 1996). At an average of four years post operatively, 22 of the 24 knees had a good or excellent result. They did not, however, conduct a follow-up study after a longer period of time to discover if these results remained the same. The purpose of the study was to review the long-term results after varus osteotomy of the distal aspect of the femur.

Finkelstein et al. (1996) used subjective and objective scoring for each patient. Points were assigned to pain, instability, ability to climb stairs, etc. Anteriorposterior x-rays were taken and were used to determine the tibial femoral angle. These roentgenograms were taken both preoperatively and at the follow-up evaluations. The operation was performed on the medial aspect of the knee, and a medially based wedge of bone was removed. A compression blade plate was inserted parallel to the articular surface. At the time of the latest follow-up, 13 of the 21 (61.9%) osteotomies were still considered successful. Seven had failed and one patient died (not related to the surgery). Three of the original 23 patients were not available for follow-up. Of the knees that failed, all had a total knee arthroplasty.

To the author's knowledge (Finkelstein et al., 1996), their study had the longest duration of follow-up following varus osteotomy of the distal part of the femur. The authors concluded that varus osteotomy of the distal part of the femur is an effective technique for the treatment of valgus deformity (Finkelstein et al., 1996). The results of Finkelstein et al. (1996) and of Edgerton et al. (1993) appear to be contradictory.

Bowen, Torres, and Forlin (1992) claimed that the correction of genu valgum can be achieved in skeletally immature patients by epiphyseal stapling, partial epiphysiodesis, or osteotomy, and that partial epiphysiodesis is the simplest operative procedure. This procedure still allows remaining growth in the physis to correct the deformity. This procedure can only be performed at a specific bone age to have proper end results of final alignment. The objective of the partial epiphysiodesis procedure is to induce a bony bridge opposite the apex of angular deformity at the margin of the growth

plate. A bony bridge in an inappropriate position along the margin of the growth plate can lead to malalignment of the extremity (Bowen et al., 1992). A follow-up postoperatively is necessary at approximately six month intervals to determine any improvement.

The senior author developed a chart to predict the proper time in which to perform the partial epiphysiodesis. This chart had a purpose to correlate the width of the bone at the area of the involved physis, the degree of deformity, the sex of the patient, and the percentile height. It also predicts a skeletal age at which time the procedure is advised (Bowen et al., 1992). The chart was utilized to compare the accuracy of using the chart for predictions, and just estimating the correct bone age to perform the surgeries in subjects. The degree of the deformity was determined by the tibial femoral angle. The width of the bone at the involved growth plate (tibia or femur) was measured from radiographs of the limb (Bowen et al., 1992). In Group I of the study, the predictive chart developed by senior author Bowen was utilized preoperatively to predict correction. There were 16 extremities in 12 patients in this group. In Group II, the correction was simply estimated preoperatively without using the predictive chart. There were 15 extremities in 10 patients in this group.

In Group I, the average age of the subjects was 12.6 years, and the average preoperative degree of tibial femoral valgus deformity was 16.8° . The surgical procedure was performed in varying growth plate areas dependent on the individual patient. Seven were performed in the medial tibial physis, six in the medial femoral physis, and three in the lateral tibial physis and proximal fibular physis. At the time of the last radiograph in

Group I, the average valgus deformity correction was 7.5° . The expected result occurred in 10 of the 12 patients in Group I (Bowen et al., 1992).

In Group II, the average age was 13.3 years and the average preoperative deformity was 17.1° of tibial femoral valgus. The procedures also varied dependent on patient individualities as in Group I. Four procedures were performed in the medial tibial physis, three in the medial femoral physis, eight in the lateral tibial physis and fibula, and four in the lateral femoral physis. At the time of the last radiograph, the average of tibial femoral valgus deformity was 12.5° . Only three of the 10 patients had the expected correction. In two of them the goal of the surgery was only stop the progression of the deformity (Bowen et al., 1992).

Stevens, Maguire, Dales, and Robins (1999) stated that adolescent idiopathic genu valgum might cause anterior knee pain, patellofemoral instability, circumduction gait, and difficulty running. The purpose of their study was to evaluate hemiphyseal stapling of the medial distal femur, a protocol they believe to be an ideal treatment. These researchers studied 76 patients (152 knees) who underwent the distal medial femoral physis stapling to correct genu valgum. The indications for the surgery was anterior knee pain, patellar instability, circumduction gait, and cosmetic concerns. Those who were not considered for the surgery were patients with physiologic genu valgum or physeal closure, which this indicated skeletal maturity (Stevens et al., 1999). In a skeletally immature patient, the manipulation of the physeal growth through surgery is suggested, however, epiphysiodesis had the disadvantage of being permanent (Stevens et al., 1999). When performing the surgery, the authors took care in avoiding placing the staples too

anteriorly. This could cause genu recurvatum, also known as back-knee. The results indicated 29% of the patients had a family history of genu valgum. Also, 41% of the patients complained of an awkward gait and six patients reported being teased by their peers. The circumduction gait was corrected in all patients, there was consistent and, sometimes, rapid improvement in the radiographic procedures, and the average time to correction following the stapling was approximately 10 months (Stevens et al., 1999). The anatomic tibial femoral angle improved to an average of 3.5° at the time of surgery from 12.8° prior to surgery. At maturity following the surgery, the tibial femoral angle improved to 5.8° (Stevens et al., 1999).

Conclusion

When discussing genu valgum, it is important to realize it has a correlation to a variety of knee problems. These problems include medial knee joint instability, anterior cruciate ligament injury, patellofemoral problems, and abnormal gait problems. Pes planus has also been associated with genu valgum, and there are documented studies that state an increased Q angle has an impact in causing patellofemoral pain. It appears that these knee problems, increased Q angle, and genu valgum are all closely related. There are a variety of treatment options available to treat the symptoms of genu valgum, and the surgical procedures appear to be the only option that can biomechanically change the degree of genu valgum. However, it is necessary to explore other options of correction for genu valgum.

METHODS

Subjects

A flyer was distributed on the campus of Montana State University to target collegiate women with genu valgum, and eleven were willing to volunteer and participate in the study. All subjects were required to sign an informed consent document that was approved by the Montana State University Human Subjects Committee. To maintain anonymity, subjects were assigned an identification number that was applied to all data collected.

Procedures

Once recruiting was complete, each subject was matched with another subject who most closely compared in body size, fitness level, and degree of genu valgum. The pair was then randomly separated with one subject assigned to the treatment group, and the other to the control group. The treatment group consisted of women with genu valgum who completed the six-week exercise program. The control group consisted of women with genu valgum who did not perform any exercises, and refrained from any procedures that may have affected their degree of genu valgum. However, all subjects were allowed to maintain their physical activity regimes.

All testing was conducted in the Montana State University Athletic Training Center, Brick Breeden Fieldhouse, Bozeman, Montana. The treatment consisted of

exercises concentrating on strengthening hip flexors, hip abductors and adductors, hip internal and external rotators, hamstring and quadriceps muscle group. The exercise battery utilized was from the Egoscue Method (Egoscue & Gittines, 1998). Supervision of the exercises and of the photograph sessions was provided by certified athletic trainer, Jaime McCafferty.

Each experimental subject had a consultation with a certified chiropractic sports physician/certified strength and conditioning specialist (Dr. Cleve T. Linebarger, D.C) and a certified athletic trainer (Jaime McCafferty, ATC) in order to determine the appropriate individualized exercises for the correction of genu valgum. The subjects were analyzed and categorized as having either "external" or "internal" knees. In order to determine if a subject had internal or external knees, the alignment of the femur was noted as being either externally or internally rotated. Only one subject in the treatment group had external knees. An example of a common exercise that was implemented in the study was "wall sits". In this quadriceps strengthening exercise, the subject stood with their back against the wall, hips and knees flexed to 90°. They were asked to hold that position for two minutes. Examples of all exercises utilized in the study are included in Appendix B. There were no costs associated with the consultation. The consultants implemented a six week individualized exercise program in an attempt to correct the genu valgum deformity and/or provide symptomatic relief. The subjects in the treatment group performed their respective exercises five times weekly for approximately one hour each session.

It was expected that each individual would have different symptoms and problems associated with their genu valgum deformity. The signs and symptoms questionnaire for genu valgum inquiring about characteristic symptoms and general demographic information was administered to the subjects prior to implementing the study and at the conclusion of the study. The signs and symptoms questionnaires served as a subjective measure of signs, symptoms, and concerns resulting from genu valgum.

A standing lower body digital photograph was taken of each subject prior to beginning the exercise program, at seven day intervals, and at the conclusion of the exercise program. The photographs were used to measure the quadriceps (Q) angle and the tibial femoral angle (TFA). These two measures provided information used to assess the degree of genu valgum in the subjects. Anatomical landmarks, including the anterior superior iliac spine(ASIS), tibial tuberosity, midpatella, and tibial shaft were marked on the subjects with reflective tape (seven mm in diameter) in order to insure accuracy of the measurements. Midpatella was determined by the intersection of a line from the medial to lateral patella and a line from the inferior to superior patella (Lathinghouse & Trimble, 2000). The tibial shaft was palpated distally from the tibial tubersity. The marker was placed at the most distal palpable location on the tibial shaft. It was necessary for the subjects to wear dark colored, tight fitting shorts/spandex to minimize error in locating landmarks and maintaining position of the reflective tape. A line 0.295 meters from the wall was placed on the floor and divided into equal halves. The subjects were instructed to stand on a 0.432 x 0.279 meter piece of paper, also divided in half. The halves of

the line and the paper were aligned, and the subject was asked to straddle the center of the line with feet pointing forward and parallel with the sagittal plane. They were instructed to stand with their feet in alignment vertically with their anterior superior iliac spines (ASIS). A tracing of the subjects' feet was made on the 0.432 x 0.279 meter paper and was used for all successive photographs to maintain consistency within individual subjects. The subject was asked to step away from her position after the first photograph, re-align herself, and a second photograph was then taken for assessing reliability.

Instrumentation

Within the signs and symptoms questionnaire for genu valgum, visual analog scales (VAS) were utilized to obtain subjective data from the subjects regarding their genu valgum deformity. The questionnaires were administered prior to and at the conclusion of the study. The questionnaires were compared at the conclusion of the study to assess any subjective improvement in the symptoms of genu valgum. The visual analog scales (VAS) are represented by a straight line with a clear ending point on each end of the line. The subject was asked to draw a perpendicular line to estimate their level of pain, ranging from "no pain" to "the most excruciating pain ever experienced." The subject was answering the VAS regarding the previous six months, and there was a VAS for each aspect of the lower extremity. The VAS prior to the study was compared to the VAS post-study at the conclusion of the project.

Circles of reflective tape seven millimeters in diameter were used for marking the bony anatomical landmarks (ASIS, midpatella, tibial tuberosity, and distal tibial shaft). The reflective tape allowed high visibility of the landmarks in the photographs. The size of the reflective circle assisted in minimizing error when making measurements of genu valgum and Q angle on a digital analyzing computer program which can measure path lengths and angles (Scion Image Beta 4.02, Scion Corporation, Frederick, Maryland).

The digital photographs were taken with a high-resolution digital camera (Sony Digital Mavica, MVC-FD85). The digital camera was mounted level on a tri-pod that stood 0.940 meters from floor to mid-lens, and was 2.53 meters away from the subject. The flash setting on the camera was manually activated to maximize the effects of the reflective circles. The camera was zoomed to each subject, but allowing the feet to be fully visible. The crosshair of the camera was aligned with the mid-thigh measure of each individual subject.

When measuring Q angles and tibial femoral angles, the Q angle was measured by drawing a line from the ASIS to mid-patella and from the tibial tubercle to the mid-patella (Figure 4). The tibial femoral angle was determined by drawing a line from the ASIS to the mid-patella and from the distal tibial shaft to the tibial tuberosity. Measurements were based on ideal alignment being 180 degrees and genu valgum being any measurement less than 180 degrees.

Strength measures were acquired before beginning the study, after the third week of intervention, and following the last day of treatment. A manual muscle tester

(Nicholas Manual Muscle Tester Model 01160, Lafayette Instrument Company) was the instrument of choice to measure strength. The manual muscle tester (MMT) is a hand-held device for objectively quantifying eccentric muscle strength. The examiner places the MMT between his/her hand and the subject maximally resists the examiner's efforts to depress the given muscle group. Measurements were expressed in Newtons of force. Each muscle group was tested twice bilaterally, and the average of the two scores was taken. The muscles that were tested were hip flexors, hip abductors and adductors, hip internal and external rotators, and knee flexors and extensors.

Statistical Analyses

The mean values of the dependent variables were analyzed using two factor (group x time) repeated measures analysis of variance (ANOVA). Post-hoc analyses utilized Scheffe's test to detect significant differences between mean values of each dependent variable across time. All statistical analyses were evaluated at the 0.05 alpha level. Intraclass reliability for all dependent measures were determined using single factor repeated measures ANOVA analyses. The software package utilized for all statistical analyses was Statistica 5.5A (Statsoft Inc., Tulsa, Oklahoma).

RESULTS

Subject Characteristics

Eleven collegiate women volunteered to participate in the study, ranged in age from 19 years to 34 years (mean = 21.6 years), and had a mean height of 166.9 centimeters and a mean weight of 146.7 pounds. Six subjects were assigned to the treatment group, and the remaining five became the control group (Table 1). All treatment group subjects were categorized as having “internal” or “external” knees, while only one subject was found to have “external” knees. One subject in the control group was only available to take preliminary and concluding digital photographs due to an ankle injury that required surgery. Accurate data was not able to be collected on this subject due to a cast she was required to wear following her operation. Thus, she was excluded from the statistical analysis portion of the study. All subjects were compliant with the specifications of the study and were dutiful in keeping all appointment arrangements.

Analysis of Quadriceps (Q) Angle Data

Data for the right and left quadriceps angle (QA_R and QA_L, respectively), as well as the average of these two angles (QA_AVG), were analyzed separately. The preliminary data, third, and sixth week data were used for analysis. The ANOVA table for QA_R (Table 2) indicated a significant Group x Time interaction ($P < 0.001$). While

Table 1. Demographic Data for the Control (n=4) and Treatment Group (n=6). Age is expressed in years, height in centimeters (cm), and weight in pounds (lbs). All measurements are given in the mean $\pm$ standard error (SE) format.

<u>Group</u>	<u>Age (years)</u>	<u>Height (cm)</u>	<u>Weight (lbs)</u>
Control	23 $\pm$ 6.2	172.2 $\pm$ 189.2	148.2 $\pm$ 30.1
Treatment	19.7 $\pm$ 0.8	162.6 $\pm$ 14.3	145.5 $\pm$ 16.6

the mean QA_R values were stable across time for the control group, the treatment group QA_R decreased from a (Mean $\pm$ SE) 20.5 $\pm$ 3.4° at pre-testing to 17.4 $\pm$ 3.9° at week three and finally 14.7 $\pm$ 3.9° at week six (Table 3). Each mean QA_R value for the treatment group differed significantly from each other (P<0.001).

The ANOVA table for QA_L (Table 2) indicated no significant main effects across the two groups (P=0.73), across the three time periods (P=0.66), nor for the interaction effect (P=0.17). The QA_L mean values for the treatment group decreased from (Mean $\pm$ SE) 18.4 $\pm$ 3.9° at pre-testing to 16.8 $\pm$ 3.6° at week three and ended at 17.7 $\pm$ 3.9° following week six. However, the means did not significantly differ from each other (P=0.35).

When the Q angles for both right and left legs were averaged (QA_AVG), the ANOVA table (Table 2) indicated a significant Group x Time interaction (P<0.001). While the QA_AVG values were stable for the control group, the treatment group values began at (Mean $\pm$ SE) 19.4 $\pm$ 3.6° at pre-testing, 17.1 $\pm$ 3.6° after week three, and 16.2 $\pm$ 3.9° following the sixth week (Table 3). The pre-testing and the third week values

Table 2. ANOVA table results for the Quadriceps Angle (QA) and Tibial Femoral Angle (TFA). Under the “Effects” category, the group-main effect analyzed the control and treatment group data, the time-main effect analyzed the data across the three time periods (preliminary, third week, and sixth week), and the group x time interaction effect (G x T interaction) was also analyzed. The variables measured were Q-angle of the right leg (QA_R), Q-angle of the left leg (QA_L), the average of the right and left Q-angles (QA_AVG), tibial femoral angle of the right leg (TFA_R), tibial femoral angle of the left leg (TFA_L), and finally, the average of the right and left tibial femoral angles (TFA_AVG). When determining significance, alpha was 0.05 and significant p-values are represented by bold and italicized print.

<u>Effects</u>	<u>Variable</u>	<u>Degrees of Freedom (df)</u>	<u>Mean Square (MS)</u>	<u>df error</u>	<u>MS error</u>	<u>F-ratio</u>	<u>p-value</u>
Group-main effect	QA_R	1	9.67	8	237.91	0.04	0.85
Time- main effect		2	19.48	16	1.53	12.76	<i>0.00047</i>
G x T interaction		2	21.30	16	1.53	13.96	<i>0.00031</i>
Group-main effect	QA_L	1	35.06	8	238.4	0.13	0.73
Time- main effect		2	0.88	16	2.08	0.42	0.66
G x T interaction		2	4.07	16	2.08	1.96	0.17
Group-main effect	QA_AVG	1	20.02	8	246.1	0.08	0.78
Time- main effect		2	4.3	16	0.72	5.94	<i>0.012</i>
G x T interaction		2	9.96	16	0.72	13.77	<i>0.00033</i>
Group-main effect	TFA_R	1	0.0068	8	18.61	0.00037	0.99
Time- main effect		2	4.64	16	0.62	7.46	<i>0.0051</i>
G x T interaction		2	5.42	16	0.62	8.71	<i>0.0028</i>
Group-main effect	TFA_L	1	8.52	8	4.49	1.9	0.21
Time- main effect		2	0.53	16	0.92	0.57	0.57
G x T interaction		2	1.63	16	0.92	1.77	0.20
Group-main effect	TFA_AVG	1	2.01	8	9.20	0.22	0.65
Time- main effect		2	2.05	16	0.42	4.94	<i>0.021</i>
G x T interaction		2	3.04	16	0.42	7.32	<i>0.0055</i>

Table 3. Quadriceps Angle (QA) and Tibial Femoral Angle (TFA) Means and Standard Errors (Mean $\pm$ SE) reported for the control and treatment groups. All Means $\pm$ SE are recorded for the right leg Q-angle (QA_R), left leg Q-angle QA_L), the average right and left leg Q-angle (QA_AVG), the right leg tibial femoral angle (TFA_R), the left leg tibial femoral angle (TFA_L), and the average right and left leg tibial femoral angle (TFA_AVG). The measures are given at pre-testing, following the third week, and at the conclusion of the study (Week 6).

Variable	Group	Pre-testing	Week 3	Week 6
QA_R	Control	18.6 $\pm$ 4.4°	18.6 $\pm$ 4.0°	18.7 $\pm$ 4.4°
	Treatment	20.5 $\pm$ 3.4°	17.4 $\pm$ 3.9°	14.7 $\pm$ 3.9°
QA_L	Control	19.1 $\pm$ 5.1°	20.0 $\pm$ 4.8°	20.4 $\pm$ 4.9°
	Treatment	18.4 $\pm$ 3.9°	16.8 $\pm$ 3.6°	17.7 $\pm$ 3.9°
QA_AVG	Control	18.9 $\pm$ 4.7°	19.3 $\pm$ 4.4°	19.6 $\pm$ 4.6°
	Treatment	19.4 $\pm$ 3.6°	17.1 $\pm$ 3.6°	16.2 $\pm$ 3.9°
TFA_R	Control	175.5 $\pm$ 0.8°	175.2 $\pm$ 0.9°	175.6 $\pm$ 1.1°
	Treatment	173.8 $\pm$ 1.3°	176.1 $\pm$ 1.1°	176.4 $\pm$ 1.2°
TFA_L	Control	176.5 $\pm$ 0.5°	176.3 $\pm$ 0.3°	176.2 $\pm$ 0.2°
	Treatment	174.6 $\pm$ 0.8°	175.3 $\pm$ 0.6°	175.9 $\pm$ 0.8°
TFA_AVG	Control	176.0 $\pm$ 0.4°	175.8 $\pm$ 0.5°	175.9 $\pm$ 0.6°
	Treatment	174.2 $\pm$ 0.9°	175.7 $\pm$ 0.8°	176.2 $\pm$ 0.9°

statistically differed from each other ($P < 0.001$), whereas week three and week six did not statistically differ from each other.

Analysis of Tibial Femoral Angle (TFA) Data

As with the Q angle, the right and left leg tibial femoral angle data (TFA_R and TFA_L, respectively) were analyzed separately, as well as the average of these two angles (TFA_AVG). The preliminary data, third, and sixth week data were used for analysis. The ANOVA results for TFA_R (Table 2) indicated a significant Group x Time interaction ($P = 0.0028$). The control group mean values for TFA_R appeared to remain constant, however the treatment group mean values at pre-testing began at (Mean $\pm$ SE) $173.8 \pm 1.3^\circ$, increased to $176.1 \pm 1.1^\circ$ at week three, and ended at $176.4 \pm 1.2^\circ$ after week six (Table 3). The statistical difference occurred between the values of pre-testing and week three ($P < 0.001$), and there was no change between week three and the final week six data.

The ANOVA results for TFA_L (Table 2) indicated no significant main effects across the two groups ($P = 0.21$), across the three time periods ($P = 0.57$), nor for the interaction effect ($P = 0.20$). The TFA_L mean values remained constant for the control group and only varied slightly in the treatment group. The treatment group began at (Mean $\pm$ SE) $174.6 \pm 0.8^\circ$, increased slightly to $175.3 \pm 0.6^\circ$ at week three, and increased only slightly to $175.9 \pm 0.8^\circ$ following the conclusion of the study (Table 3). The mean values did not statistically differ from each other ($P = 0.19$).

When averaging the left and right leg TFA data (TFA_AVG), the ANOVA results (Table 2) indicated there was a significant Group x Time interaction ($P=0.0055$). As in all subsequent control group data, the TFA_AVG for the control group stayed constant. The treatment data was (Mean $\pm$ SE) $174.2 \pm 0.9^\circ$ at the onset of study, $175.7 \pm 0.8^\circ$ following week three, and finally, $176.2 \pm 0.9^\circ$ at the conclusion of week six (Table 3). The pre-testing and third week values statistically differed from each other, whereas week three and week six had no difference ($P=0.0031$).

Analysis of Strength Measurement Data

The strength measures obtained, expressed in Newtons (N), using a manual muscle tester (MMT) were analyzed as an average of the right and left leg, and the right and left leg separately. The average of the right and left leg is reported due to consistent and equal strength gains in both legs while the control groups' measures remained constant (Table 6).

The ANOVA results noted hip flexor (HF) strength as having a statistically significant Group x Time interaction ($P=0.018$) (Table 4). The HF values started at (Mean $\pm$ SE) 635.2 ± 15.5 N at pre-testing, 630.0 ± 16.6 N at week three, and 651.2 ± 6.7 N following week six (Table 5). The difference was not detected between preliminary testing and week three or week three and week six, but was detected between preliminary testing and week six ($P=0.044$).

The ANOVA results for hip adduction (HAD) strength did not show a significant Group x Time interaction effect, but demonstrated a significant group-main effect difference ($P < 0.001$) (Table 4). At pre-testing for the treatment group, HAD strength began at (Mean $\pm$ SE) 571.7 ± 9.9 N, increased to 589.7 ± 6.0 N at week three, and increased again to 591.2 ± 8.1 N following week six (Table 5). However, there were no significant pairwise differences among the means ($P = 0.16$).

The data in Table 4 for hip abduction (HAB) indicated there was a significant Group x Time interaction effect ($P = 0.019$). The HAB strength for the treatment group was (Mean $\pm$ SE) 569.3 ± 6.9 N at pre-testing, 587.6 ± 8.1 N at the end of week three, and concluded week six at 594.4 ± 6.9 N (Table 5). There was a significant mean difference between pre-testing and week three, but none detected elsewhere ($P = 0.002$).

For knee flexion (KF), the ANOVA results did not show a significant Group x Time interaction effect, but detected a significant difference in the group- main effect only ($P < 0.001$) (Table 4). The KF strength in the treatment group actually decreased over the course of the study. The mean values (Mean $\pm$ SE) began at 618.4 ± 19.5 N at pre-testing, decreased to 592.1 ± 7.4 N at week three, and decreased again to 581.9 ± 11.1 N at week six (Table 5). A significant mean difference was not detected anywhere among the two groups, across the three time periods, or in the Group x Time interaction ($P = 0.26$).

The ANOVA results (Table 4) displayed no differences in the strength values of knee extension (KE) ($P = 0.073$). At the beginning of the study, the values (Mean $\pm$ SE)

were 593.7 ± 18.1 N, 618.8 ± 12.0 N following week three, and ended week six at 631.0 ± 11.2 N (Table 5). There were no significant differences among the means ($P=0.18$).

The strength values for hip external rotation (HER) in the ANOVA results noted a significant Group x Time interaction effect ($P= 0.007$). In fact, all p-values in the HER data were significant, including differences among the groups ($P= 0.0017$) and across time ($P < 0.001$) (Table 4). The preliminary values for HER (Mean $\pm$ SE) was 528.5 ± 12.4 N, 560.6 ± 5.9 N at week three, and 588.3 ± 8.1 N at the end of week six. There was a significant difference between the means of the preliminary data and week six ($P < 0.001$), but there were no differences between preliminary data and week three and week three and week six.

The ANOVA results for hip internal rotation (HIR) did not detect a significant Group x Time interaction effect, but noted a significant difference for the group interaction ($P= 0.005$) and time interaction ($P < 0.001$) (Table 4). The HIR values (Mean $\pm$ SE) were 524.27 ± 9.28 N at pre-testing, increased to 557.49 ± 6.25 N following week three, and increased again to 575.63 ± 7.94 N following week six (Table 5). There was a significant difference detected between pre-testing and week three ($P < 0.001$).

Analysis of Subjective Visual Analog Scale (VAS) Data

The Visual Analog Scale (VAS) data was statistically analyzed, however, nothing proved to be significant. All p-values were greater than 0.10 for main effects and interactions in the ANOVA results. The means and standard deviations for the control

Table 4. ANOVA table results for Strength Measure data. Under the “Effects” category, the group-main effect analyzed the control and treatment group data, the time-main effect analyzed the data across the three time periods (preliminary, third week, and sixth week), and the group x time interaction effect (G x T interaction) was also analyzed. The variables measured were hip flexion (HF), hip adduction (HAD), hip abduction (HAB), knee flexion (KF), knee extension (KE), hip external rotation (HER), and hip internal rotation (HIR). All measures were analyzed with the average of the right and left leg values. When determining significance, alpha was 0.05 and significant differences in p-value are represented by bold and italicized print.

<u>Effects</u>	<u>Variable</u>	<u>Degrees of Freedom (df)</u>	<u>Mean Square (MS)</u>	<u>df error</u>	<u>MS error</u>	<u>F-ratio</u>	<u>p-value</u>
Group-main effect	HF	1	19349.84	8	1524.65	12.69	<i>0.0074</i>
Time- main effect		2	61.32	16	136.24	0.45	0.65
G x T interaction		2	709.48	16	136.24	5.21	<i>0.018</i>
Group-main effect	HAD	1	21915.79	8	374.89	58.46	<i>0.00006</i>
Time- main effect		2	79.34	16	259.05	0.31	0.74
G x T interaction		2	609.84	16	259.05	2.35	0.13
Group-main effect	HAB	1	11842.50	8	838.3	14.13	<i>0.0056</i>
Time- main effect		2	310.35	16	103.17	3.01	0.078
G x T interaction		2	528.03	16	103.17	5.12	<i>0.019</i>
Group-main effect	KF	1	20547.31	8	439.89	46.71	<i>0.00013</i>
Time- main effect		2	1397.56	16	990.96	1.41	0.27
G x T interaction		2	789.90	16	990.96	0.80	0.47
Group-main effect	KE	1	7106.35	8	1662.97	4.27	0.073
Time- main effect		2	2316.15	16	915.63	2.53	0.11
G x T interaction		2	119.34	16	915.63	0.13	0.88
Group-main effect	HER	1	14087.64	8	659.19	21.37	<i>0.0017</i>
Time- main effect		2	3002.5	16	222.49	13.49	<i>0.00037</i>
G x T interaction		2	1529.46	16	222.49	6.87	<i>0.0070</i>
Group-main effect	HIR	1	10359.98	8	702.74	14.74	<i>0.0050</i>
Time- main effect		2	2451.83	16	125.07	19.60	<i>0.00005</i>
G x T interaction		2	98.25	16	125.07	0.79	0.47

Table 5. Strength Measures Means and Standard Errors (Mean $\pm$ SE) reported for the control and treatment groups. All Means $\pm$ SE are recorded as averages taken from the right and left leg data for hip flexion (HF_AVG), hip adduction (HAD_AVG), hip abduction (HAB_AVG), knee flexion (KF_AVG), knee extension (KE_AVG), hip external rotation (HER_AVG), and hip internal rotation (HIR_AVG). The measures are given at pre-testing, following the third week, and at the conclusion of the study (Week 6). Values are expressed in Newtons (N).

Variable	Group	Pre-Testing	Week 3	Week 6
HF_AVG	Control	587.7 $\pm$ 3.9 N	592.8 $\pm$ 8.9 N	580.4 $\pm$ 10.5 N
	Treatment	635.2 $\pm$ 15.5 N	630.0 $\pm$ 10.6 N	651.2 $\pm$ 6.7 N
HAD_AVG	Control	534.9 $\pm$ 7.1 N	526.2 $\pm$ 4.0 N	525.9 $\pm$ 5.4 N
	Treatment	571.7 $\pm$ 9.9 N	589.7 $\pm$ 6.0 N	591.2 $\pm$ 8.1 N
HAB_AVG	Control	594.7 $\pm$ 8.8 N	544.7 $\pm$ 13.9 N	540.4 $\pm$ 4.8 N
	Treatment	569.3 $\pm$ 6.9 N	587.6 $\pm$ 8.1 N	594.4 $\pm$ 6.9 N
KF_AVG	Control	544.8 $\pm$ 8.6 N	553.7 $\pm$ 8.1 N	533.6 $\pm$ 8.3 N
	Treatment	618.4 $\pm$ 19.5 N	592.1 $\pm$ 7.4 N	581.9 $\pm$ 11.1 N
KE_AVG	Control	569.5 $\pm$ 10.2 N	587.1 $\pm$ 15.9 N	592.6 $\pm$ 22.0 N
	Treatment	593.7 $\pm$ 18.1 N	618.8 $\pm$ 12.0 N	631.0 $\pm$ 11.2 N
HER_AVG	Control	507.1 $\pm$ 3.8 N	520.5 $\pm$ 7.1 N	517.0 $\pm$ 6.3 N
	Treatment	528.5 $\pm$ 12.4 N	560.6 $\pm$ 5.9 N	588.3 $\pm$ 8.1 N
HIR_AVG	Control	493.7 $\pm$ 2.4 N	515.9 $\pm$ 10.5 N	515.9 $\pm$ 10.5 N
	Treatment	524.3 $\pm$ 9.3 N	557.5 $\pm$ 6.3 N	575.5 $\pm$ 7.9 N

Table 6. Right and left leg strength measure means and standard deviations (Mean $\pm$ SD) reported for the control and treatment groups. All Means $\pm$ SD are recorded for the right leg hip flexor (HF_R), left leg hip flexor (HF_L), right leg hip adductor (HAD_R), left leg hip adductor (HAD_L), right leg hip abductor (HAB_R), left leg hip abductor (HAB_L), right leg knee flexor (KF_R), left leg knee flexor (KF_L), right leg knee extensor (KE_R), left leg knee extensor (KE_L), right leg hip external rotator (HER_R), left leg hip external rotator (HER_L), right leg hip internal rotator (HIR_R), and left leg hip internal rotator (HIR_L). The measures are given at pre-testing, following the third week, and at the conclusion of the study (Week 6).

Variable	Group	Pre-Testing	Week 3	Week 6
HF_R	Treatment	628.3 $\pm$ 37.3 N	626.8 $\pm$ 25.7 N	651.4 $\pm$ 18.4 N
	Control	582.4 $\pm$ 15.8 N	586.6 $\pm$ 11.1 N	580.7 $\pm$ 21.7N
HF_L	Treatment	642.0 $\pm$ 40.1 N	633.3 $\pm$ 27.1 N	651.0 $\pm$ 15.6 N
	Control	592.9 $\pm$ 8.9 N	598.9 $\pm$ 25.0 N	580.1 $\pm$ 22.9 N
HAD_R	Treatment	579.5 $\pm$ 21.2 N	591.5 $\pm$ 17.7 N	585.2 $\pm$ 15.2 N
	Control	542.2 $\pm$ 17.1 N	529.6 $\pm$ 12.3 N	534.2 $\pm$ 15.2 N
HAD_L	Treatment	563.9 $\pm$ 32.1 N	587.9 $\pm$ 18.5 N	597.3 $\pm$ 25.2 N
	Control	527.6 $\pm$ 25.4 N	522.9 $\pm$ 11.1 N	517.6 $\pm$ 11.4 N
HAB_R	Treatment	566.0 $\pm$ 22.4 N	582.8 $\pm$ 25.8 N	593.9 $\pm$ 25.6 N
	Control	541.7 $\pm$ 29.3 N	541.9 $\pm$ 36.4 N	536.7 $\pm$ 14.6 N
HAB_L	Treatment	572.7 $\pm$ 20.3 N	592.5 $\pm$ 17.2 N	594.9 $\pm$ 17.7 N
	Control	547.6 $\pm$ 11.8 N	547.5 $\pm$ 19.3 N	544.0 $\pm$ 5.8 N
KF_R	Treatment	622.3 $\pm$ 47.9 N	587.9 $\pm$ 23.2 N	581.8 $\pm$ 21.9 N
	Control	549.4 $\pm$ 17.0 N	551.3 $\pm$ 14.2 N	532.3 $\pm$ 18.2 N
KF_L	Treatment	614.5 $\pm$ 52.5 N	596.2 $\pm$ 23.4 N	582.1 $\pm$ 42.9 N
	Control	540.2 $\pm$ 23.3 N	556.1 $\pm$ 22.1 N	534.9 $\pm$ 15.3 N
KE_R	Treatment	594.9 $\pm$ 42.2 N	618.9 $\pm$ 30.5 N	629.9 $\pm$ 25.3 N
	Control	570.4 $\pm$ 24.3 N	593.1 $\pm$ 27.8 N	592.8 $\pm$ 47.9 N
KE_L	Treatment	592.6 $\pm$ 46.6 N	618.7 $\pm$ 30.5 N	632.1 $\pm$ 36.2 N
	Control	568.6 $\pm$ 21.6 N	581.2 $\pm$ 37.8 N	592.5 $\pm$ 41.1 N
HER_R	Treatment	537.0 $\pm$ 20.5 N	564.4 $\pm$ 15.3 N	592.0 $\pm$ 26.7 N
	Control	501.0 $\pm$ 5.6 N	521.1 $\pm$ 16.7 N	517.3 $\pm$ 12.9 N
HER_L	Treatment	520.0 $\pm$ 40.6 N	556.6 $\pm$ 16.3 N	584.7 $\pm$ 22.5 N
	Control	513.3 $\pm$ 12.6 N	519.9 $\pm$ 13.0 N	516.7 $\pm$ 13.8 N
HIR_R	Treatment	515.8 $\pm$ 27.1 N	553.9 $\pm$ 14.9 N	582.7 $\pm$ 18.5 N
	Control	487.9 $\pm$ 6.5 N	516.3 $\pm$ 20.5 N	520.1 $\pm$ 13.4 N
HIR_L	Treatment	532.8 $\pm$ 21.1 N	561.1 $\pm$ 17.2 N	568.6 $\pm$ 24.5 N
	Control	499.5 $\pm$ 14.2 N	515.4 $\pm$ 22.5 N	514.3 $\pm$ 10.9 N

Table 7. Pre-Testing Subjective Visual Analog Scale (VAS) Means and Standard Deviations. The values for the Means and Standard Deviations (Mean $\pm$ SD) are given a percentage representing the mark made on a nine centimeter (cm) VAS from the subject. The subjects were asked to rank pain on the VAS for the feet, ankles, lower legs, knees, thighs, hips, groin, and low back prior to exercise, during and following an individual exercise bout.

<u>Group</u>	<u>Exercise phase</u>	<u>Feet</u>	<u>Ankles</u>	<u>Low legs</u>	<u>Knees</u>	<u>Thigh</u>	<u>Hip</u>	<u>Groin</u>	<u>Low back</u>
Control	pre-exercise	4.7 $\pm$ 5.2%	12.2 $\pm$ 11.4%	7.8 $\pm$ 7.8%	19.0 $\pm$ 23.6%	7.8 $\pm$ 6.5%	4.7 $\pm$ 4.1%	12.8 $\pm$ 14.4%	16.5 $\pm$ 14.8%
	during-exercise	6.8 $\pm$ 7.8%	29.3 $\pm$ 26.5%	8.9 $\pm$ 11.5%	32.8 $\pm$ 28.9%	17.1 $\pm$ 15.1%	26.4 $\pm$ 22.9%	25.3 $\pm$ 29.9%	16.1 $\pm$ 13.5%
	post-exercise	13.3 $\pm$ 15.5%	24.4 $\pm$ 17.9%	13.6 $\pm$ 14.3%	27.9 $\pm$ 16.5%	24.9 $\pm$ 17.9%	22.8 $\pm$ 16.5%	20.1 $\pm$ 28.3%	16.4 $\pm$ 15.4%
Treatment	pre-exercise	5.9 $\pm$ 7.9%	24.2 $\pm$ 21.0%	17.0 $\pm$ 28.2%	50.4 $\pm$ 20.5%	5.6 $\pm$ 6.8%	5.4 $\pm$ 14.1%	5.9 $\pm$ 9.3%	21.3 $\pm$ 21.9%
	during-exercise	6.1 $\pm$ 5.6%	32.5 $\pm$ 25.2%	20.7 $\pm$ 33.2%	56.9 $\pm$ 24.0%	10.0 $\pm$ 17.7%	9.5 $\pm$ 14.1%	4.4 $\pm$ 6.2%	8.8 $\pm$ 10.3%
	post-exercise	3.9 $\pm$ 4.3%	25.5 $\pm$ 17.6%	16.9 $\pm$ 32.7%	49.5 $\pm$ 33.5%	5.3 $\pm$ 8.0%	5.8 $\pm$ 8.4%	3.2 $\pm$ 5.2%	17.8 $\pm$ 33.2%

Table 8. Week Six Subjective Visual Analog Scale (VAS) Means and Standard Deviations. The values for the Means and Standard Deviations (Mean $\pm$ SD) are given a percentage representing the mark made on a nine centimeter (cm) VAS from the subject. The subjects were asked to rank pain on the VAS for the feet, ankles, lower legs, knees, thighs, hips, groin, and low back prior to exercise, during and following an individual exercise bout.

<u>Group</u>	<u>Exercise phase</u>	<u>Feet</u>	<u>Ankles</u>	<u>Low legs</u>	<u>Knees</u>	<u>Thigh</u>	<u>Hip</u>	<u>Groin</u>	<u>Low back</u>
Control	pre-exercise	12.5 $\pm$ 12.3%	16.3 $\pm$ 14.3%	13.8 $\pm$ 12.9%	19.7 $\pm$ 20.4%	10.1 $\pm$ 9.9%	10.1 $\pm$ 9.8%	8.6 $\pm$ 9.3%	11.9 $\pm$ 10.9%
	during-exercise	14.7 $\pm$ 12.2%	20.9 $\pm$ 16.5%	14.4 $\pm$ 15.8%	20.0 $\pm$ 17.0%	14.7 $\pm$ 13.2%	22.5 $\pm$ 17.2%	15.3 $\pm$ 13.2%	11.9 $\pm$ 11.9%
	post-exercise	12.8 $\pm$ 10.0%	21.1 $\pm$ 16.9%	12.8 $\pm$ 12.5%	26.1 $\pm$ 21.4%	19.3 $\pm$ 18.9%	22.8 $\pm$ 17.9%	12.4 $\pm$ 11.3%	16.5 $\pm$ 14.2%
Treatment	pre-exercise	6.7 $\pm$ 4.7%	18.8 $\pm$ 18.8%	24.4 $\pm$ 24.1%	31.7 $\pm$ 24.6%	4.3 $\pm$ 4.1%	6.5 $\pm$ 5.3%	6.2 $\pm$ 8.3%	8.7 $\pm$ 7.3%
	during-exercise	5.8 $\pm$ 4.2%	32.6 $\pm$ 33.9%	14.4 $\pm$ 17.8%	44.4 $\pm$ 26.9%	5.0 $\pm$ 7.1%	8.7 $\pm$ 4.6%	5.2 $\pm$ 6.2%	8.5 $\pm$ 7.5%
	post-exercise	3.4 $\pm$ 3.8%	22.3 $\pm$ 17.8%	9.3 $\pm$ 13.6%	37.6 $\pm$ 18.9%	4.3 $\pm$ 4.9%	9.4 $\pm$ 8.7%	6.8 $\pm$ 11.3%	9.8 $\pm$ 6.3%

and treatment groups (Tables 7 and 8) represent pain experienced pre-exercise, during exercise, and post-exercise in individual exercise bouts.

Reliability Data

All digital photograph measures of Q angle and TFA were analyzed twice (i.e., two trials) to evaluate reliability (Tables 9 and 10). Most p-values were greater than 0.05, with the exception of the left leg Q angle after week 4 (Q4L) ($P = 0.03$) and the right leg TFA after week 3 (TF3R) ($P = 0.049$). Intraclass reliability measures across both trials (i.e., $k=2$) were greater than or equal to 0.80, with the exception of the preliminary left leg TFA (TFPL) ($R_{xx}(k=2) = 0.583$) and left leg TFA after week 2 (TF2L) ($R_{xx}(k=2) = 0.634$). Intraclass reliability for a single trial (i.e., $k=1$) tended to remain high ($R_{xx} \geq 0.80$) except for those variables with low reliability for two trials (TFPL) ($R_{xx}(k=1) = 0.411$) (TF2L) ($R_{xx}(k=1) = 0.464$). The standard error of measurement (SEM) gave a range of ± 0.529 -1.876, and it is of interest to note that for TFPL, the SEM tended to be low (± 0.529) when the intraclass reliability data (R_{xx} values) were also low.

Table 9. Summary of reliability data for Quadriceps (Q) Angle. The variables analyzed were the measures for left leg Q Angle preliminary pictures (QPL), left leg Q Angle after week 1 (Q1L), left leg Q Angle after week 2 (Q2L), left leg Q angle after week 3 (Q3L), left leg Q angle after week 4 (Q4L), left leg Q angle after week 5 (Q5L), left leg Q Angle after week 6 (Q6L), right leg Q angle preliminary pictures (QPR), right leg Q angle after week 1 (Q1R), right leg Q angle after week 2 (Q2R), right leg Q angle after week 3 (Q3R), right leg Q angle after week 4 (Q4R), right leg Q angle after week 5 (Q5R), and right Q angle after week 6 (Q6R). Intraclass reliability was assessed for two trials (Rxx (k=2) and for one trial (Rxx (k=1)). The standard error of measurement (SEM) is also given. When determining significance, alpha was 0.05 and significant p-values are represented by bold and italicized print.

Variable	p-value	Rxx (k=2)	Rxx (k=1)	SEM	Trial 1 (Mean $\pm$ SD)	Trial 2 (Mean $\pm$ SD)
QPL	0.435	0.995	0.989	± 0.968	$18.9 \pm 9.6^\circ$	$18.5 \pm 8.9^\circ$
Q1L	0.478	0.993	0.986	± 1.043	$18.4 \pm 8.9^\circ$	$18.0 \pm 8.5^\circ$
Q2L	0.179	0.968	0.938	± 1.876	$17.2 \pm 7.5^\circ$	$18.1 \pm 7.5^\circ$
Q3L	0.749	0.986	0.972	± 1.476	$17.9 \pm 8.8^\circ$	$18.2 \pm 8.9^\circ$
Q4L	0.03	0.997	0.994	± 0.688	$18.8 \pm 8.9^\circ$	$19.6 \pm 8.9^\circ$
Q5L	0.975	0.996	0.992	± 0.841	$19.7 \pm 9.4^\circ$	$19.7 \pm 9.1^\circ$
Q6L	0.542	0.991	0.982	± 1.242	$18.9 \pm 9.6^\circ$	$18.6 \pm 8.9^\circ$
QPR	0.535	0.987	0.975	± 1.306	$19.5 \pm 8.2^\circ$	$19.9 \pm 8.2^\circ$
Q1R	0.872	0.982	0.965	± 1.511	$19.3 \pm 8.1^\circ$	$19.4 \pm 8.0^\circ$
Q2R	0.402	0.988	0.976	± 1.179	$18.9 \pm 7.9^\circ$	$19.4 \pm 7.3^\circ$
Q3R	0.425	0.991	0.982	± 1.150	$17.6 \pm 8.8^\circ$	$18.1 \pm 8.2^\circ$
Q4R	0.635	0.993	0.987	± 1.043	$16.7 \pm 9.1^\circ$	$16.9 \pm 8.9^\circ$
Q5R	0.4	0.996	0.991	± 0.815	$16.8 \pm 8.8^\circ$	$17.1 \pm 8.5^\circ$
Q6R	0.5445	0.998	0.996	± 0.600	$16.2 \pm 9.1^\circ$	$16.4 \pm 8.9^\circ$

Table 10. Summary of reliability data for Tibial Femoral Angle (TFA). The variables analyzed were the measures of the left leg TFA preliminary pictures (TFPL), left leg TFA after week 1 (TF1L), left leg TFA after week 2 (TF2L), left leg TFA after week 3 (TF3L), left leg TFA after week 4 (TF4L), left leg TFA after week 5 (TF5L), left leg TFA after week 6 (TF6L), right leg TFA preliminary pictures (TFPR), right leg TFA after week 1 (TF1R), right leg TFA after week 2 (TF2R), right leg TFA after week 3 (TF3R), right leg TFA after week 4 (TF4R), right leg TFA after week 5 (TF5R), and right leg TFA after week 6 (TF6R). Intraclass reliability was assessed for two trials (Rxx (k=2) and for one trial (Rxx (k=1)). The standard error of measurement (SEM) is also given. When determining significance, alpha was 0.05 and significant p-values are represented by bold and italicized print.

Variable	p-value	Rxx (k=2)	Rxx (k=1)	SEM	Trial 1 (Mean $\pm$ SD)	Trial 2 (Mean $\pm$ SD)
TFPL	0.101	0.583	0.411	± 0.529	$175.6 \pm 1.8^\circ$	$175.1 \pm 1.9^\circ$
TF1L	0.804	0.909	0.834	± 0.823	$175.2 \pm 1.9^\circ$	$175.1 \pm 2.1^\circ$
TF2L	0.374	0.634	0.464	± 0.788	$176.1 \pm 0.7^\circ$	$175.8 \pm 1.4^\circ$
TF3L	0.783	0.928	0.866	± 0.456	$175.7 \pm 1.3^\circ$	$175.7 \pm 1.2^\circ$
TF4L	0.777	0.840	0.725	± 0.990	$175.9 \pm 1.7^\circ$	$176.1 \pm 2.1^\circ$
TF5L	0.537	0.950	0.904	± 0.543	$176.4 \pm 1.9^\circ$	$176.2 \pm 1.6^\circ$
TF6L	0.532	0.888	0.798	± 0.691	$176.1 \pm 1.4^\circ$	$175.9 \pm 1.6^\circ$
TFPR	0.934	0.882	0.789	± 1.280	$174.5 \pm 2.9^\circ$	$174.5 \pm 2.7^\circ$
TF1R	0.185	0.978	0.958	± 0.445	$174.4 \pm 2.2^\circ$	$174.7 \pm 2.1^\circ$
TF2R	0.59	0.965	0.932	± 0.620	$176.0 \pm 2.3^\circ$	$175.9 \pm 2.5^\circ$
TF3R	<i>0.049</i>	0.961	0.926	± 0.636	$175.4 \pm 2.4^\circ$	$176.08 \pm 2.3^\circ$
TF4R	0.0182	0.982	0.996	± 0.394	$176.3 \pm 2.1^\circ$	$175.8 \pm 2.2^\circ$
TF5R	0.517	0.961	0.926	± 0.746	$176.1 \pm 2.9^\circ$	$175.9 \pm 2.6^\circ$
TF6R	0.245	0.969	0.939	± 0.646	$176.3 \pm 2.7^\circ$	$175.9 \pm 2.6^\circ$

DISCUSSION

Introduction

The primary goal of this study was to utilize a variety of exercises from the Egoscue Method to determine if improvement of the genu valgum deformity can occur. Genu valgum is defined as when the femur and tibia are angled inward. In order to gauge improvement, quadriceps (Q) angle and tibial femoral angle (TFA) were monitored weekly in ten college-aged women. The secondary goal of the study was to utilize the exercise protocol in order to provide symptomatic relief associated with genu valgum. In regards to the primary goal, there was a decrease in Q angle and an increase in TFA over the six-week study in the treatment group only. Due to the variability of pain experienced within the treatment group, there were no statistical improvements in symptoms. However, individual subject interviews revealed symptomatic improvement.

Exercise Protocol Justification

It was justified to utilize strengthening exercises in an attempt to correct genu valgum. Boucher et al. (1992) concluded that rehabilitative strategies should include mechanical management and functional neuromuscular management. In further support of using strengthening exercises in this study, Hahn and Foldspang (1997) stated that the stronger the quadriceps muscle group, the smaller the Q angle. Therefore, the researcher acted on the premise that muscles in the body determine bony alignment. For example,

the strength and tightness of the lower extremity muscles may have a direct effect on the femoral, patellar, tibial, and fibular alignment. In regards to the Q angle and TFA, if an abnormal measure exists for an individual, strengthening weaker musculature should, in theory, improve the structural deformity.

Quadriceps (Q) Angle

The goal of these exercises was to bring the subjects closer to average Q angle alignment. Average alignment has been defined in women as a Q angle between 14-17° (Lathinghouse & Trimble 2000) with danger of patellofemoral problems beginning at 19° (Liss & Liss, 2000). As stated in the literature review, Woodland and Francis (1992) conducted a study to establish the average values for Q angle and found that from a study sample of 257 women, the average Q angle for asymptomatic knees was 15.8-17°. Similarly, Aglietti, Insall, and Cerulli (1983) had a control population of 75 women with normal asymptomatic knees and found that the average Q angle was (Mean $\pm$ SD) $17 \pm 3^\circ$ in women. Within the same study, a female group of 56 pathologic or symptomatic knees were evaluated, and Aglietti et al. (1983) discovered that when the Q angle exceeded 20° in women, knee problems arose. These problems included chondromalacia, frequent patellar subluxations and/or dislocations, and general patellofemoral pain. In the pathologic group, the mean Q angle was (Mean $\pm$ SD) $19 \pm 4^\circ$, and Q angles greater than 20° and 23° existed in seven women (Aglietti, et al., 1983).

In the present study for the treatment group, the mean Q angle was (Mean $\pm$ SE) $20.48 \pm 3.43^\circ$ in the right leg and $18.4 \pm 3.92^\circ$ in the left leg. According to the literature, these measures are within the parameters that lead to lower extremity symptoms. There was a decrease of Q angle in the treatment group over the course of the study when the right and left leg measures were averaged. Yet, it is of interest to note that when comparing changes in the right and left Q angles separately, the right leg yielded greater changes throughout the course of the study in all treatment group subjects.

In the study conducted by Byl, Cole, and Livingston (2000), Q angle measurements differed in the right and left limbs by more than 4° in most of the subjects studied with larger value Q angles reported for the right leg. A possible explanation is that all of the treatment group subjects were right hand dominant. This was not a demographic question that was asked in any of the questionnaires prior to the study, but after the data were analyzed, each treatment group subject was contacted to verify their upper extremity dominance. Dominance is defined as a genetic pattern of inheritance that results in an individual preferring a hand or side of the body (Taber's cyclopedic medical dictionary, 1997). Typically, if an individual is right hand dominant, the left leg will be dominant in the lower extremity (Kendall et al., 1993). Larger strength gain occurs in weaker muscles as opposed to trained muscles. Therefore, it is possible that the right leg had more significant change due to the fact that those muscles were weaker to begin with, and were more readily adaptable to the exercises performed. This is supported by the findings of Neumann, Soderberg, and Cook (1988). It was stated by Neumann et al. (1988) that weakness in the right leg (mainly the hip abductors) was more prevalent in

right-handed individuals. However, it is still debatable whether dominance is opposite between upper and lower extremities. Reiss and Reiss (1997) found that right-handed subjects showed dominance of the right lower extremity, whereas Kauranen and Vanharanta (2001) found that correlations between the upper and lower extremities were lower in ipsilateral limbs than opposing limbs.

In the current study, the degree of change for the Q angle in the treatment group was approximately 6° in the right leg, approximately 1° in the left leg, and approximately 3° in the average between the right and left legs. These results suggest that the exercise protocol implemented for this study may serve to decrease Q angle, in turn, improving the physical appearance of genu valgum.

Tibial Femoral Angle (TFA)

Average tibial femoral angle (TFA) alignment is defined as 180° - 195° , and TFA's less than 180° are classified as genu valgum (Starkey & Ryan, 1996). Along with decreasing the Q angle, it was a goal of the exercises to increase the TFA. When data on the right and left leg were averaged together, there was an increase in treatment group TFA over time. When analyzed separately, the right leg data showed increase in the treatment group TFA over time, whereas the TFA in the left leg did not increase noticeably. This is congruent with the Q angle treatment group data. The same theory of dominance and strength applies in this situation as well. The degree of change was approximately 3° in the right leg, approximately 1° in the left leg, and approximately 2° in the average between the right and left legs. These results suggest that the exercise

protocol implemented for this study may serve to increase TFA, which improves the physical appearance of genu valgum.

Reliability Data

Since the digital photograph measures (Q angle and TFA) were analyzed twice for the left and right leg, it is necessary to determine whether the duplicate measures provided support for the methods used to make these measurements. There were some outlying data, but generally, the data collected displayed reasonably valid support for the methods used in the study. The greatest difference in p-value occurred in the left leg Q angle measure after week 4 (Q4L) when Trial 1 was (Mean $\pm$ SD) $18.8 \pm 8.9^\circ$ and Trial 2 was $19.6 \pm 8.9^\circ$. In regards to intraclass reliability, there was a disruption of reliability in the left leg TFA after week 2 (TF2L), as in the preliminary left leg TFA (TFPL). However, TFPL has a standard error of measurement (SEM) of ± 0.5 which was the lowest value amongst the SEM data. Intraclass reliability will always tend to be lower when the range of measurements is low (as indicated by a low SEM). The Q angle SEM values ranged from 0.6° to 1.9° . This indicates that Q angle needed to change in the present study by at least $\pm 2^\circ$ in order to be certain that true changes in Q angle were happening. There was a greater than 2° change in the treatment group right leg Q angle and when the right and left leg Q angle values were averaged together. The TFA SEM values ranged from 0.4° to 1.3° . This indicates that the TFA needed to change in the present study by at least $\pm 1^\circ$ in order to be certain that true changes in TFA occurred.

There was a greater than 1° change in the treatment group right leg TFA, left leg TFA, and when the right and left leg TFA's were averaged together. Any disruption in reliability is most likely due to human error, rather than any computer or program malfunctions.

Strength Measures

The strength measures were utilized to ensure that the exercises were indeed strengthening the intended muscle groups. The present study design assumed that musculature dictates bony alignment, it was necessary to validate the exercises by measuring strength gain of the targeted muscle groups. The muscle groups that were measured were as follows: the hip flexors, adductors and abductors, knee flexors and extensors, and hip internal and external rotators. The exercises were proved to increase strength due to the statistical significance that occurred in the treatment group. The control group had no noticeable strength gains. To conclude, it is apparent that the exercises did, indeed, promote strength gain. The only outlying finding was in regards to knee flexion. There was a steady decrease in strength for the treatment group, while the control group remained constant. This was an unforeseen occurrence for the researcher. A possible explanation is that in normal gait patterns, the hamstring muscles primarily fire during initial contact and in terminal swing (Kendall, et al., 1993). In people with genu valgum, however, the hamstrings work harder in order to compensate for the deformity and for apparent hip flexor weakness. The hamstrings gain strength because of

more activity. With this study, hip flexor strength was gained through the exercises and so, in theory, gait mechanics improved. The hamstring muscles would no longer have to compensate for the hip flexor weakness, which would decrease hamstring contractions significantly. Therefore, hamstring weakness would occur with the implemented exercise program.

Visual Analog Scales (VAS)

Although no significant statistical changes occurred with the VAS scores, they were useful to determine individual symptomatic changes. Therefore, the VAS scores were only utilized to further enhance individual subject changes.

Subject Characteristics

Within the study conducted, the eleven subjects were all fairly equal with their daily physical activity. This was determined by comparing the signs and symptoms questionnaire forms given at the beginning of the study. There were all moderately active, and were currently exercising on a reasonably regular basis. There were a few isolated instances that occurred during the data collection period of the study. One subject, who was assigned to the control group, sustained an inversion right ankle injury that required surgery to repair torn ligaments. She also had a severe degree of pes planus. It is noted in the literature reviewed that pes planus is commonly associated with genu valgum, which in turn, may lead to ankle injuries (Arnheim & Prentice, 2000, & Feeny, 1997). She attained her injury while playing competitive volleyball. In the pre-testing

for genu valgum, this subject had a quadriceps (Q) angle of 35.9° and a tibial femoral angle (TFA) of 174.2° in the right leg, and a Q angle of 22.8° and TFA of 175.7° in the left leg. Another subject, who was also in the control group, acquired a fracture of her left 5th metatarsal. This injury occurred on impact after jumping from a higher surface. This subject also had a noted degree of pes planus. At pre-testing, this particular subject had a Q angle of 13.14° and TFA of 176.845° in the right leg, a Q angle of 15.37° and TFA of 175.79° in the left leg. In both instances, the Q angle was higher and the TFA was lower in the injured extremity.

In the treatment group, there were two subjects who experienced knee pain. One had iliotibial (IT) band friction syndrome in her left knee. This was a condition that she had previously, but was re-aggravated during data collection from her running workout. Knee pain associated with genu valgum is well documented (AAOS, 1991, Boucher et al., 1992, Starkey & Ryan, 1996, Tomisch et al., 1996, Heiderscheit et al., 1999, Arnheim & Prentice, 2000, Liss & Liss, 2000, and Lathinghouse & Trimble, 2000). It is also worth noting that change in running pattern can occur with genu valgum as well (Heiderscheit et al., 1999). It is quite possible that these two factors led to her knee pain. At pre-testing, this subject had a Q angle of 21.8° and TFA of 172.3° in the right leg, and Q angle of 22.1° and TFA of 172.5° in the left leg. The other subject with knee pain was an active gymnast with a pre-existing bilateral meniscus injury with associated IT band friction syndrome. She was unable to continue her gymnastic work-outs with her pain. However, by the end of the study, her pain had decreased significantly and she was

able to return to modified work-outs. She was still not able to participate fully, but her condition was much improved. Her improvement can possibly be attributed to the rest from gymnastics, and the rehabilitative qualities of the exercise program she followed for the treatment group. At pre-testing, this gymnast had a Q angle of 32.1° and TFA of 171.8° in the right leg, and a Q angle of 34.2° and TFA of 173.5° in the left leg. It is of importance to correlate the individual measurements with the literature from Liss and Liss (2000) and Lathinghouse and Trimble (2000). Liss and Liss (2000) stated that if an individual had a Q angle of more than 19° , there is an increased chance for patellofemoral pain. Lathinghouse and Trimble (2000) stated that an increased chance for patellofemoral pain exists at a Q angle of greater than 17° . In both cases mentioned, it seems their pain can be at least partially attributed to their excessive degree of genu valgum. Liss and Liss (2000) also noted an improvement in patellofemoral pain with isometric strengthening exercises. This is consistent with the gymnast having decreased pain following the exercise protocol.

Subject Comments

Treatment group subject #1 had been diagnosed with genu valgum from a physician and complained of pes planus, repeated inversion ankle sprains, iliotibial band tightness and friction syndrome. Her main complaint was discomfort associated with her genu valgum prior to treatment. Following treatment, she stated she had improvement in her knee pain. She also thought that "longer duration would help- still have knee pain, but not as much pain as before the exercises."

Subject #2 reported that she wore orthotics but did not have any real complaints of pain other than knee pain associated with exercise. Her main complaint was the appearance of genu valgum prior to treatment. After the exercises, she did not notice a visual structural change. However, she said she would recommend the exercise protocol to others due to her increase in strength.

Subject #3 in the treatment group was the only external knee subject in the study. Her main concern prior to treatment was the appearance of genu valgum. She stated that her appearance improved, but she did not notice any improvement with her daily physical activities.

Treatment group Subject #4 had also been diagnosed with genu valgum from a physician and had to stop participating in cross-country due to pain in knees and overpronation in her feet. Her main complaint prior to treatment was pain and the appearance of genu valgum. This subject noticed visual improvements in the knees following the treatment. In daily activities, she also noted improvements and stated that "all activities were easier." She also mentioned she "could tell her legs were getting increasingly stronger and more toned."

Subject #5 complained of knee pain and shin soreness after running before the treatment, with the main complaint being pain in her knees while running. She stated she did notice an improvement in her shins and ankles following the study. In regards to daily activities, she noticed an improvement saying that "daily jogs seem easier, and I don't get as sore (shins)". Her comment on the study was "although the change is small, these exercises did help my problem."

The final subject in the treatment group was the gymnast who was experiencing a large amount of associated knee problems. Her main complaint was her landing technique in gymnastics. Her knees tended to "buckle towards each other." Following the study, she did not notice any improvements other than her ability to return to gymnastics with some pain relief.

All subjects who participated in the treatment group would recommend the protocol to others who had genu valgum and experienced some type of benefit from the six-week study.

Further Discussion

When observing the data collected, it is important to address the change that occurred in the treatment group as practical or not. It is believed by the researcher that the six-week exercise protocol did, in fact, begin to make an improvement in the appearance of genu valgum, or knock-knees. The change was practical in the sense that individual symptomatic improvement occurred as well, as determined from individual subject comments. When a program succeeds in alleviating painful symptoms, it can be incorporated into clinical settings in order to improve the health of a patient. It is noted in the literature, for example, that increased Q angle and tibial femoral angles (TFA) can lead to an increase in noxious symptoms. Therefore, the change in the Q angle and TFA measures in this study could possibly be used for treating people afflicted with genu valgum. Most of the subjects in this study stated they were also concerned with the perceived unattractive appearance of genu valgum. Since slight differences occurred

with a six-week program, it is possible that a longer program may cause an even greater change in Q angle and TFA. More research is required to determine how long the exercise program would need to be in order to produce desired results in appearance.

It has already been discussed that symptomatic relief may indicate practical significance, but in order to have an observable change occur in genu valgum, the degree of change would have to be greater than the values found in this study. Since surgical procedures are the only definitive methods for correcting genu valgum, it is rationalized that significant change needed in correcting genu valgum should come from the surgical data literature. When performing a partial epiphysiodesis, Bowen et al. (1992) stated that when the Q angle is 15-20°, operative correction is recommended, and the average correction for the surgical patients was 7.5°. Stevens et al. (1999) discussed the surgical procedure known as physeal stapling, and this procedure is warranted in subjects with genu valgum up to 20°. Stevens et al. (1999) stated that 10-15 mm of lateral physeal growth is often sufficient to correct the deformity, the Q angle with this surgery improves by an average of 8°, and is considered a complete solution for the deformity if successful. On the basis of the literature on surgical procedures, it seems that a change of 7-8° could be classified as a significant observable improvement to the genu valgum deformity. When using this guideline, there were no significant *observable* changes in the subjects involved in this study, even though there were statistically significant changes. In regards to the TFA, there is no known documented literature for specific changes that need to occur for observable changes to occur in genu valgum.

In order to definitively measure the Q angle and TFA of an individual, it is believed that roentgenograms (x-rays) would be the most accurate. Due to limited funding resources, it was impossible for x-rays to be utilized in this study. However, x-rays would reveal the actual bony alignment, and results would be more valid as opposed to taking measurements from anatomical landmarks on a subject.

It is also believed that standard weight training may, in fact, produce the same results of this study if the same muscle groups were targeted for strengthening. The determining factor of change in genu valgum appeared to be the strength gain that occurred in the treatment group of this study. If this finding is accurate, then it is logical to suggest that any exercises that would strengthen the targeted muscle groups would assist in decreasing genu valgum. However, further research would be required to test this hypothesis.

CONCLUSION

The purpose of this study was to utilize strengthening exercises to decrease the Quadriceps (Q) angle and increase the tibial femoral angle (TFA) in collegiate women. This condition is known as genu valgum, or "knock-knees," and abnormal measures of these angles have been documented as increasing lower extremity symptoms of pain and injury. Due to the pain experienced by people afflicted with genu valgum, it was the secondary goal of the study to alleviate these symptoms.

A six-week exercise protocol was implemented in six female subjects, and the targeted muscle groups for strengthening were as follows: the hip flexors, adductors and abductors, knee flexors and extensors, and hip internal and external rotators. Digital photographs were taken weekly and strength measures were taken prior to, after week three, and immediately following the study. This data was used to determine whether change in Q angle and TFA occurred with the protocol.

The results of the study noted that a decrease in Q angle did appear in the treatment group, although the changes were only a few degrees. More change occurred in the right leg. There was also a change revealed in the TFA, and like the Q angle changes, more was present in the right leg. Strength did, in fact, increase with the exercises in the treatment group, and the subjects reported a decrease in their symptoms.

It is presumed that an even longer time period devoted to the exercise protocol would yield greater change in the appearance of genu valgum. It is also suggested that further study on this subject should include roentgenograms (x-rays) as a more valid part

of the data collection process. The strength gain appears to be the driving factor in achieving a decrease in the appearance of genu valgum. On that assumption, it is suggested that a traditional weight training program targeting the specified muscle groups would produce results as well.

To conclude, this protocol proved to be a beginning step to correcting the appearance of genu valgum, or "knock-knees." Also, this study confirmed that strengthening exercises will lead to decreasing individual symptomatic problems associated with genu valgum.

GLOSSARY

Angle of inclination:

Angular relationship of the femoral head and the femoral shaft. Can be determined roughly by observing the correlation between the femur and the tibia (Starkey & Ryan, 1996).

Anteversion:

A forward bending or angulation of a bone or organ (Starkey & Ryan, 1996).

Arthroplasty:

Plastic surgery to reshape or reconstruct a diseased joint. This may be done to alleviate pain, permit normal function, or to correct a development or hereditary joint defect (Taber's cyclopedic medical dictionary, 1997).

Chondromalacia:

Degenerative process that results in a softening or degeneration of the articular surface of the patella (Booher & Thibodeau, 1994).

Complementary physeal-shaft (CPS) angle:

The angle formed between a line drawn along the long axis of the tibia and a line perpendicular to the proximal tibial physis (McCarthy et al., 1998).

Coxa vara:

A deformity produced when the angle made by the head of the femur with the shaft is decreased below 120 degrees (Taber's cyclopedic medical dictionary, 1997).

Electromyography (EMG):

A graphic record of the contraction of a muscle as a result of electrical stimulation (Taber's cyclopedic medical dictionary, 1997).

Epiphyseal:

Thin plate of cartilage separating the diaphysis from each epiphysis in growing bones; the extremities, or ends, of long bones (Booher & Thibodeau, 1994).

Epiphysiodesis:

Bone lengthening; A surgical procedure that can lengthen a bone (www.adam.com/ency/article/002965.htm, 2000).

Genu valgum:

Knock-knees; the femur and tibia are angled inward (Starkey & Ryan, 1996).

Genu varum:

Bowleg; the femur and tibia are angled outward (Starkey & Ryan, 1996).

Genu recurvatum:

Back-knees; over hyperextension of the knees (Hoppenfeld, 1976).

Goniometer:

Instrument used to objectively measure range of motion. Consists of two rigid shafts connected by a hinge joint, with a protractor fixed to one shaft to accurately read the ROM in degrees (Booher & Thibodeau, 1994).

Heel spurs:

Bony projection at the plantar aspect of the calcaneal tuberosity, which may accompany or result from severe cases of plantar fasciitis (Booher & Thibodeau, 1994).

Hemiphyseal:

Pertaining to one physis.

Idiopathic:

Pertaining to conditions without recognizable cause, as of spontaneous origin (Taber's cyclopedic medical dictionary, 1997).

Malicious malalignment syndrome:

Excessive internal rotation of the hips, genu valgus, pes planus, and increased Q angle (Liss & Liss, 2000).

Osteoarthritis:

A type of arthritis marked by progressive cartilage deterioration in synovial joints and vertebrae (Taber's cyclopedic medical dictionary, 1997).

Osteotomy:

The operation for cutting through a bone (Taber's cyclopedic medical dictionary, 1997).

Pes planus:

Flat feet, static structural abnormality in which the relative position of the foot bones have been altered, resulting in a lowering of the longitudinal arch (Booher & Thibodeau, 1994).

Physis:

The segment of bone concerned mainly with growth (Booher & Thibodeau, 1994).

Quadriceps (Q) angle:

Angle formed by the intersection of a line from the anterior superior iliac spine to the midpatella and another line from midpatella to the tibial tuberosity; an angle of 15 degrees or less is considered normal (Booher & Thibodeau, 1994).

Roentgenograms:

X-rays

Squinting patella:

Occurs secondary to an internal rotation of the lower extremity and is noted by medially positioned patellae on the femur (Starkey & Ryan, 1996).

Terminal extension:

The end degrees of extension (Boucher et al., 1992).

Tibial-femoral angle (TFA):

The angle formed by a line drawn along the long axis of the tibia and a line drawn along the long axis of the femur (McCarthy et al., 1998).

REFERENCES CITED

- Aglietti, P., Insall, J.N., & Cerulli, G. (1983). Patellar pain and incongruence. I: Measurements of incongruence. Clinical Orthopaedics and Related Research, 176, 217-224.
- American Academy of Orthopedic Surgeons. (1991). Athletic Training and Sports Medicine (2nd ed.). Park Ridge, IL: Author.
- Arnheim, D.D., & Prentice, W.E. (2000). Principles of Athletic Training (10th ed.). Boston: McGraw-Hill.
- Balthazar, D.A., & Pappas, A.M. (1984). Acquired valgus deformity of the tibia in children. Journal of Pediatric Orthopaedics, 4, 538-541.
- Biedert, R.M., & Gruhl, C. (1997). Axial computed tomography of the patellofemoral joint with and without quadriceps contraction. Archives of Orthopedic Trauma Surgery, 116, 77-82.
- Booher, J.M., & Thibodeau, G.A. (1994). Athletic Injury Assessment (3rd ed.). St. Louis: Mosby.
- Boucher, J.P., King, M.A., Lefebvre, R., & Pepin, A. (1992). Quadriceps femoris muscle activity in patellofemoral pain syndrome. American Journal of Sports Medicine, 20, 527-532.
- Bowen, J.R., Torres, R.R., & Forlin, E. (1992). Partial Epiphysiodesis to Address Genu Varum or Genu Valgum. Journal of Pediatric Orthopaedics, 12, 359-364.
- Byl, T., Cole, J.A., & Livingston, L.A. (2000). What Determines the Magnitude of the Q Angle? A Preliminary Study of Selected Skeletal and Muscular Measures. Journal of Sport Rehabilitation, 9, 26-34.
- Cowan, D.N., Jones, B.H., Frykman, P.N., Polly, D.W., Harman, E.A., Rosenstein, R.M., & Rosenstein, M.T. (1996). Lower limb morphology and risk of overuse injury among male infantry trainees. Medicine and Science in Sports and Exercise, 28, 945-952.
- Edgerton, B.C., Mariani, E.M., & Morrey, B.F. (1993). Distal Femoral Varus Osteotomy for Painful Genu Valgum: A Five-to-11 Year Follow-Up Study. Clinical Orthopaedics and Related Research, 288, 263-269.

- Ecoscue, P. & Gittines, R. (1998). Pain Free. New York: Bantam Books.
- Feeny, T. (1997). If the shoe fits. Advance Magazine for Physical Therapists, 7, 7-14.
- Finkelstein, J.A., Gross, A.E., & Davis, A. (1996). Varus Osteotomy of the Distal Part of the Femur. The Journal of Bone and Joint Surgery, 78, 1348-1352.
- Griffin, L.Y., Agel, J., Albohm, M.J., Arendt, E.A., Dick, R.W., Garrett, W.E., Garrick, J.G., Hewett, T.E., Huston, L., Ireland, M.L., Johnson, R.J., Kibler, W.B., Lephart, S., Lewis, J.L., Lindenfeld, T.N., Mandelbaum, B.R., Marchak, P., Teitz, C.C., & Wojtys, E.M. (2000). Noncontact Anterior Cruciate Ligament Injuries: Risk Factors and Prevention Strategies. Journal of the American Academy of Orthopedic Surgeons, 8, 141-150.
- Guerra, J, Arnold, M, & Gajdosik, R. (1994). Q-Angle: effects of isometric quadriceps contraction and body position. Journal of Orthopedic Sports Therapy, 19, 200-204.
- Hahn, T., & Foldspang, A. (1997). The Q angle and sport. Scandinavian Journal of Medical Science and Sports, 7, 43-48.
- Heiderscheit, B.C., Hamill, J., & Van Emmerik, R.E.A. (1999). Q-angle influences on the variability of lower extremity coordination during running. Medicine and Science in Sports and Exercise, 31, 1313-1320.
- Hoppenfeld, S. (1976). Physical Examination of the Spine and Extremities. Norwalk, Connecticut: Appleton & Lance.
- Kauranen, K.J., & Vanharanta, H.V. (2001). Relationship between extremities in motor performance. Perceptual and Motor Skills, 92, 11-18.
- Kendall, F.P., McCreary, E.K., & Provance, P.G. (1993) Muscles: Testing and Function (4th ed.). Baltimore: Williams & Wilkins.
- Kreighbaum, E. & Barthels, K.M. (1996). Biomechanics: A Qualitative Approach for Studying Human Movement (4th ed.). Boston: Allyn & Bacon.
- Lathinghouse, L.H., & Trimble, M.H. (2000). Effects of Isometric Quadriceps Activation on the Q-Angle in Women Before and After Quadriceps Exercise. Journal of Orthopaedic and Sport Physical Therapy, 30, 211-216.

- Liss, H. & Liss, D. (No date). *Patellofemoral Syndrome* [Online]. Available: <http://www.rehabmed.net/documents/patelloff.html> [2000, September 25].
- Livingston, L.A. (1998). The Quadriceps Angle: A Review of the Literature. Journal of Orthopedics and Sport Physical Therapy, 28, 105-109.
- Lysholm, J., Nordin, M., & Ekstrand, J. (1984). The effect of a patella brace on performance in a knee extension strength test in patients with patellar pain. American Journal of Sports Medicine, 12, 110.
- McCarthy, J.J., Kim, D.H., & Eilert R.E. (1998). Posttraumatic genu valgum: operative versus nonoperative treatment. Journal of Pediatric Orthopedics, 18, 517-521.
- Moeller, J.L., & Lamb, M.M. (1997). Anterior cruciate ligament injuries in female athletes: Why are women more susceptible? The Physician and Sports Medicine, 25, 1-10.
- Neumann, D.A., Soderberg, G.L., & Cook, T.M. (1988). Comparison of maximal isometric hip abductor muscle torques between hip sides. Physical Therapy, 68, 496-502.
- Powers, CM. (1998). Rehabilitation of patellofemoral joint disorders: a critical review. Journal of Orthopedic Sports Physical Therapy, 28, 345-354.
- Reiss, M. & Reiss, G. (1997). Asymmetry of the stepping test. Perceptual and Motor Skills, 85, 305-306.
- Shahane, S.A., & Bickerstaff, D.R. (1998). Proximal advancement of the medial collateral ligament for chronic medial instability of the knee joint. The Knee, 5, 191-197.
- Shambaugh, J.P., Klein, A., & Herbert, J.H. (1991). Structural measures as predictors of injury in basketball players. Medicine and Science in Sports and Exercise, 23, 522-527.
- Starkey, C., & Ryan, J.L. (1996). Evaluation of Orthopedic and Athletic Injuries. Philadelphia: F.A. Davis Company.
- Stevens, P.M., Maguire, M., Dales, M.D., & Robins, A.J. (1999). Physeal Stapling for Idiopathic Genu Valgum. Journal of Pediatric Orthopedics, 19, 645-649.

- Thomas, C.L., Egan, E.J., Vardara, D.R., Wight, A.A., Morelli, N.A., Fithian, M., Houska, A., & Willert, B.A. (Ed.). (1997). Taber's cyclopedic medical dictionary (18th ed.). Philadelphia: F.A. Davis Company.
- Tomsich, D.A., Nitz, A.J., Threlkeld, A.J., & Shapiro, R. (1996). Patellofemoral Alignment: Reliability. Journal of Orthopedics and Sport Physical Therapy, 23, 200-208.
- Woodland, L.H., & Francis, R.S. (1992). Parameters and comparisons of the quadriceps angle of college-aged men and women in the supine and standing positions. American Journal of Sports Medicine, 20, 208-211.

APPENDICES

APPENDIX A

SIGNS AND SYMPTOMS QUESTIONNAIRES

Signs and Symptoms Questionnaire for Genu Valgum

Pre-Study

DEMOGRAPHIC INFORMATION:

NAME: _____	AGE: _____
WEIGHT: _____	HEIGHT: _____
PHONE: _____	

HISTORY:

Have you ever been diagnosed with genu valgum ("knock-knees") by a physician?

Yes _____ No _____

If answered yes, when? _____

Please list any orthopedic problems you have experienced with your feet, ankles, lower legs, knees, thighs, hips, groin, and/or low back.

Do you wear orthotics?

Yes _____ No _____

If answered yes, why? _____

Has an attempt ever been used to correct your genu valgum?

Yes _____ No _____

What method(s) were used? _____

Have you ever received physical therapy for genu valgum?

Yes _____ No _____

If answered yes, did you have satisfactory results?

Yes _____ No _____

What is your main complaint of having genu valgum? (appearance, pain, discomfort, etc.)

Do you consider yourself to be inactive, moderately active, or extremely physically active?

Please list your physical activities and the typical duration of activity:

VISUAL ANALOG SCALES:

Please place a perpendicular line on the following scales to rate your pain for the last 6 months.

The far left of the scale represents no pain, and the far right represents the most excruciating pain you have experienced.

Pre-Exercise Pain

FEET

|_____|
 No pain Most pain ever experienced

ANKLES

|_____|
 No pain Most pain ever experienced

LOWER LEGS

|_____|
 No pain Most pain ever experienced

KNEES

|_____|
 No pain Most pain ever experienced

THIGHS

|_____|
 No pain Most pain ever experienced

HIPS

|_____|
 No pain Most pain ever experienced

GROIN

|_____|
 No pain Most pain ever experienced

LOW BACK

|-----|
No pain Most pain ever experienced

During Exercise Pain

FEET

|-----|
No pain Most pain ever experienced

ANKLES

|-----|
No pain Most pain ever experienced

LOWER LEGS

|-----|
No pain Most pain ever experienced

KNEES

|-----|
No pain Most pain ever experienced

THIGHS

|-----|
No pain Most pain ever experienced

HIPS

|-----|
No pain Most pain ever experienced

GROIN

|-----|
No pain Most pain ever experienced

LOW BACK

|-----|
No pain Most pain ever experienced

Post Exercise Pain

FEET

|-----|
No pain Most pain ever experienced

ANKLES

|-----|
No pain Most pain ever experienced

LOWER LEGS

|-----|
No pain Most pain ever experienced

KNEES

|-----|
No pain Most pain ever experienced

THIGHS

|-----|
No pain Most pain ever experienced

HIPS

|-----|
No pain Most pain ever experienced

GROIN

|-----|
No pain Most pain ever experienced

LOW BACK

|-----|
No pain Most pain ever experienced

PAR-Q: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise and completion of a PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life. For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read the following questions carefully and check the YES or NO opposite the question if it applies to you.

YES NO

1. Has your doctor ever said you have heart trouble?
2. Do you ever have pains in your heart or chest?
3. Do you ever feel faint or have spells of severe dizziness?
4. Has a doctor ever said your blood pressure was too high?
5. Has a doctor ever said your blood cholesterol was too high?
6. Have you ever been diagnosed with diabetes mellitus?
7. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise?
8. Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to?
9. Are you over the age of 65 or NOT accustomed to vigorous exercise?
10. Are you a habitual cigarette or cigar smoker?
 if YES, how many years? _____
 if NO, and you have recently quit smoking, how long ago did you quit? _____ (give answer in months or years)

11. Is there any other physical ailment not mentioned above that could be considered a health risk if you were to participate in the testing described by the Informed Consent Document? If YES, please describe below...

If you answered "YES" to one or more questions...

If you have not recently done so, consult with your personal physician by telephone or in person before increasing your physical activity, taking a fitness test, or participating in the present research study. Tell the physician what questions you answered "YES" on PAR-Q or show a copy of the form. Be certain to talk with the principal investigator before proceeding further with your involvement in this study.

If you answered "NO" to all questions...

You have reasonable assurance that your participation in the present study will not put you at higher risk for injury or illness.

NOTE: Postpone exercise testing if you suffer from minor illness such as a common cold or flu!

Your signature below indicates you have completed the preceding PAR-Q form to the best of your knowledge.

Signed: _____ Date _____
(Subject's Signature)

Signed: _____ Date _____
(Project Director)

Signs and Symptoms Questionnaire for Genu Valgum
Post-Study (Treatment Group)

DEMOGRAPHIC INFORMATION:

NAME: _____	AGE: _____	
WEIGHT: _____	HEIGHT: _____	PHONE: _____

HISTORY:

Did you notice any improvements with any of your previous lower extremity pain?

Yes _____ No _____

If answered yes, which body part(s)? _____

Did you notice an alteration in the appearance of your genu valgum?

Yes _____ No _____

If answered yes, is your condition improved or worsened? _____

Have you noticed any improvement in daily activities?

Yes _____ No _____

If answered yes, please list improved activities.

Are you satisfied with the results of the exercises?

Yes _____ No _____

Comments:

Would you recommend this exercise protocol to others with genu valgum?

Yes _____ No _____

The far left of the scale represents no pain, and the far right represents the most excruciating pain you have experienced.

Pre-Exercise Pain

LOW BACK

No pain Most pain ever experienced

During Exercise Pain

FEET

|-----|
No pain Most pain ever experienced

ANKLES

|-----|
No pain Most pain ever experienced

LOWER LEGS

|-----|
No pain Most pain ever experienced

KNEES

|-----|
No pain Most pain ever experienced

THIGHS

|-----|
No pain Most pain ever experienced

HIPS

|-----|
No pain Most pain ever experienced

GROIN

|-----|
No pain Most pain ever experienced

LOW BACK

|-----|
No pain Most pain ever experienced

Post Exercise Pain

FEET

|_____|
No pain Most pain ever experienced

ANKLES

|_____|
No pain Most pain ever experienced

LOWER LEGS

|_____|
No pain Most pain ever experienced

KNEES

|_____|
No pain Most pain ever experienced

THIGHS

|_____|
No pain Most pain ever experienced

HIPS

|_____|
No pain Most pain ever experienced

GROIN

|_____|
No pain Most pain ever experienced

LOW BACK

|_____|
No pain Most pain ever experienced

Signs and Symptoms Questionnaire for Genu Valgum
Post-Study (Control Group)

DEMOGRAPHIC INFORMATION:

NAME: _____	AGE: _____
WEIGHT: _____	HEIGHT: _____
PHONE: _____	

HISTORY:

Did you comply with the guidelines of being in the control group?

Yes _____ No _____

Have you noticed any physical change in your genu valgum?

Yes _____ No _____

If answered yes, did your condition improve or worsen? _____

Would you be interested in attempting the exercise protocol given to the other group?

Yes _____ No _____

VISUAL ANALOG SCALES:

Please place a perpendicular line on the following scales to rate your pain for the last 6 months.

The far left of the scale represents no pain, and the far right represents the most excruciating pain you have experienced.

Pre-Exercise Pain

FEET

| _____ |
No pain Most pain ever experienced

ANKLES

| _____ |
No pain Most pain ever experienced

LOWER LEGS

|-----|
No pain Most pain ever experienced

KNEES

|-----|
No pain Most pain ever experienced

THIGHS

|-----|
No pain Most pain ever experienced

HIPS

|-----|
No pain Most pain ever experienced

GROIN

|-----|
No pain Most pain ever experienced

LOW BACK

|-----|
No pain Most pain ever experienced

During Exercise Pain

FEET

|-----|
No pain Most pain ever experienced

ANKLES

|-----|
No pain Most pain ever experienced

LOWER LEGS

|-----|
No pain Most pain ever experienced

KNEES

|-----|
No pain Most pain ever experienced

THIGHS

|-----|
No pain Most pain ever experienced

HIPS

|-----|
No pain Most pain ever experienced

GROIN

|-----|
No pain Most pain ever experienced

LOW BACK

|-----|
No pain Most pain ever experienced

Post Exercise Pain

FEET

|-----|
No pain Most pain ever experienced

ANKLES

|-----|
No pain Most pain ever experienced

LOWER LEGS

|-----|
No pain Most pain ever experienced

KNEES

|-----|
No pain Most pain ever experienced

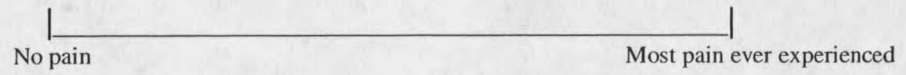
THIGHS

|-----|
No pain Most pain ever experienced

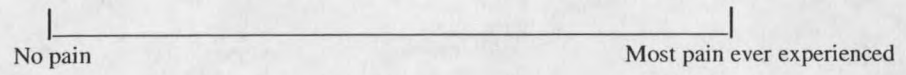
HIPS

|-----|
No pain Most pain ever experienced

GROIN



LOW BACK



APPENDIX B

EXERCISE PROTOCOL

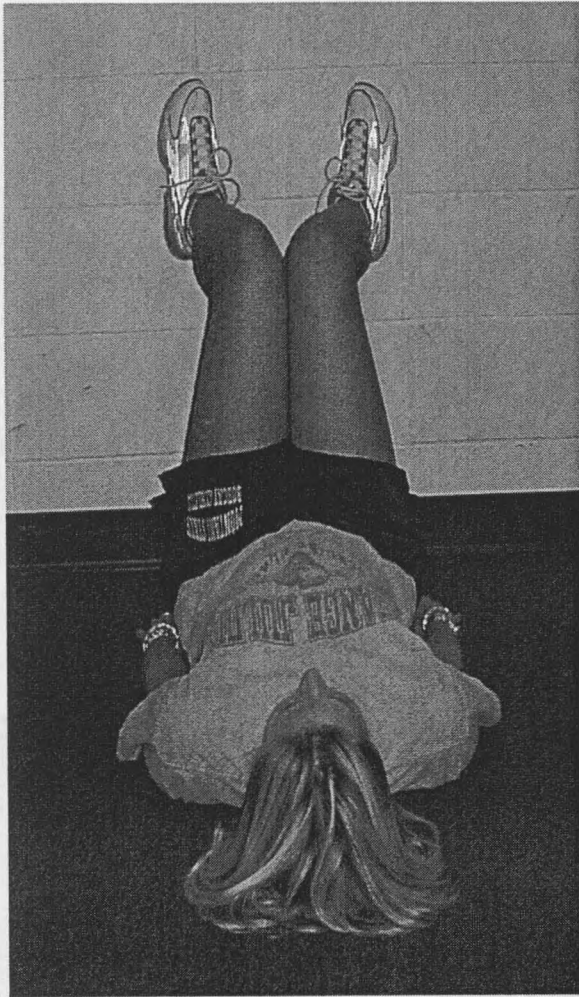
Table 11. Exercise Menu for subjects classified with Internal Knees. The exercise names are given for week 1-2, week 3-4, and week 5-6. The desired repetitions per set or minutes for each exercise are given.

<u>Week</u>	<u>Exercise Name</u>	<u>Sets</u>	<u>Repetitions</u>	<u>Timed Exercise</u>
1-2	Wall Drop	3	25	
	Foot Circles / Point Flex	3	20	
	Abduction / Adduction	3	10	
	Sitting Heel Raises	3	20	
	Isolated Hip Flexor Lifts	3	25	
	Cats and Dogs	1	10	
	Active Cobra	1		3 minutes
	Supine Groin Stretch	1		10 minutes/ each
	Wall Sit	1		2 minute
3-4	Sitting Floor	1		3 minutes
	Sitting Floor Twist	1		1 minute/ each
	Cats and Dogs	1	10	
	Kneeling Counter Stretch	1		1 minute
	Counter Stretch	1		1 minute
	Kneeling Groin Stretch	1		1 minute/ each
	Modified Runner's Stretch	1		1 minute/ each
	Kneeling Counter Stretch	1		1 minute
	Cats and Dogs	1	10	
	Crocodile Twist	1		1 minute/ each
	Active Bridge	1		1 minute
	Hand-Leg Opposite Blocked	1		2 minutes/ each
	Hand-Leg Opposite Glide	1	10	
	Cats and Dogs	1	10	
	Supine Groin Stretch	1		10 minutes/ each
	Squat	1		1 minute
5-6	Counter Stretch	1		1 minute
	Foot Circles / Point Flex	1	20	
	Supine Gastroc / Hamstring Stretch	1		1 minute/ each
	Abduction / Adduction	2	20	
	Assisted Hip Lift	1		1 minute/ each
	Hip Crossover	1		1 minute/ each
	Cats and Dogs	1	10	
	Supine Groin Stretch	1		15 minutes/ each
	Static Wall	3	20	

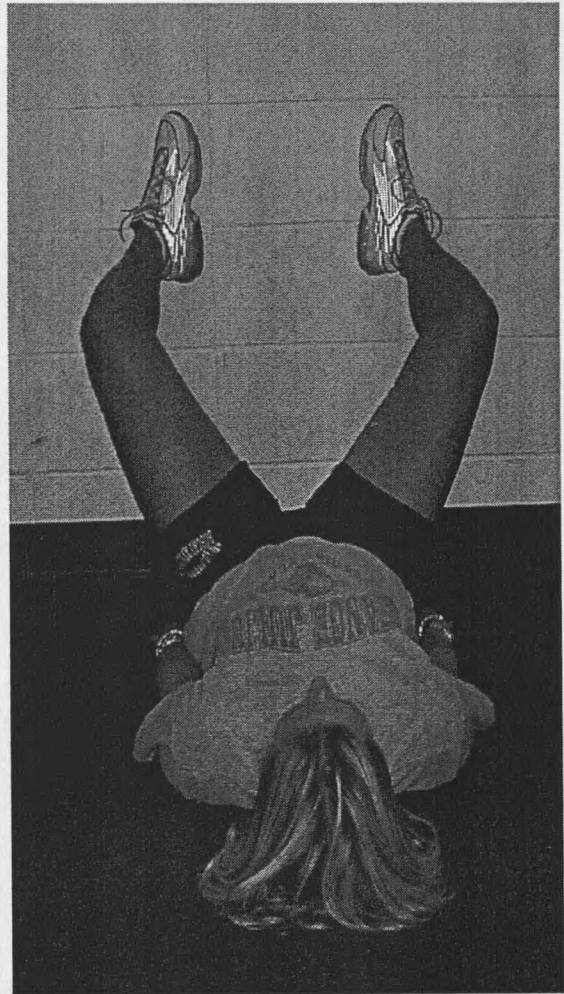
Table 12. Exercise Menu for subjects classified with External Knees. The exercise names are given for week 1-2, week 3-4, and week 5-6. The desired repetitions per set or minutes for each exercise are given.

<u>Week</u>	<u>Exercise Name</u>	<u>Sets</u>	<u>Repetitions</u>	<u>Timed Exercise</u>
1-2	Static Back	1		1 minute
	Abduction / Adduction	3	10	
	Foot Circles / Point Flex	3	20	
	Cats and Dogs	1	10	
	Sitting Floor	1		3 minutes
	Double – Double	3	25	
	Double – Switch	3	25	
	Cats and Dogs	1	10	
	Progressive Supine	1		15 minutes/ each
	Wall Sit	1		2 minutes
3-4	Foot Circles / Point Flex	3	20	
	Static Back	1		10 minutes
	Pullovers	1	20	
	Reverse Presses	3	20	
	Upper Spinal Floor Twist	1		1 minute/ each
	Cats and Dogs	1	10	
	Abduction / Adduction	3	10	
	Assisted Hip Lift	1		1 minute/ each
	Hip Crossover	1		1 minute/ each
	Pelvic Tilts	1	10	
	Static Wall	1		3 minutes
	Static Wall Femur Rotation	3	10	
	Counter Stretch	1		1 minute
	Sitting Adductor Press	3	20	
	Progressive Supine	1		5 minutes/ each
	Wall Sit	1		2 minutes
5-6	Counter Stretch	1		1 minute
	Foot Circles / Point Flex	1	20	
	Supine Gastroc / Hamstring	1		1 minute/ each
	Abduction / Adduction	2	20	
	Assisted Hip Lift	1		1 minute/ each
	Hip Crossover	1		1 minute
	Cats and Dogs	1	10	
	Supine Groin Stretch	1		15 minutes/ each
	Static Wall	3	20	

ADDUCTION / ABDUCTION



A



B

Figure 6. The model is demonstrating Adduction (A) and Abduction (B). The standardized instructions were as follows: "Lie on your back with your feet on a wall. Touch your knees together (adduction) while keeping your feet straight and at the width of your hips. Open the knees as wide as you can (abduction) while rolling to the outside edge of the foot and then back to the center. Do not let your feet flair out" (Egoscue & Gittines, 1998).

ACTIVE BRIDGE

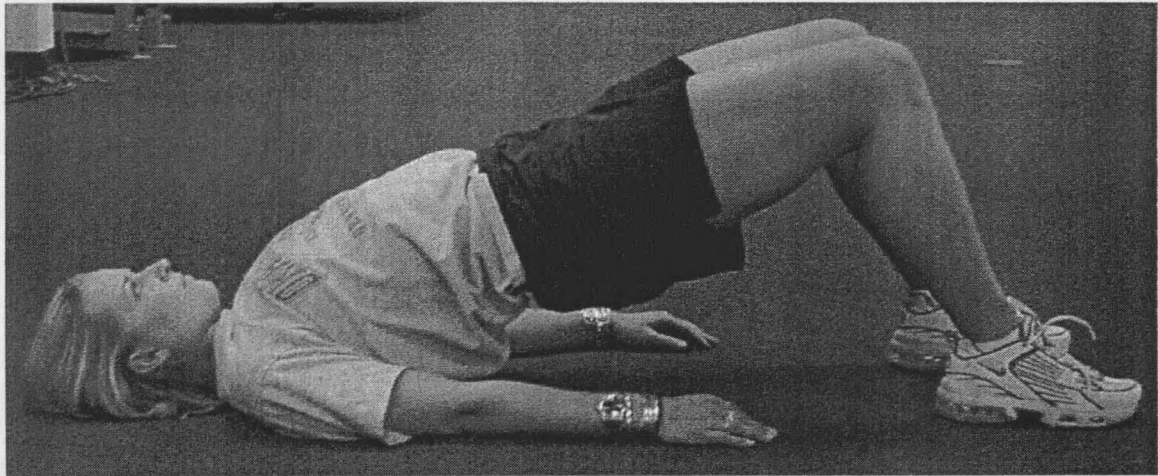


Figure 7. The model is demonstrating the Active Bridge exercise. The standardized instructions were as follows: "Lie supine with your knees bent, feet straight, and arms at your side. Pull the scapulas together and lift the hips off the floor. Keep the shoulders, hips, and knees in a straight line. Do not let your knees adduct or abduct. Hold for desired time" (Egoscue & Gittines, 1998).

ACTIVE COBRA

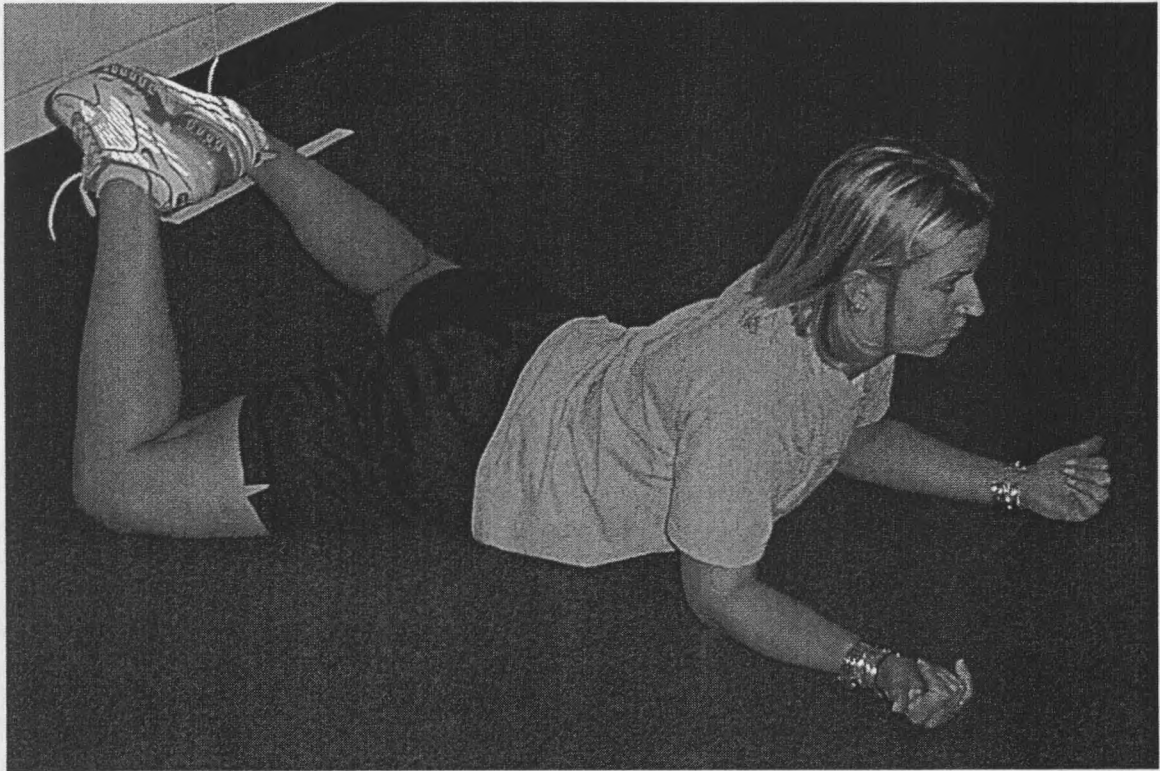


Figure 8. The model is demonstrating the Active Cobra exercise. The standardized instructions were as follows: "Lie prone with your knees far apart and the soles of your feet together. With your upper body on your elbows, form fists with your hands and point the thumbs up. Look straight ahead. Relax the gluteal muscles, externally rotate the forearms, let the scapulas adduct toward each other, and press the feet together. Hold for desired time" (Egoscue & Gittines, 1998).

ASSISTED HIP LIFT

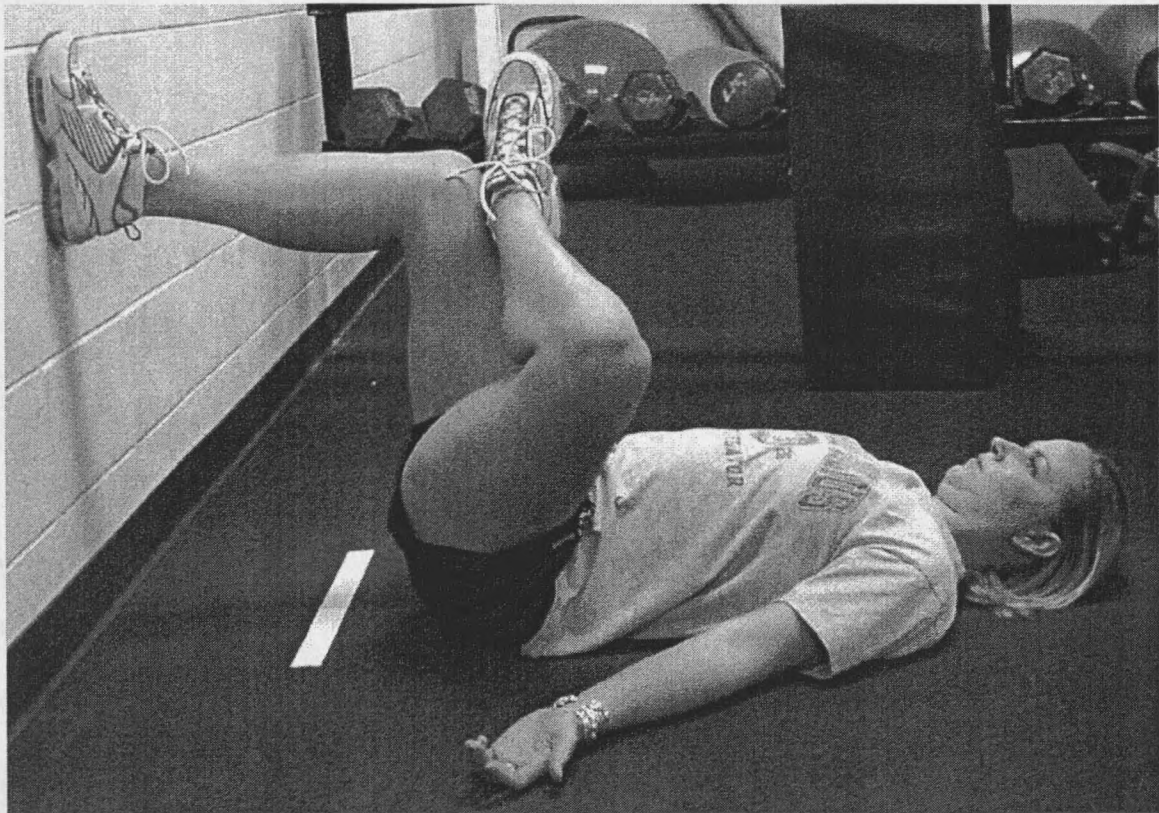
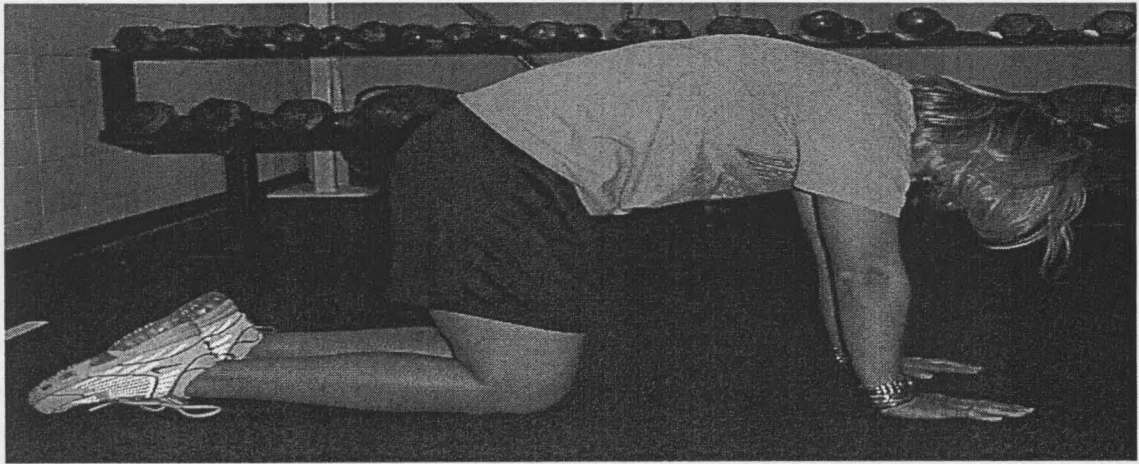
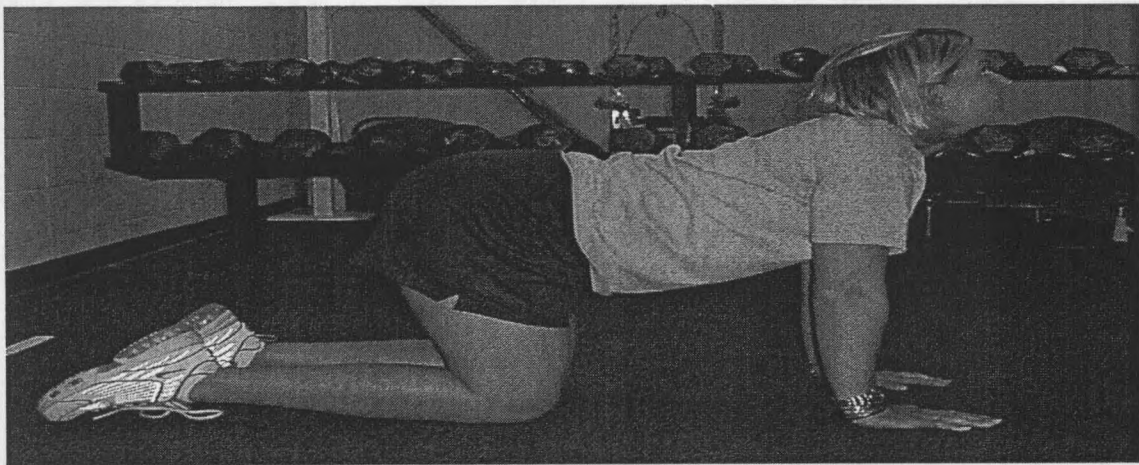


Figure 9. The model is demonstrating the Assisted Hip Lift exercise. Standardized instructions for this exercise were as follows: "With the right leg against a wall, pull the left foot on the right knee. Push the right knee away from you using your left leg. Keep the hips level and square. Breathe with the stomach and repeat the exercise with the opposite leg" (Egoscue & Gittines, 1998).

CATS AND DOGS



A



B

Figure 10. The model is demonstrating Cat (A) and Dog (B). Standardized instructions for this exercise were as follows: "On hands and knees, place hands in line with the shoulders and the knees in line with the hips. Your lower legs should be straight and distribute weight evenly. CAT: Round your back up while moving your chin towards your chest. This should create a curve from the buttocks to the neck. DOG: Arch downward from Cat position. The shoulders should come together. Make these two moves flow smoothly between each other and make the hips do the work" (Egoscue & Gittines, 1998).

COUNTER STRETCH

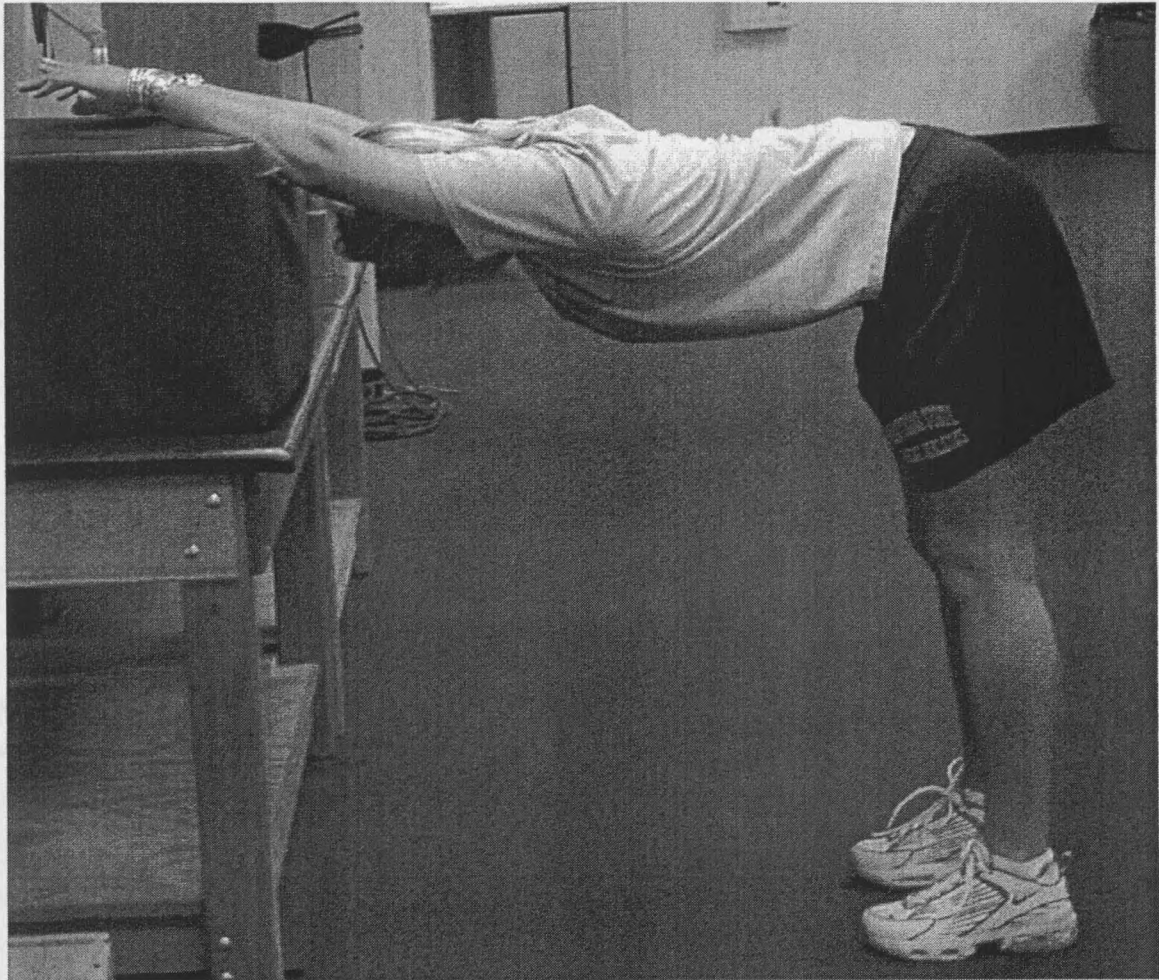
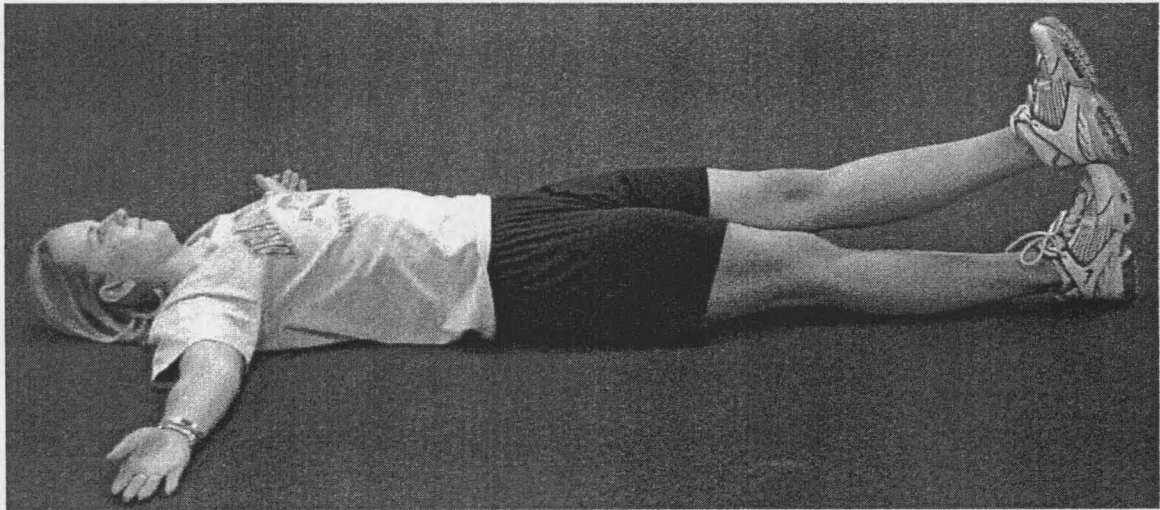
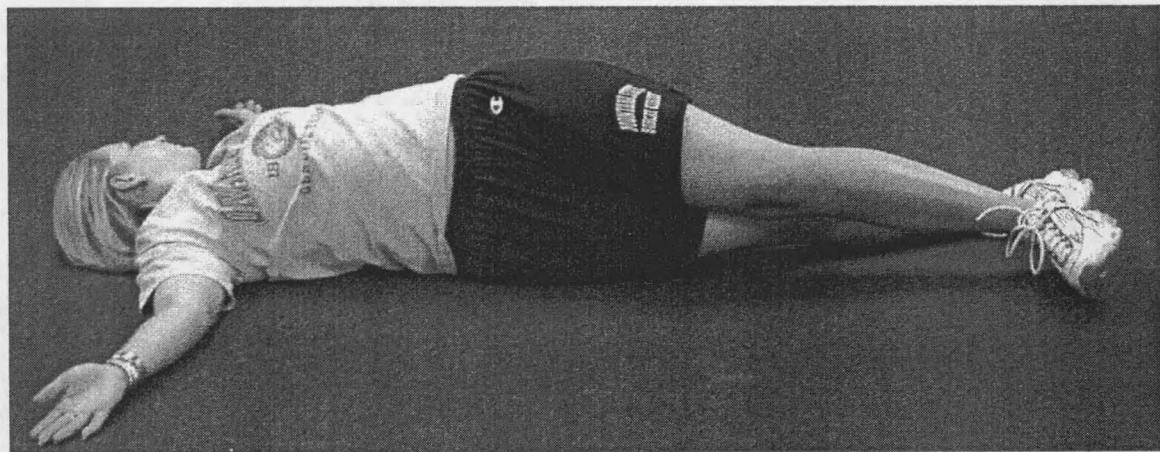


Figure 11. The model is demonstrating the Counter Stretch exercise. The standardized instructions for this exercise were as follows: "Put your hands flat on a counter top that is waist level. Forward flex at the waist while maintaining the lumbar curve. The feet should be straight and directly under your hips. You can walk the feet back to get full extension from the legs. The arms are outstretched on the same plane as the head. Tighten the quadriceps muscles and relax the shoulder and abdominal muscles" (Egoscue & Ginttines, 1998).

CROCODILE TWIST



A



B

Figure 12. The model is demonstrating the Crocodile Twist: Start Position (A) and the Crocodile Twist: End Position (B). Standardized instructions for this exercise is as follows: "Lie supine with legs extended and arms out to the side. Place the left heel on top of the right toes. Tighten the quadriceps muscles of both legs and hold. Keeping the feet in a straight line, roll the feet to the right. As you do this, lift the left hip off the floor and point it towards the ceiling. Turn your head to the opposite direction. Hold for desired amount of time" (Egoscue & Gittines, 1998).

DOUBLE – DOUBLE



Figure 13. The model is demonstrating the Double – Double exercise. Standardized instructions for this exercise were as follows: “Lie supine with knees bent, feet straight and at hip width apart. Place a strap around your knees and a six-inch block between the feet. Abduct the legs while squeezing the block. Do not tighten the abdominal muscles” (Egoscue & Gittines, 1998).

DOUBLE - SWITCH



Figure 14. The model is demonstrating the Double – Switch exercise. The standardized instructions for this exercise were as follows: “Lie supine with your knees bent and your feet flat and straight. Put a six-inch block between your knees and a strap around your ankles. Adduct the legs while pressing out on the strap. Do not tighten the abdominal muscles” (Egoscue & Gittines, 1998).

FOOT CIRCLES / POINT FLEX

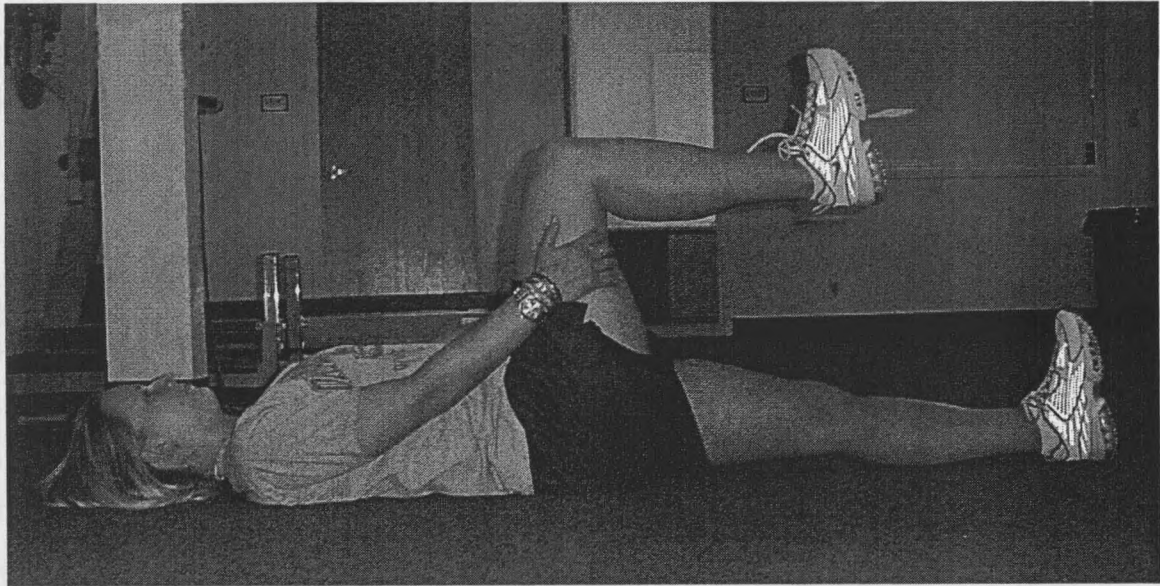


Figure 15. The model is demonstrating the Foot Circles / Point Flex exercise. Standardized instructions for this exercise is as follows: "Lie on your back with one leg extended and the other bent at 90°. Grab the bent leg behind the knee with both hands. Pull the shoulders back and relax the abdominal muscles. Tighten the quadriceps muscles of the straight leg and point the foot straight up. Keeping the shin of the bent leg still, circle the foot clockwise then reverse the direction. Then pull the toes toward the shin for flexes and point the toes in the opposite direction. Make sure the foot travels in a straight line; it should not wander in or out. Repeat with the other leg" (Egoscue & Gittines, 1998).

HAND-LEG OPPOSITE BLOCKED

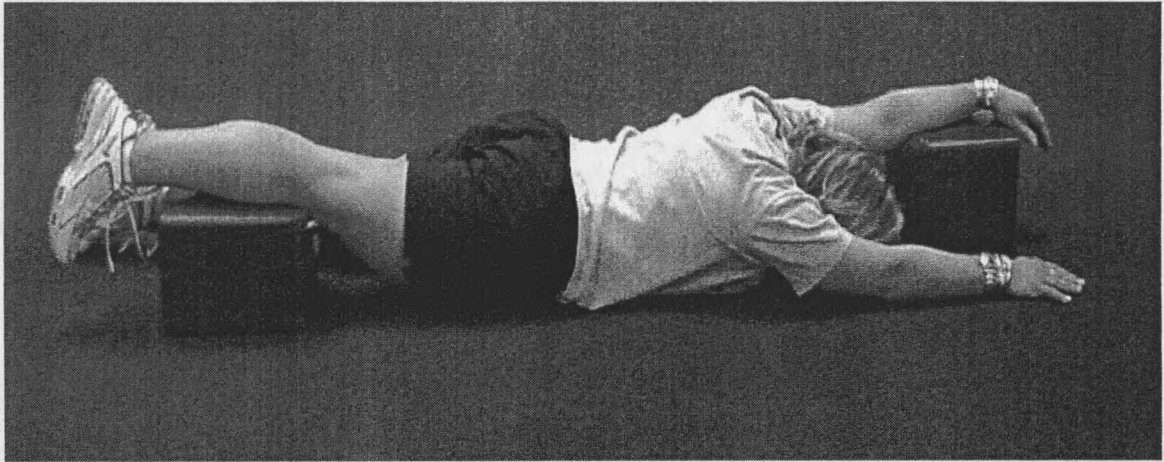


Figure 16. The model is demonstrating the Hand – Leg Opposite Blocked exercise. Standardized instructions for this exercise were as follows: “Lie prone and place a six-inch block under one forearm and another under the thigh of the opposite leg. Place the block above the patella so it does not create an uncomfortable pressure on the knee. Your forehead should be on the ground. Relax and let gravity pull the hip and shoulder to the floor. Hold for desired time” (Egoscue & Gittines, 1998).

HAND-LEG OPPOSITE GLIDE

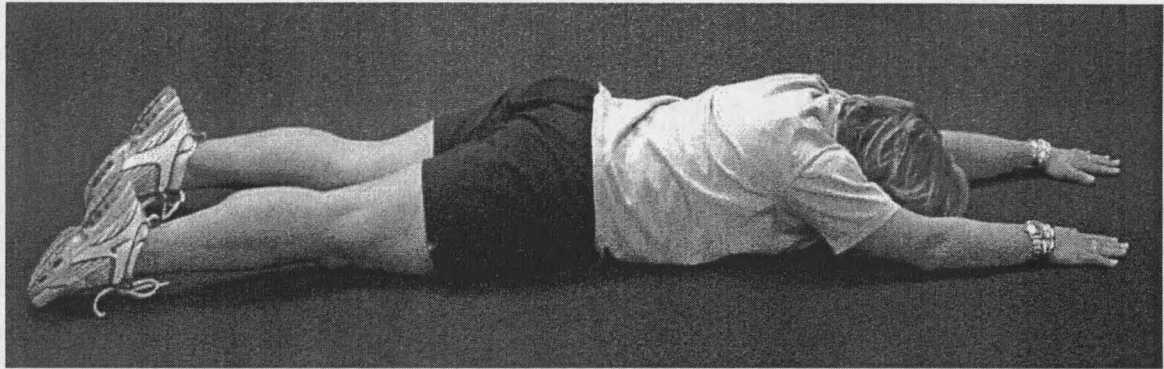


Figure 17. The model is demonstrating the Hand – Leg Opposite Glide exercise. The standardized instructions for this exercise were as follows: “Lie prone with your arms extended over your head. Legs should be in line with the hips. Stretch out one hand and the opposite leg (keeping in line with the hips) as far as you can. Hold for five seconds and then relax. Repeat for opposite extremities” (Egoscue & Gittines, 1998).

HIP CROSSOVER

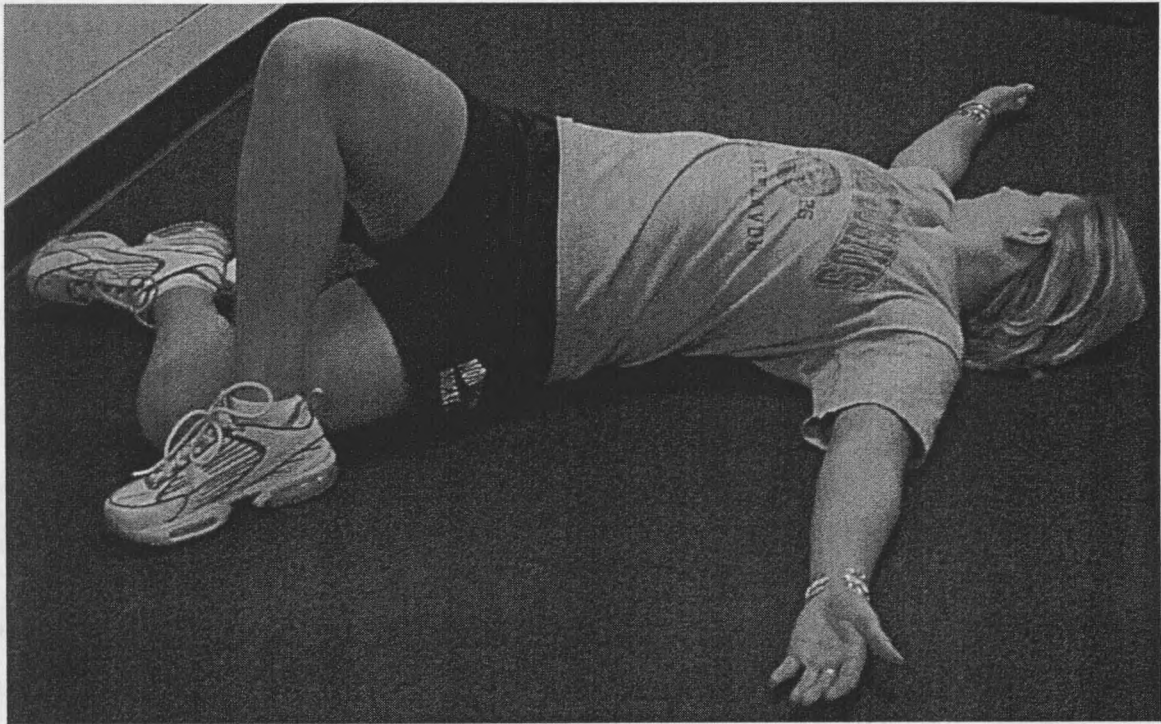
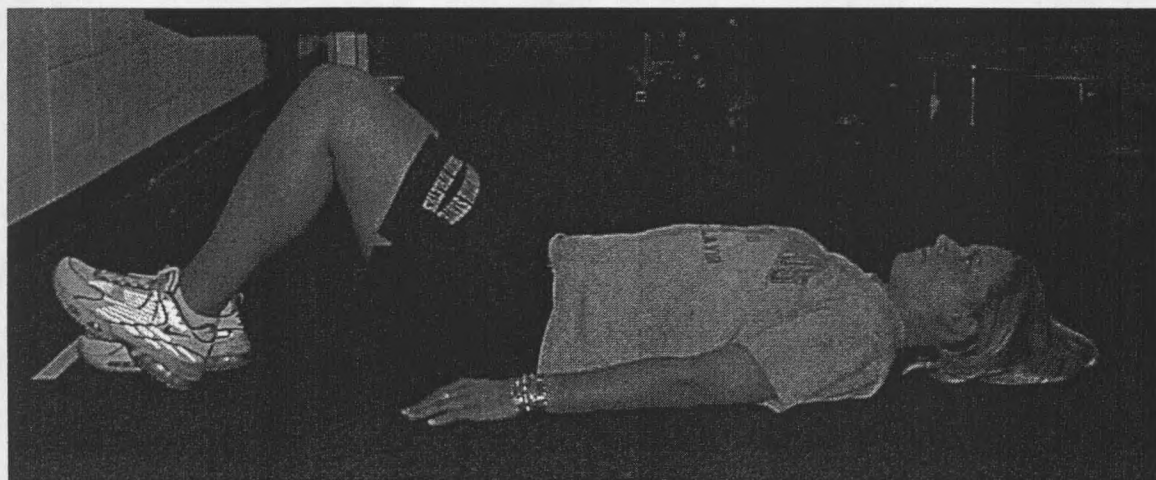
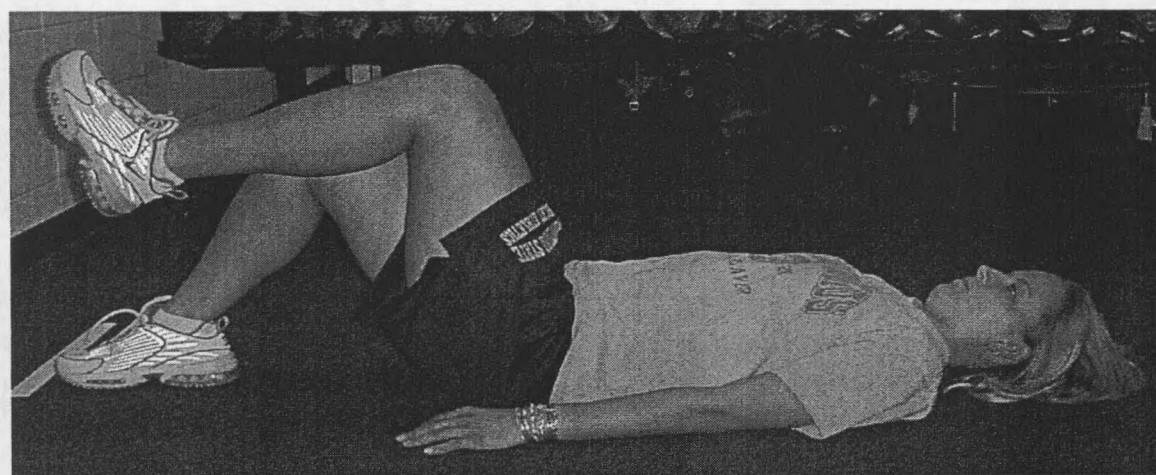


Figure 18. The model is demonstrating the Hip Crossover exercise. Standardized instructions for this exercise were as follows: "Lie supine with your feet straight, flat on the ground, and at hip width apart. Knees should be bent at 90°. Put your right heel on your left knee. Rock the legs and hips to the left. Keep the foot parallel with the thigh and do not let the left foot slide to the mid-line of the body. Arms are at the side with the palms up as you look to the right. Push the right knee away for the desired time. Repeat for the opposite side" (Egoscue & Gittines, 1998).

ISOLATED HIP FLEXOR LIFTS



A



B

Figure 19. The model is demonstrating the Isolated Hip Flexor Lifts: Start Position (A) and the Isolated Hip Flexor Lifts: End Position (B) exercise. Standardized instructions for this exercise were as follows: "Start with feet at hip width apart. Raise one foot six to eight inches off the floor while keeping the leg in the same plane as the hip. Relax the abdominals and the quadriceps muscles. Repeat with the other leg" (Egoscue & Gittines, 1998).

KNEELING COUNTER STRETCH

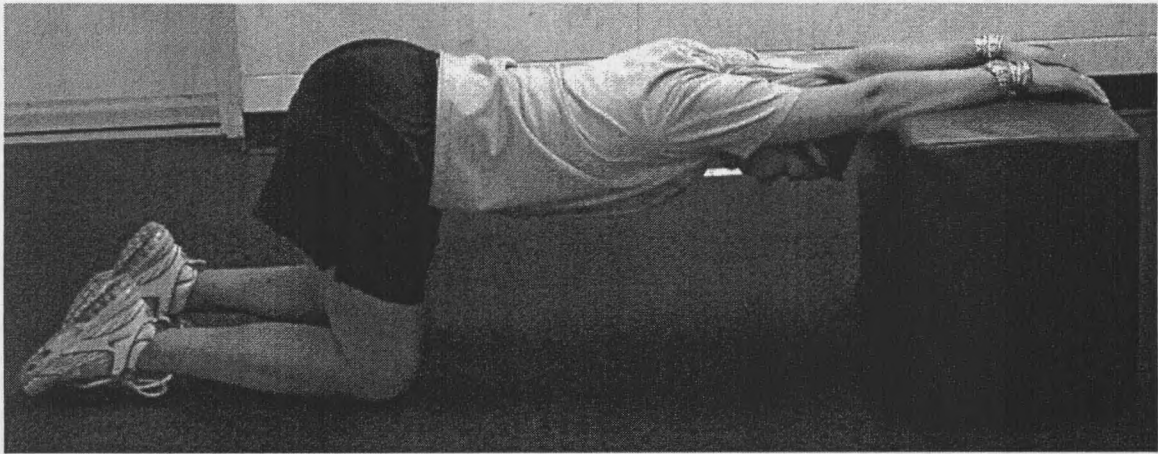


Figure 20. The model is demonstrating the Kneeling Counter Stretch exercise. Standardized instructions for this exercise were as follows: "Kneel in front of a block that is about hip height when on your knees. Put your forearms on the block and let your back arch towards the floor from the hips to the hands. Relax your abdominal muscles while inhaling" (Egoscue & Gittines, 1998).

KNEELING GROIN STRETCH

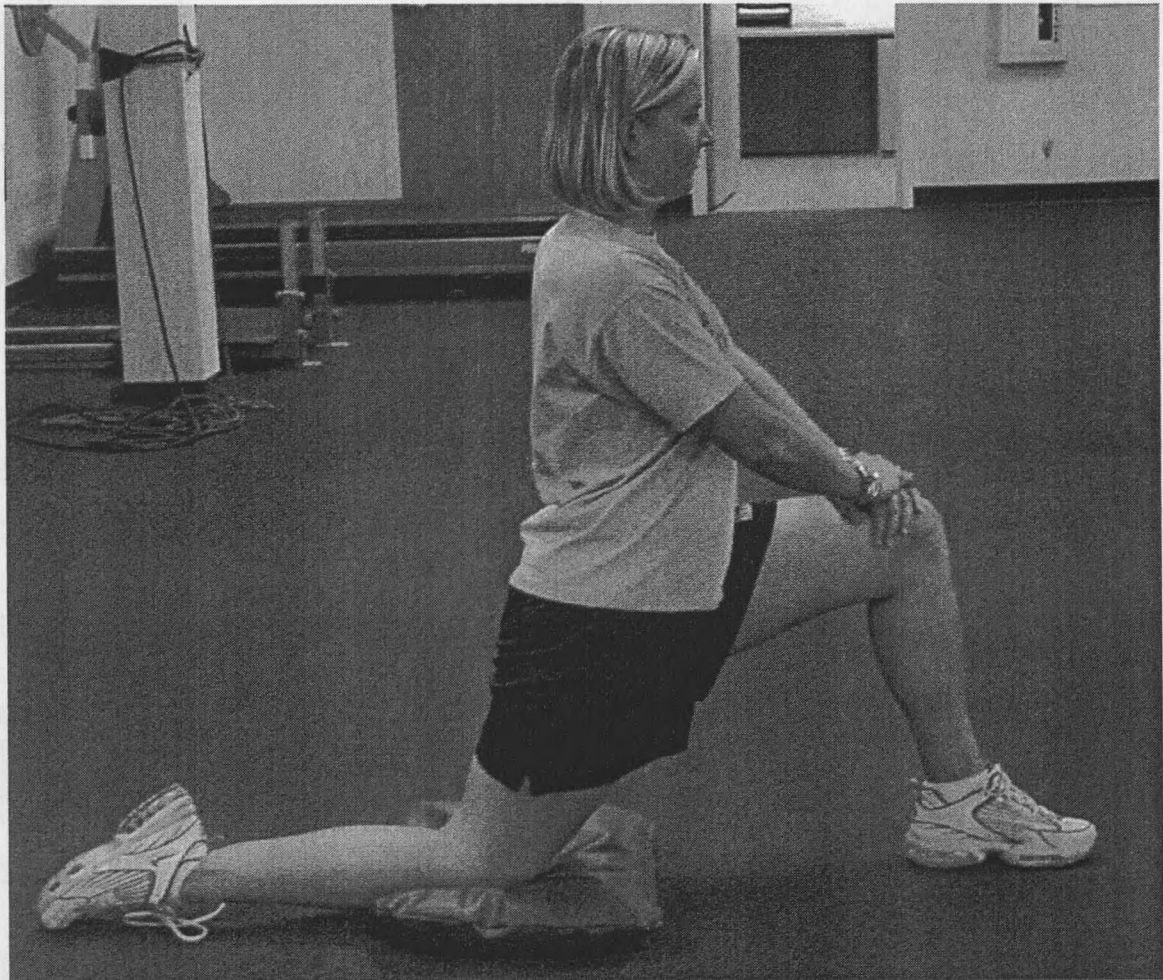


Figure 21. The model is demonstrating the Kneeling Groin Stretch exercise. The standardized instructions for this exercise were as follows: "Keep the front and back foot straight and in line with the coordinating hip. Place your hands on the knee in front of you and pull your shoulders back. Keep the hips square. Keep the knee in front of you behind the ankle joint" (Egoscue & Gittines, 1998).

MODIFIED RUNNERS STRETCH

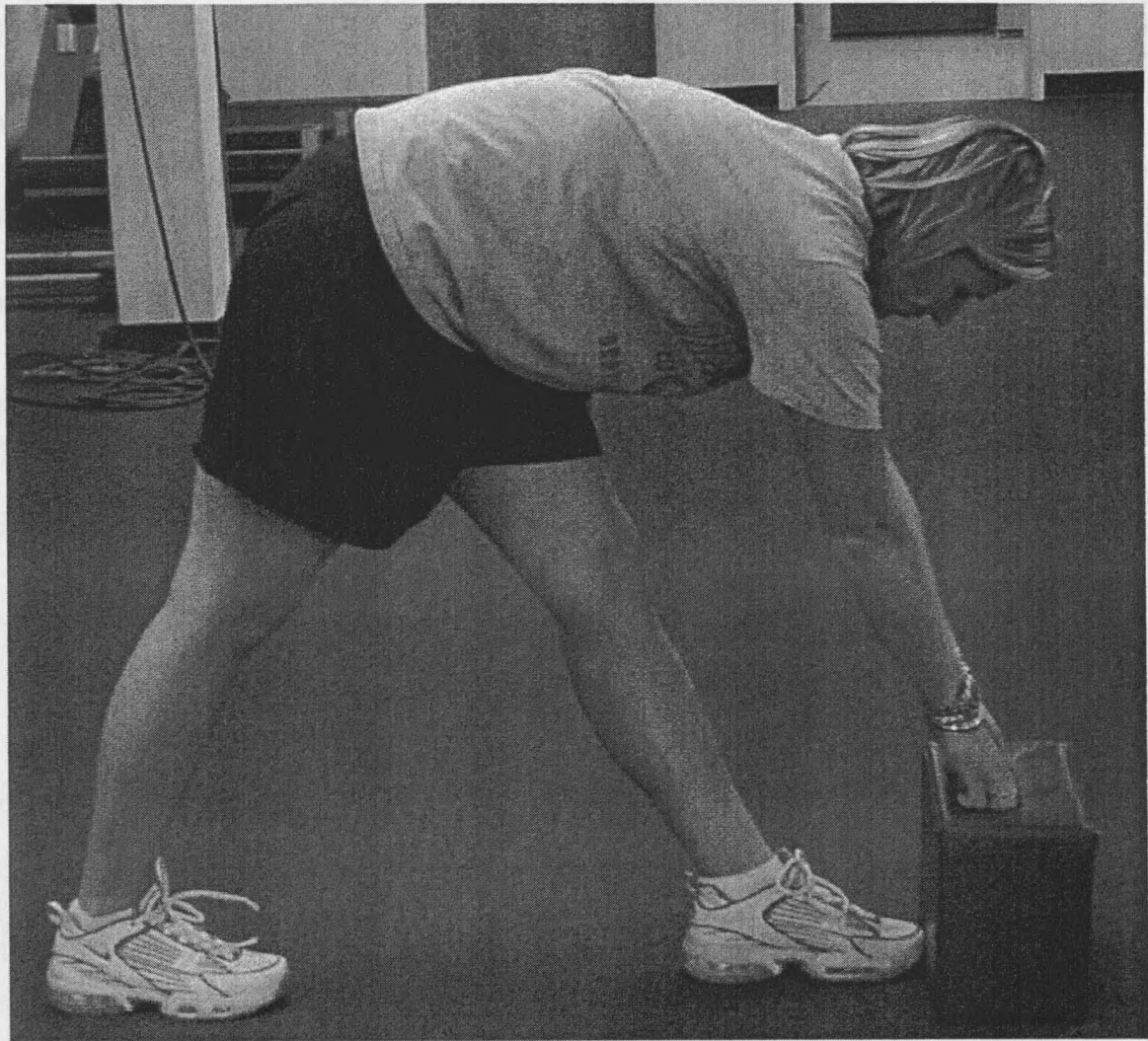


Figure 22. The model is demonstrating the Modified Runners Stretch. The standardized instructions for this exercise were as follows: "Kneel on one knee and then place the opposite foot just in front of this knee. Put your hands on a block for balance. Now stand up while keeping the hips square. Both legs should be straightened while keeping the heels flat on the floor. Relax the upper body and hold. The block is necessary if you cannot place your hands on the ground without rounding the back. Repeat with opposite side" (Egoscue & Gittines, 1998).

PELVIC TILTS



Figure 23. The model is demonstrating Pelvic Tilts. The standardized instructions for this exercise were as follows: "Lie supine with knees bent and your feet flat and straight. Rock your hips to create a space under the lower back while inhaling. Now rock the hips back to press the lower back to the floor while exhaling. Do these rolls in a smooth continuous motion without letting the hips come off the floor at any time. Keep the knees in line with the hips" (Egoscue & Gittines, 1998).

PROGRESSIVE SUPINE GROIN

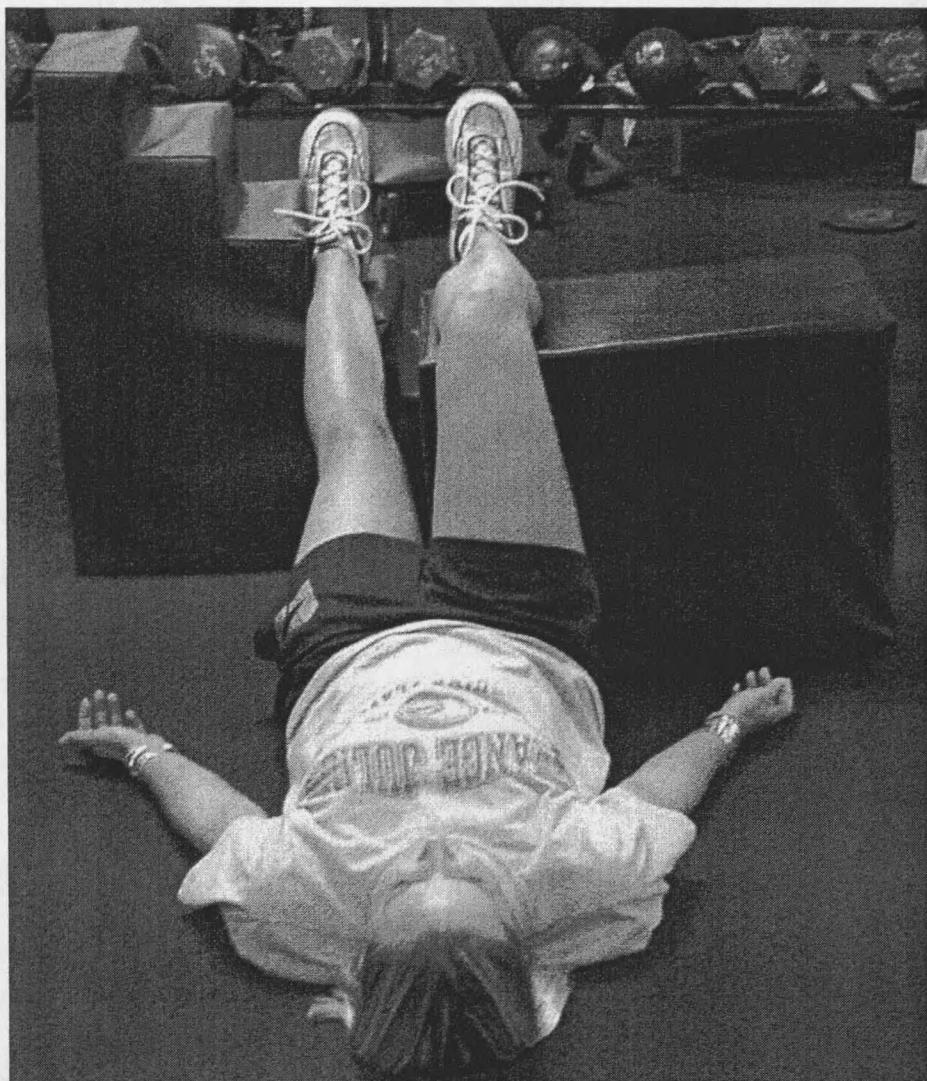
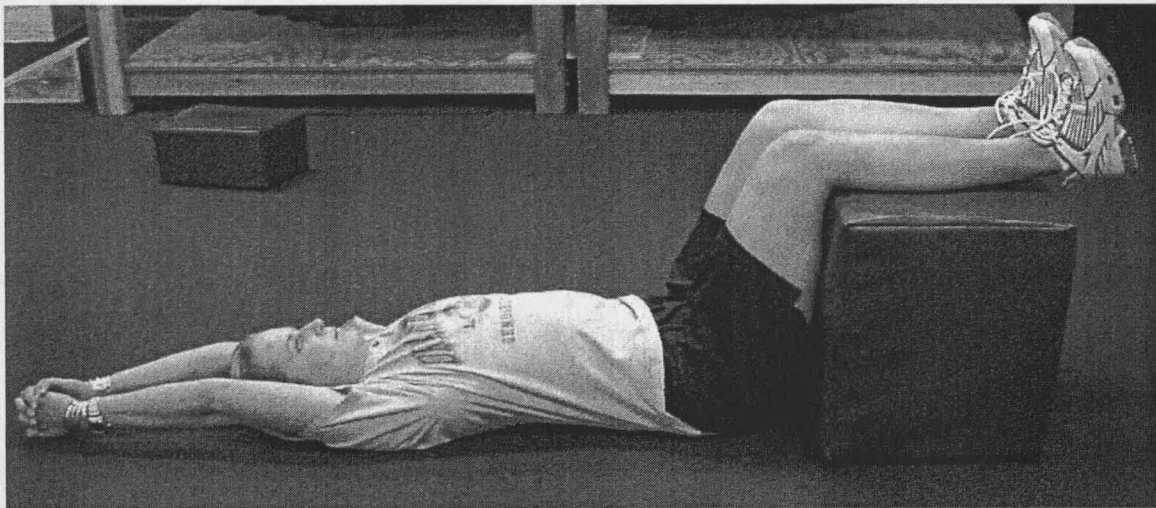


Figure 24. The model is demonstrating the Progressive Supine Groin exercise. The standardized instructions for this exercise were as follows: "Lie supine with one leg bent at 90° resting on a block. The other leg should be raised to a height so your hips and back are flat. The calcaneus should be resting on the block while the foot is places against a parallel surface to prevent external rotation of the lower leg. Gradually lower the extended leg about six inches at a time until it reaches the floor. Relax the back and hold each position for the desired amount of time" (Egoscue & Gittines, 1998).

PULLOVERS



A



B

Figure 25. The model is demonstrating Pullovers: Start Position (A) and Pullovers: End Position (B). The standardized instructions for this exercise were as follows: "Interlace your fingers with your elbows straight and your palms tight. Begin with your arms pointed at the ceiling. Extend your arms so they are parallel to the floor. If your elbows bend or your palms open up, stop and return to the starting position" (Egoscue & Gittines, 1998).

REVERSE PRESSES



Figure 26. The model is demonstrating Reverse Presses. The standardized instructions for this exercise were as follows: "With your shoulders abducted, press straight into the ground with your elbows and relax. The forearm should remain perfectly still. If the chest lifts up do not push as hard. You should only feel the scapulas slide together and release. Keep the abdominal muscles relaxed" (Egoscue & Gittines, 1998).

SITTING ADDUCTOR PRESS

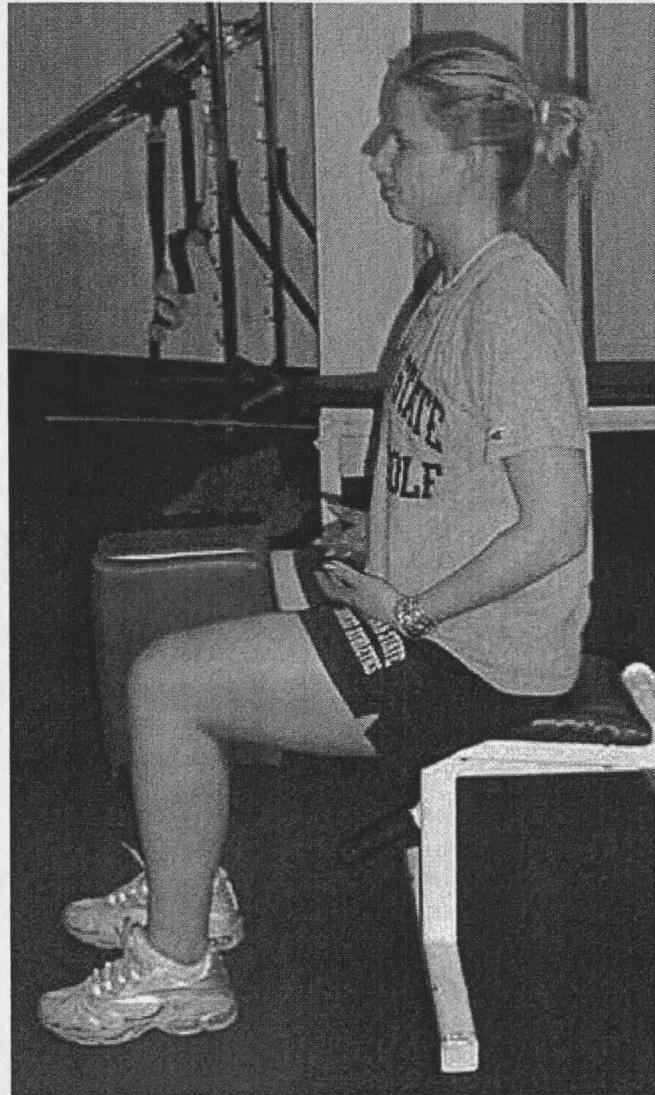


Figure 27. The model is demonstrating the Sitting Adductor Press. The standardized instructions for this exercise were as follows: "Sit in a chair with your feet straight and at hip width. Place a five-inch pillow between your knees, also at hip width apart. Roll the hips forward and hold the shoulders and head in proper alignment. Press in equally with both legs against the pillow and then relax. Do not let the hips move out of position during the exercise" (Egoscue & Gittines, 1998).

SITTING FLOOR

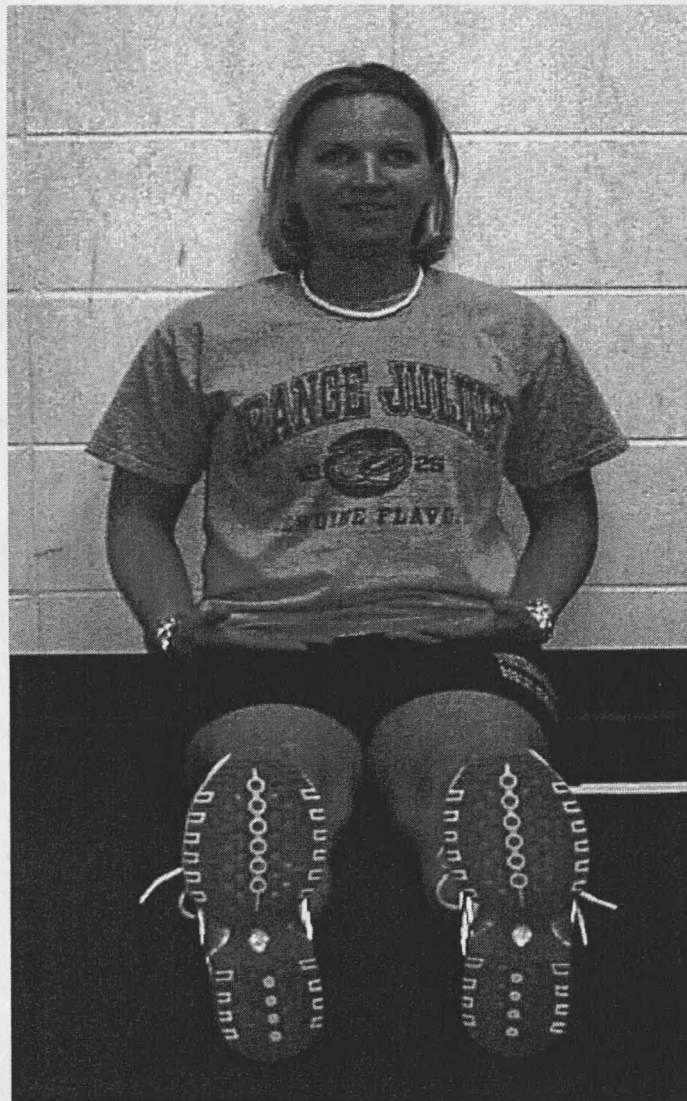


Figure 28. The model is demonstrating the Sitting Floor exercise. The standardized instructions for this exercise were as follows: "Sit on the floor with your legs straight and hip width apart. Flex your quadriceps and dorsiflex your ankles. Your feet must be at a 90° angle with the floor. Roll your hips forward and try to pull your lower back off the wall. Squeeze your scapulas together without elevating them. Relax the arms and abdominal muscles. Hold for desired time" (Egoscue & Gittines, 1998).

SITTING FLOOR TWIST



Figure 29. The model is demonstrating the Sitting Floor Twist exercise. The standardized instructions for this exercise were as follows: "Bend the left leg and cross it over the right. Your left foot should be beside the knee and parallel with the straight leg. Take the right elbow and place it on the left knee. Put the left hand behind you in a straight line with the center of your body. Roll your hips as far forward as possible. Pull the left shoulder back and hold. Flex the quadriceps and dorsiflex the ankle on the straight leg. Relax the right shoulder. Repeat with opposite side and breathe with the stomach" (Egoscue & Gittines, 1998).

SITTING HEEL RAISES

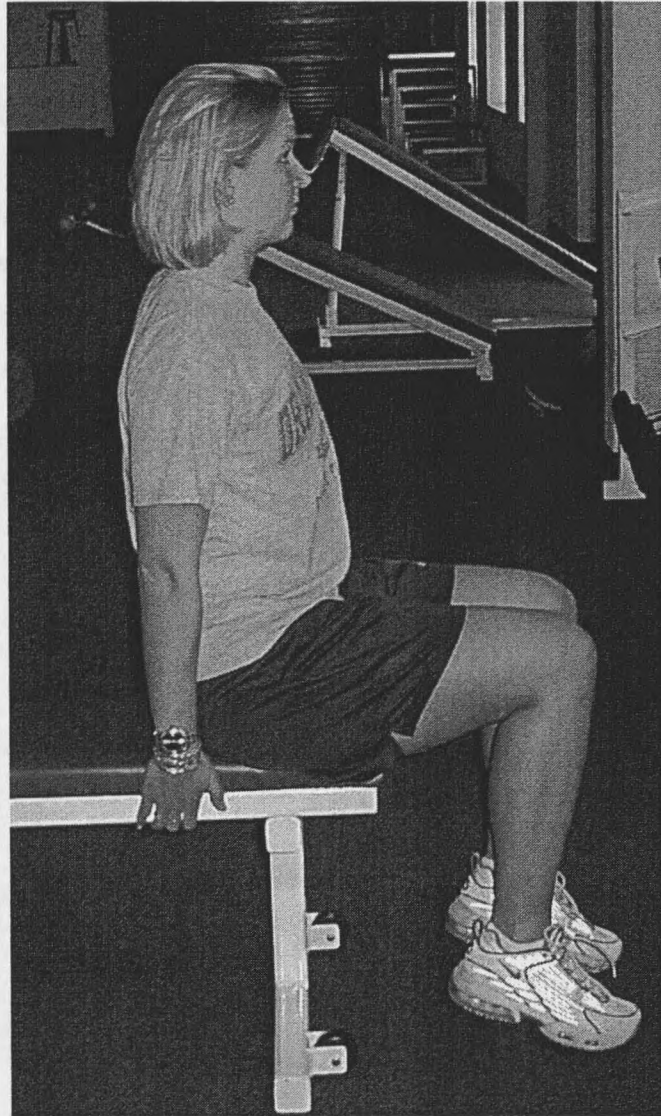


Figure 30. The model is demonstrating Sitting Heel Raises. The standardized instructions for this exercise were as follows: "Sit in a chair with your pelvis rolled forward to place an arch in your lower back. Hold this position. Keep your feet pointed straight ahead and begin lifting your hips off the floor using your hip flexors to create the movement. Do not use the gastrocnemius and lower leg muscles. Lift and lower your heels" (Egoscue & Gittines, 1998).

SQUAT

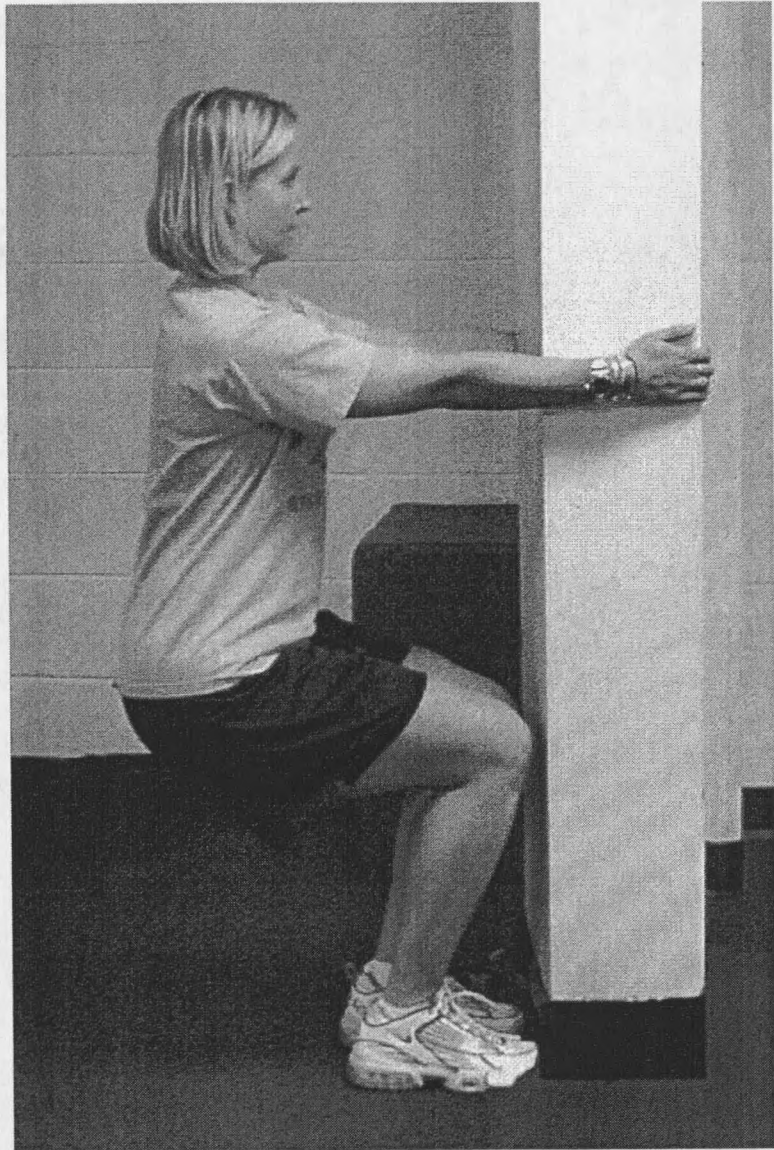


Figure 31. The model is demonstrating the Squat exercise. The standardized instructions for this exercise were as follows: "Holding on to a pole, bend your knees and arch your lower back. Keep your torso straight. Lower your body so that the knees and hips are parallel. Keep the arms straight and the knees aligned with the hips and feet. The torso remains vertical throughout the exercise. Hold for desired time" (Egoscue & Gittines, 1998).

STATIC BACK

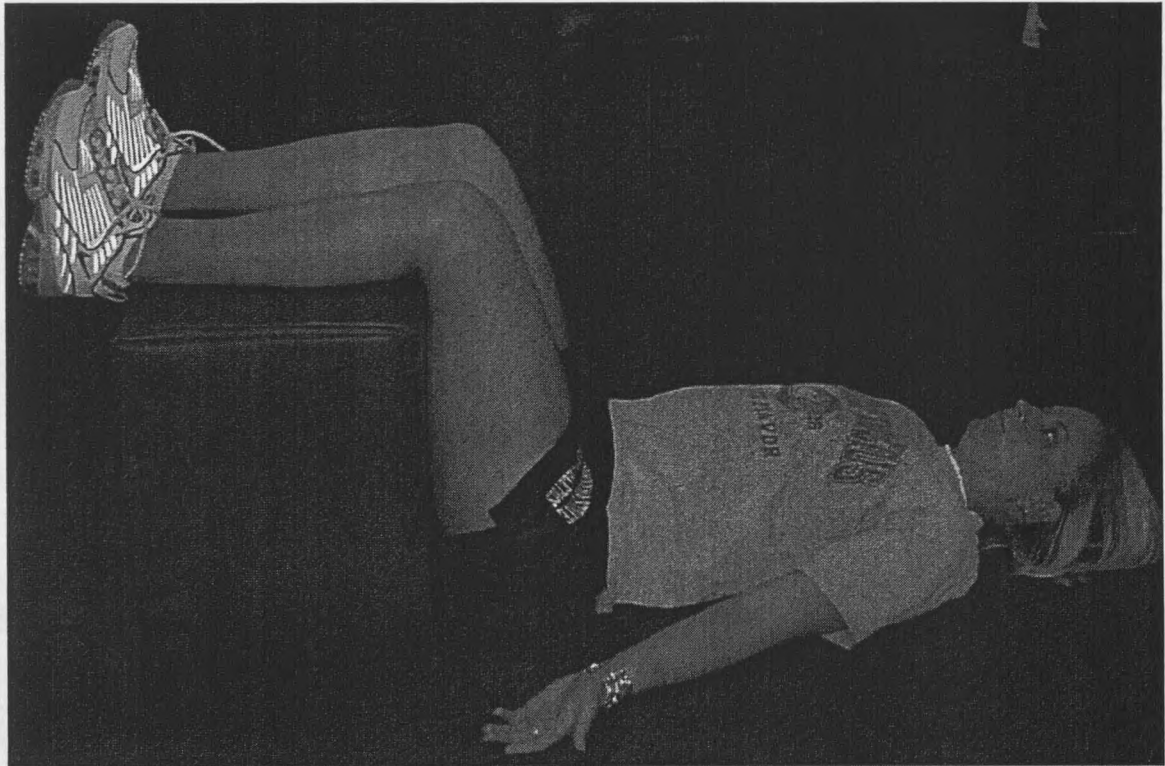


Figure 32. The model is demonstrating the Static Back exercise. The standardized instructions for this exercise were as follows: "Lie supine with your knees on a block. The block should be high enough to create a 90° angle with your knees. Your hips should be flat on the floor. Place arms out to the side in anatomical position (palms facing up). Knees and feet should be hip width apart. Breathe with the stomach and not the chest" (Egoscue & Gittines, 1998).

STATIC WALL

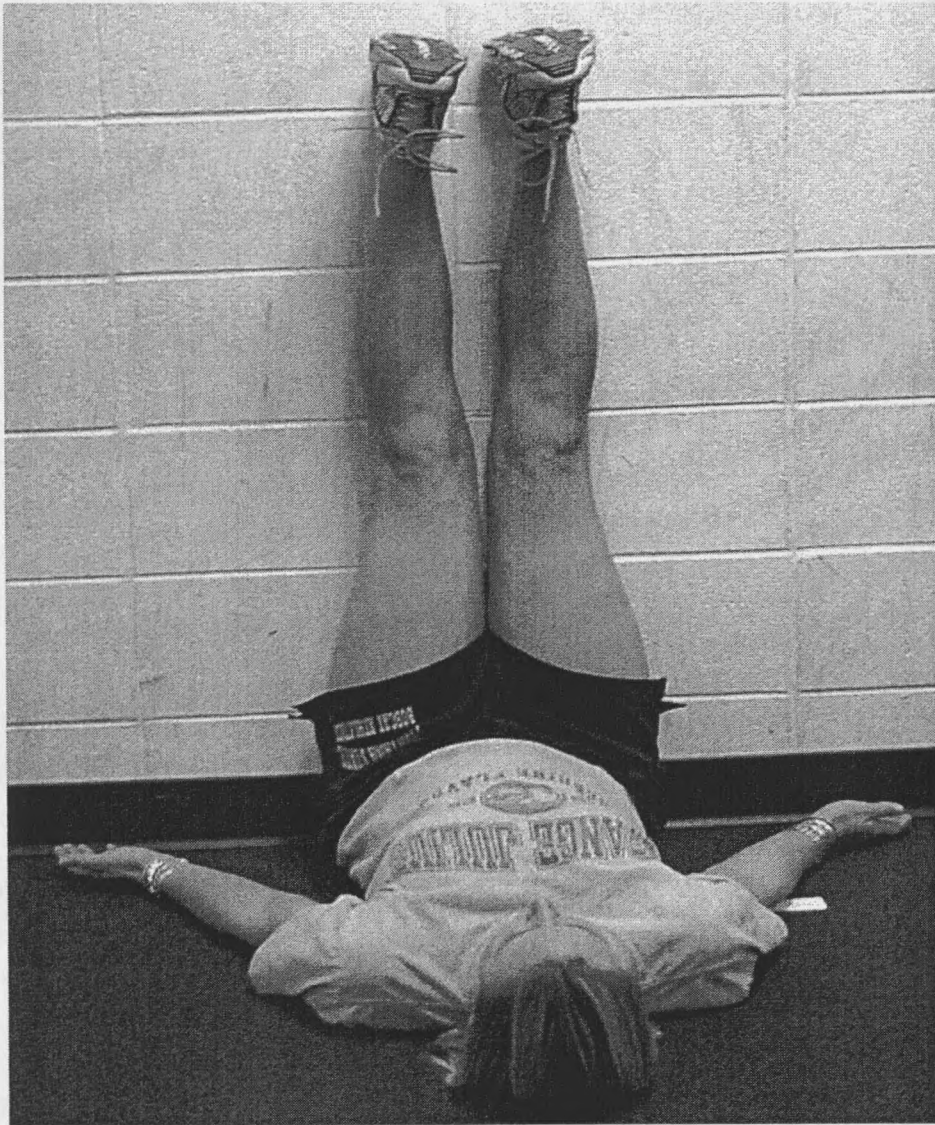
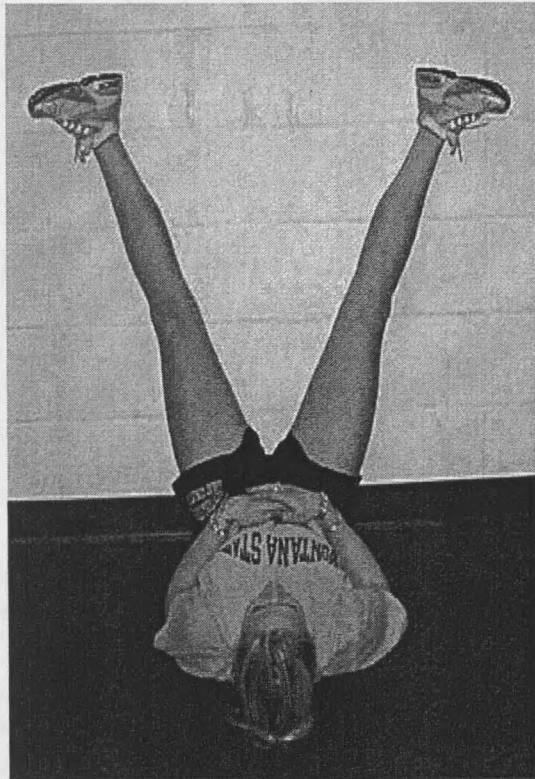
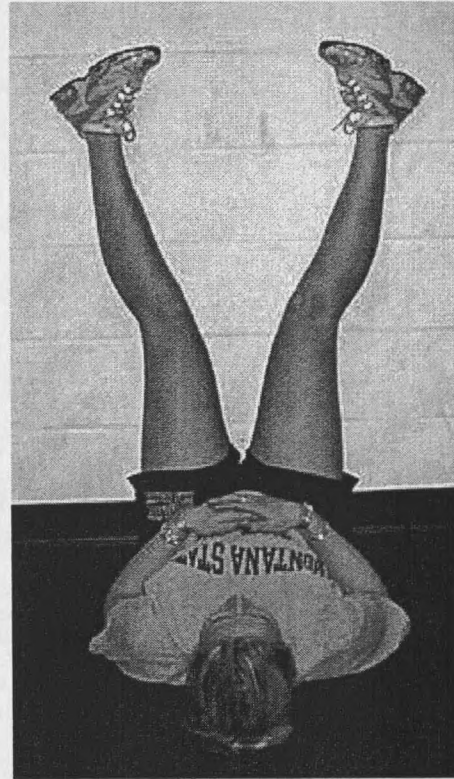


Figure 33. The model is demonstrating the Static Wall exercise. The standardized instructions for this exercise were as follows: "Lie supine and place pelvic girdle as close to the wall as you can, ideally with your buttocks touching it. Relax the upper body, tighten the quadriceps, and dorsiflex your ankles. Your feet should be parallel to the floor, and legs should be hip width apart. Hold this position for the desired time" (Egoscue & Gittines, 1998).

STATIC WALL FEMUR ROTATIONS



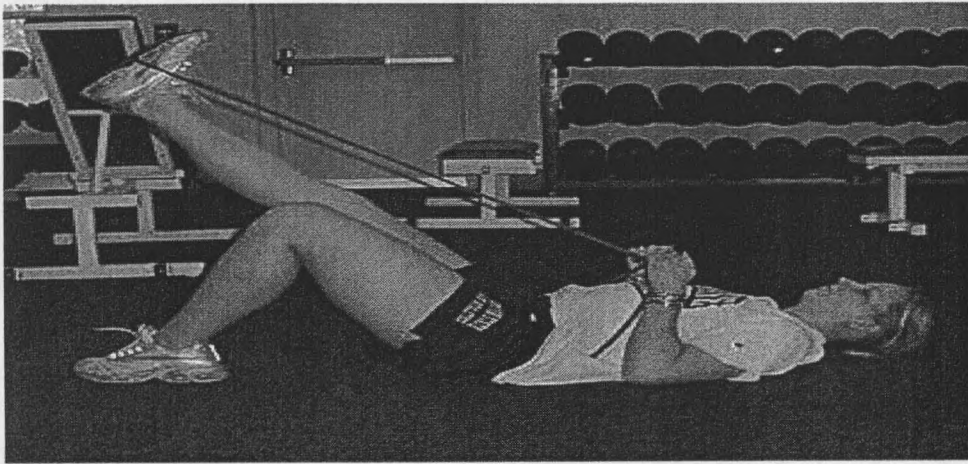
A



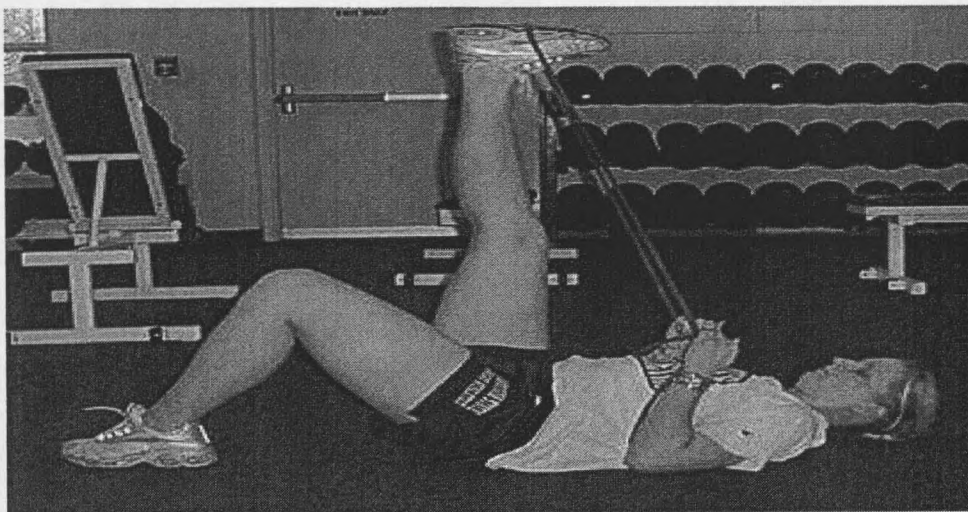
B

Figure 34. The model is demonstrating Static Wall Femur Rotations: Start Position (A) and Static Wall Femur Rotations: End Position (B). The standardized instructions for this exercise were as follows: "Lie supine and place pelvic girdle as close to the wall as you can, ideally with your buttocks touching it. Relax the upper body; tighten the quadriceps, and dorsiflex your ankles. Your feet should be parallel to the floor. Move your legs out to 2 o'clock and ten o'clock position. Tighten your quadriceps and internally and externally rotate your legs at the hip. Repeat for desired repetitions" (Egoscue & Gittines, 1998).

SUPINE GASTROC / HAMSTRING STRETCH



A



B

Figure 35. The model is demonstrating the Supine Gastroc / Hamstring Stretch: Start Position (A) and the Supine Gastroc / Hamstring Stretch: End Position (B). The standardized instructions for this exercise were as follows: "Lie supine with your hips and knees flexed to 45°. With a strap placed around the sole of your right foot, use the strap to elevate your leg so that it is parallel with the left thigh. Hold this position for the desired time. Then, using the strap, elevate your leg to 90° or as far as possible while keeping the leg straight. Hold this position for the desired time. Repeat for the opposite leg" (Egoscue & Gittines, 1998).

SUPINE GROIN STRETCH



Figure 36. The model is demonstrating the Supine Groin Stretch. The standardized instructions for this exercise were as follows: "In the supine position, place one leg out straight and the foot supported by a block. The other leg is on a block that enables the knee to be flexed 90°. Both legs should be in line with the hip joints. Place a 3.5-inch thick rolled towel under the neck and lower back. Breathe with the stomach; not with the chest. To determine how long to stay in position, perform the thigh test. Contract the quadriceps of the straight leg to feel for the "tension spot", or the spot where the muscle knots up. Then relax the quadriceps. Repeat this test every three minutes. The spot will first be near the patella and will move up the quadriceps with every test. When you feel the tension spot in the upper leg, you are finished. Repeat for opposite leg" (Egoscue & Gittines, 1998).

UPPER SPINAL FLOOR TWIST

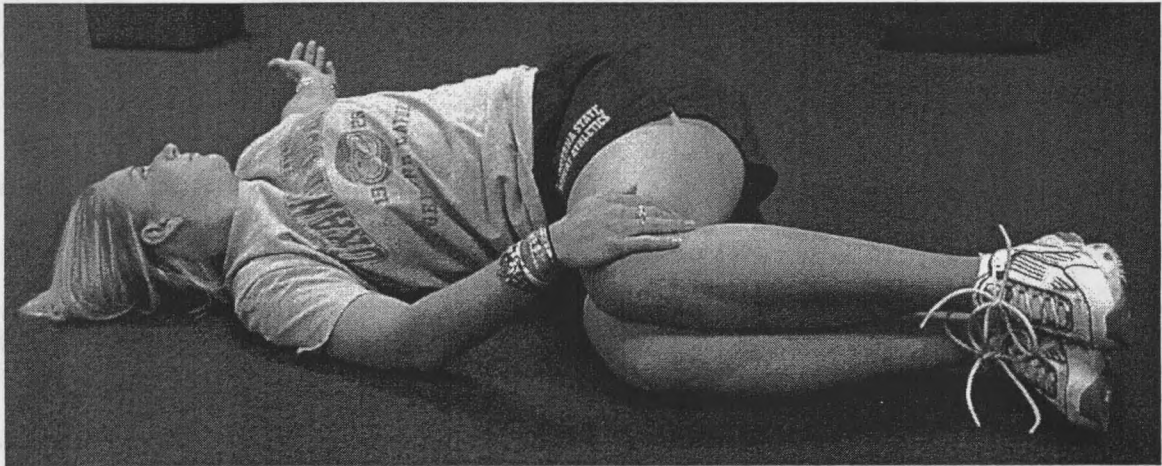


Figure 37. The model is demonstrating the Upper Spinal Floor Twist exercise. The standardized instructions for this exercise were as follows: "Lie on your side with knees bent to 90°. Begin with both arms in front of you so they are parallel with the knees. Now raise the upper arm over your body and place it on the floor on the other side with the palm up. Let gravity pull the arm to the floor and breathe deeply. Use the lower arm to keep the knees together. Repeat with opposite side" (Egoscue & Gittines, 1998).

WALL DROP

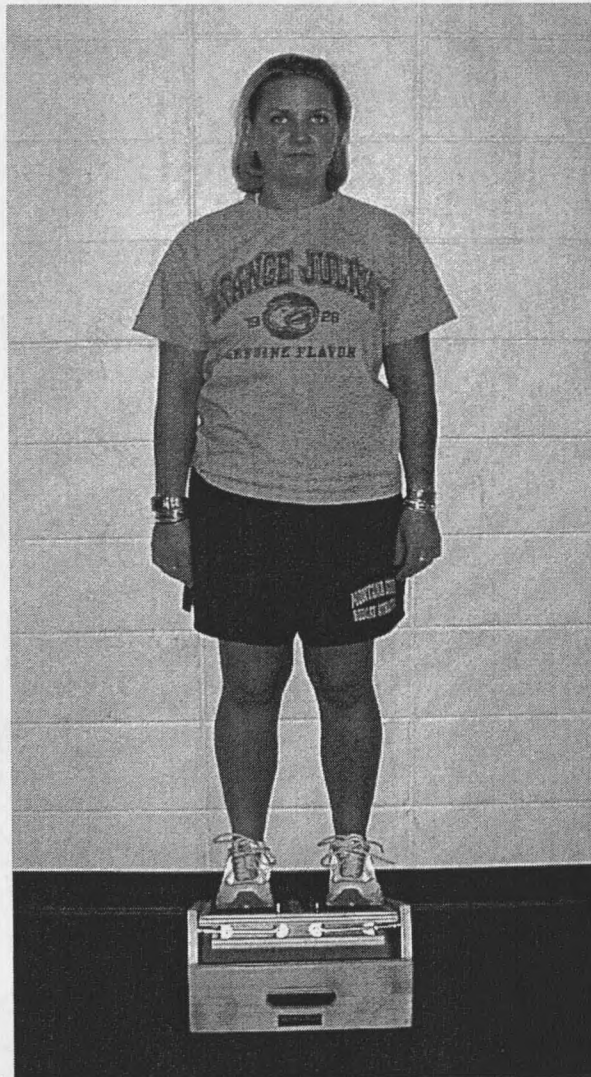


Figure 38. The model is demonstrating the Wall Drop exercise. The standardized instructions for this exercise were as follows: "Stand with your back to a wall on a slanted board or block. Your feet should be at hip width apart and pointed straight ahead. Keep your head against the wall and relax the shoulders and arms. If you are using a block, make sure the balls of your feet are on the edge of the step and your heels are touching the wall. Do not let your heels wander in. Tighten the thighs and press the backs of your knees toward the wall while tightening the gluteal muscles" (Egoscue & Gittines, 1998).

WALL SIT

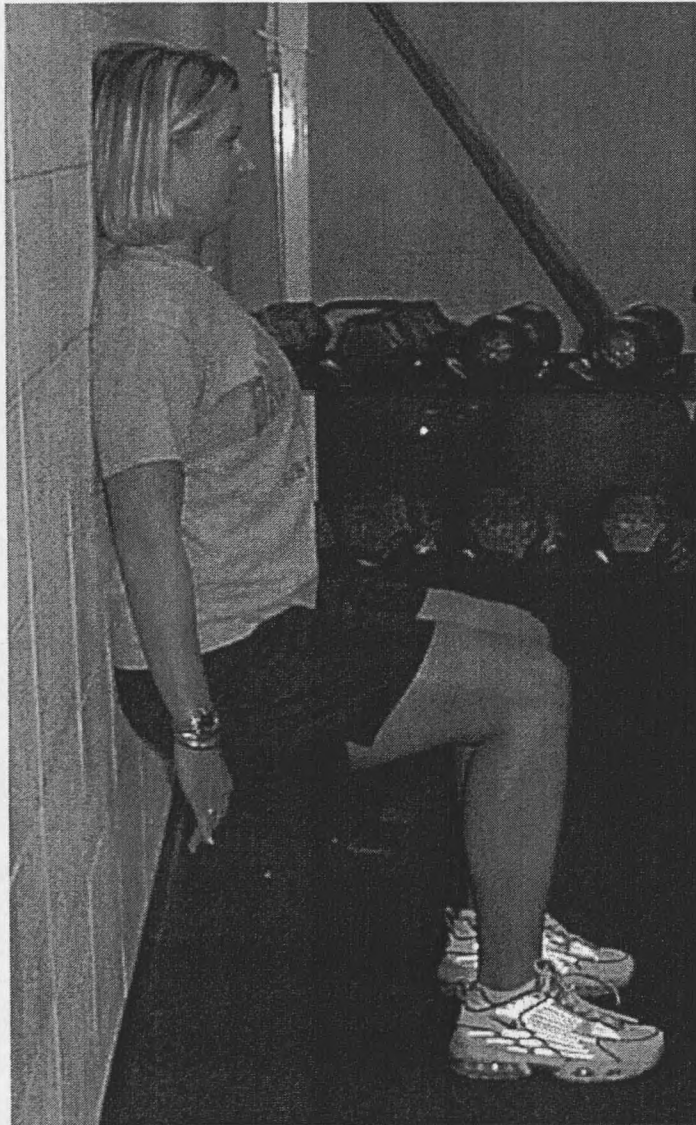


Figure 39. The model is demonstrating the Wall Sit exercise. The standardized instructions for this exercise were as follows: "Stand with your back to a wall. Walk the feet out approximately two feet and keep back flat against the wall. It is important to always have the knees behind the ankles. Distribute weight evenly on both sides of the hips and lower back. The weight should be in the heels of the feet and equal from right to left. Relax your shoulders and stomach. Hold for desired time" (Egoscue & Gittines, 1998).

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