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Assessment of quadriceps/hamstring strength, knee ligament stability, functional and sports activity levels five years after anterior cruciate ligament reconstruction

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ABSTRACT

The purpose of this study was to examine individuals 5 years after ACL reconstruction and analyze changes involving strength, stability, function, and sports activities. Nineteen males and six females, mean age =31.4± 7.31 years, participated in this study. Fifteen subjects had received extraarticular and ten subjects had received intraarticular ACL reconstructions. Subjects completed a 100 point subjective functional activity questionnaire and a sports participation survey. Knee ligament stability was assessed during an objective knee examination. Isokinetic quadriceps and hamstring muscle strength were tested at 240 and 120 deg/sec using the Cybex II dynamometer. Anterolateral rotatory instability and positive Lachman were elicited on the operated leg for 80% of the subjects. No significant relationship was found between objective instability and the functional activity score. For the intraarticular group, a significant correlation ($P < 0.05$) was found between increased quadriceps and hamstring strength on the operated leg and return to functional activities. Subjects' functional activity score was positively correlated ($P < 0.001$) with their ability to participate in sports. Subjects participating in sports involving cutting and twisting motions were less successful in returning to their preinjury participation levels and reported more subjective complaints of pain, swelling, and/or instability. These results indicate that long-term progressive rehabilitation emphasizing increased quadriceps and hamstring strength to approximate the nonoperated leg may enhance successful return to functional and sports activities after ACL reconstruction.

Management of the patient with an ACL injury has been a challenge to orthopaedic specialists for decades. The ACL provides 86% of the primary restraint to anterior tibial excursion.[4] Extensive damage to this ligament leaves the knee joint vulnerable to progressive deterioration possibly resulting in chronic instability, meniscal tears, articular degeneration, and arthritic changes.[7,14] The goal in the treatment of ACL-injured patients is to prevent this detrimental progression and return individuals to their preinjury functional status. Surgical reconstruction of a damaged ACL attempts to structurally compensate for decreased knee stability. Postoperatively, patients often become involved in a strengthening program to rehabilitate atrophied thigh muscles. Follow-up studies on patients with surgically repaired ACLs have shown that both increased knee stability[11,13,14] and thigh muscle strength[3,16] on the operated leg are associated with a satisfactory return to preinjury activities.

Investigators assessing knee stability have shown that the subjective[13] and objective clinical signs of anterior instability, such as a positive pivot shift,[11] Lachman,[11] and/or anterior drawer test,[11,14] are associated with poor functional results. Lysholm et al.[13] conducted a 1 to 8 year follow-up

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study of 175 patients treated for various combinations of ligament injuries involving the ACL, PCL, and collateral ligaments. They found that patients who complained of instability frequently did not return to athletics when compared to subjects without complaints of instability ($P < 0.001$).

Johnson et al.[11] examined the relationship between objective anterior stability and functional return for 87 patients who had undergone ACL reconstruction an average of 7.9 years prior to the study. Patients were classified as having excellent, good, fair, or poor functional results based upon incidence of pain and instability and modification of athletic activities. Patients in the excellent and good functional groups had significantly less tibial excursion during the anterior drawer ($P < 0.05$) and Lachman tests ($P < 0.025$) than patients in the fair or poor groups. In addition, a moderate or marked positive pivot shift was associated with fair or poor functional results ($P < 0.05$).

Marshall et al.[14] investigated the relationship between objective anterior instability and return to sports activities for 70 patients 2.5 years after primary surgical ACL repair (surgery within 1 month of injury). At followup, 69% of these patients had returned to full participation at their preinjury sports competition level. The Lachman test was recorded postoperatively for all 70 patients with 92% showing no difference between legs or only a slight increased tibial excursion in the operated leg. The pivot shift test, which was recorded for 63 of the 70 subjects, was negative in 75% of the patients. The authors did not report if any difference in stability existed among patients who returned to sports competition and patients who did not. However, followup for these subjects was only 2.5 years. Ellison[6] reported that 20% of the subjects classified with excellent results at 2.5 years postsurgery dropped to the good results classification at 3.5 years because of increased instability associated with increased discomfort and swelling.

Postsurgical evaluations of the quadriceps muscle group have shown that increased strength in the surgically treated knee is positively associated with improved functional return.[3,16] Arvidsson et al.[3] found that 7.9 years after ACL reconstruction the maximum torque produced by the quadriceps at 120 deg/sec was significantly less in the involved leg than the uninvolved leg for the fair ($P < 0.001$) and poor ($P < 0.05$) functional groups. Maximum quadriceps torque was not significantly different in the good or excellent groups. Arvidsson et al. did not report stability test results for their subject population. These studies did not discuss whether individuals with fair or poor functional return had decreased knee stability in addition to decreased muscle strength.

Odensten et al.[16] found that successful return to preinjury functional status was positively correlated ($r = 0.62$) with increased quadriceps strength at 120 deg/sec. In addition, subjects who demonstrated instability in the lateral pivot shift or Slocum maneuvers had a significantly greater quadriceps strength deficit in the operated leg ($P < 0.01$) and significantly lower functional scores ($P < 0.05$) than subjects with more stable knees. Odensten et al. included subjects with medial collateral ligament (MCL) damage which has been shown to negatively affect functional return.[19] Therefore, the relationship between functional return and instability following ACL reconstruction without additional ligament damage is unclear.

Whether a patient is successful in returning to sports activities after surgical ACL reconstruction has been found to depend upon a number of factors, one of which is the type of sport the patient wishes to pursue. Warren and Marshall[19] assessed the success of surgical treatment of 79 patients with ACL and/or MCL injuries. The predominant recreational activities the patients participated in prior to injury were skiing (22 cases) and football (20 cases). Postoperatively, 14% of the injured skiers and 30% of the football players had complete return to their respective sport. Discontinuation of the original sport was seen for 46% of the skiers and 60% of the football players.

Currently, there are no published reports that have studied individuals surgically treated for ACL injuries and provided a complete assessment of the patient's preinjury and postinjury participation levels in conjunction with the sports activity pursued. Giove et al.[8] addressed the issue of sports participation following nonsurgical treatment for ACL injury. Few individuals were able to return to activities requiring quick turns, cutting maneuvers, and sudden stops.

The purpose of this study was to examine individuals 5 years following ACL reconstruction surgery and to analyze the following relationships: 1) Changes in muscular strength versus changes in knee ligament stability. 2) Changes in muscular strength versus functional status. 3) Changes in knee ligament stability versus functional status. 4) Changes in preinjury and follow-up patient participation levels for sports activities.

MATERIALS AND METHODS

Subjects

The subject population was obtained from patients who underwent intraarticular *or* extraarticular ACL reconstruction by orthopaedic surgeons at the Southwestern Orthopaedic Medical Group (now known as the Kerlan-Jobe Orthopaedic Clinic) during the period from January 1979 to December 1980. These subjects met the following criteria:

- No evidence of collateral ligament or PCL damage or repair at the time of surgery.
- No previous ACL knee surgery or subsequent knee surgery on the involved leg.
- No history of surgery or traumatic injury to the contralateral knee.
- No history of a medical problem that limited activities within the 6 weeks prior to testing.
- Participation in a physical therapy rehabilitation program for the injured knee following knee surgery.

One hundred one possible subjects were contacted by letter and follow-up phone calls. Fifty-one individuals had moved without leaving forwarding addresses or phone numbers and were lost to followup. Twenty-five individuals lived out of the area or were for other reasons unavailable to participate. A total of 25 patients participated in this study.

Materials

Each subject completed a subjective evaluation of his or her functional activity and sports participation levels. The functional activity questionnaire (Appendix 1) developed and tested in this study used aspects of the functional scales described by Lysholm and Gillquist[12] and Noyes et al.[15] The 100 point numerical distribution used in this study was shown by Lysholm and Gillquist[12] to be valid for the ACL-injured population. The presence of pain, swelling, and instability were classified according to six activity levels following the guidelines set by Noyes et al.[15]

The sports participation survey (Appendix 2) used in this study was patterned after the survey used in the Giove et al.[8] study. Subjects rated their activity level for 13 sports. Points were assigned to each activity in the following manner:

4 = full activity with no significant signs or symptoms in the injured knee
3 = full activity with occasional or recurring mild episodes of pain, swelling, or instability
2 = limited activity due to moderate or severe episodes of pain, swelling, or instability
1 = does not participate in activity due to the injured knee
0 = does not participate in activity, but not because of the injured knee

In addition, subjects rated their preinjury and present participation levels by frequency and duration. Points were assigned to participation levels as follows:

1 = Competitive: participation in a sports activity six to seven times per week and/or regular participation in organized competition or activity of a similar intensity
2 = Recreational: participation in a sports activity three to five times per week or two times per week and greater than 2 hours per session, *or* participation in seasonal sports (e.g., skiing) an average of 5 or more days per month
3 = Weekend: participation in a sports activity two or less times per week with each session lasting approximately 1 hour, *or* participation in seasonal sports (e.g., skiing) an average of 4 or less days per month.

The subjects were instructed to engage in no exercise on the day of testing. Demographic information and details regarding the date and mechanism of injury, diagnosis, surgery date, and surgical procedure were obtained through interview and confirmed by medical records. The following parameters were examined and recorded on the knee examination form (Appendix 3): effusion, total range of motion (ROM), thigh girth, joint line tenderness, swelling, and crepitus.

The following ligament tests were performed bilaterally on each subject: 1) varus stress in 0° extension,[9] 2) varus stress in 30° flexion,[9] 3) valgus stress in 0° extension,[9] 4) valgus stress in 30° flexion,[9] 5) anterior drawer with the tibia in neutral rotation,[9] 6) anterior drawer with the tibia in 15° external rotation,[9] 7) Lachman,[17] and 8) lateral pivot shift.[11] Each ligament test was administered first to the control leg followed immediately by the involved leg. Except for the lateral pivot shift, a grade of 1+ (0 to 5 mm of excursion), 2+ (5 to 10 mm), or 3+ (>10 mm) was assigned after each test. The lateral pivot shift test was recorded as either negative or positive.

A Cybex II (Division of Lumex, Ronkonkoma, NY) isokinetic dynamometer interfaced with a NorthStar Computer System (NorthStar Inc., San Leandro, CA) was used to evaluate quadriceps femoris and hamstring muscle strength. The subjects were positioned for testing as outlined in the standard Cybex protocol.[5]

Knee flexion and extension were tested at 120 and 240 deg/sec. Before data collection began, the subjects performed four practice repetitions at each speed setting at 75% of their subjective maximal effort. The warm-up phase was followed by a 1 minute rest period. The evaluation phase consisted of four maximal reciprocal extension and flexion repetitions of each leg. Subjects were first tested at 240 deg/sec followed by a 2 minute rest period prior to testing at 120 deg/sec. Testing was completed on the control leg before testing the operated leg. Each subject had a 5 minute rest period before the warm-up phase commenced on the operated leg.

To reduce the risk of experimenter bias and maintain consistency throughout data collection, each examiner was responsible for separate sections of this study. The functional activity and sports participation surveys were administered by JLS. The knee and stability examination was conducted by MCM. The Cybex test was executed by ASO.

Data analysis

A functional activity score was determined for each individual based on responses to the functional activity questionnaire. An average preinjury and follow-up participation level and an average sports activity score were calculated for each subject from the sports participation survey. The 13 sports were divided into two categories: cutting and noncutting. Cutting sports were defined as basketball, football, racquetball, downhill skiing, water skiing, softball, tennis, and volleyball. Noncutting sports were defined as bicycling, golf, running, swimming, and weight lifting.

For all subjects, the maximum quadriceps and hamstring torque generated at 120 and 240 deg/sec were compared during each of the four trials. The quadriceps and hamstring strength data used in this study were the torque values generated during the highest work output for a contraction set. Work output was defined as the sum of the area under the knee flexion/extension torque curve. Data was normalized for each subject by reporting the operated leg's torque as a percentage of the control leg's torque.

The stability tests were assigned the following points: one point for a grade of 1+, two points for a grade of 2+, and three points for a grade of 3+. A negative lateral pivot shift was assigned one point and a positive lateral pivot shift was assigned two points.

Significant differences between strength and stability measurements on the operated and control legs were determined using paired *t*-tests. Significant relationships between variables were determined using the Pearson product-moment correlation coefficient.

RESULTS

Nineteen males and six females, with a mean age of 31.4 ± 7.3 years and a range of 22 to 48 years, participated in this study. Thirteen males and two females received extraarticular Pes/Ellison[17] ACL reconstructions ($N = 15$) and six males and four females received intraarticular reconstructions ($N = 10$) with associated ACL procedures (Table 1).

Knee injury occurred during sports activity for 23 subjects: noncontact injury ($N = 13$) and contact injury ($N = 10$). Two subjects had knee damage related to motor vehicle accidents. Thirteen subjects reported sustaining knee injury in their nondominant leg and 12 subjects to their dominant leg. The average time period from injury to surgery, injury to followup, and the number of weeks of rehabilitation for the extraarticular and intraarticular groups are reported in Table 2.

Objective knee examination

Results from the objective knee examination found that neither surgical group showed a significant difference for the symptoms of effusion, crepitus, or joint line tenderness between the operated and control leg. The only significant ROM difference was found for the intraarticular group which had significantly less ($P < 0.05$) knee flexion ROM $\bar{x} = 6.5 \pm 7.1°$; range, 5° to 20°) on their operated leg as compared to their control leg.

Stability examination

The stability examination results (Table 3) are tabulated according to the number of subjects whose operated leg had no grade difference, a one grade, or a two grade increase when compared to the control leg. The lateral pivot shift test was recorded as either positive or negative. Nine of the ten subjects from the intraarticular group had a one or two grade increase for the anterior drawer test in neutral rotation, anterior drawer test in 15° external rotation, and Lachman test. In the extraarticular group ($N = 15$), a one or two grade increase was seen in 12 subjects for the anterior drawer test in 15° external rotation and 11 subjects for the Lachman test. In addition, two-thirds of the extraarticular group had a one or two grade increase in the valgus stress test in extension. Statistically significant differences ($P < 0.05$) were found between the control and operated knee for all stability tests except for the varus test in extension in the extraarticular group and for the varus test in extension and 30° flexion and the valgus test in extension for the intraarticular group.

TABLE 1
Type of surgical procedure for the extraarticular and intraarticular groups

Surgical procedure	Extraarticular ($N = 15$)	Intraarticular ($N = 10$)
Pes	15	7[a]
Ellison	15	7[a]
Erickson	0	5
Jones	0	4
Patellar tendon	0	1
McIntosh	0	3[a]
Semimembranosus transfer	0	2[a]

[a] These surgical procedures were augmentations to the intraarticular ACL reconstructions.

TABLE 2
Average age and time from injury to surgery, injury to followup, and weeks of rehabilitation

	Extraarticular ($N = 15$)			Intraarticular ($N = 10$)		
	Mean	Range	SD	Mean	Range	SD
Age (years)	31.9	21–48	5.6	30.8	24–38	5.0
Injury to surgery (months)	272.5	4–884	305.7	288.3	23–928	332.8
Injury to followup (months)	516.7	212–1123	322.9	547.0	255–1198	322.0
Weeks of rehabilitation	20.3	4–52	12.4	24.6	8–56	15.9

TABLE 3
Stability tests for extraarticular (EXTRA) and intraarticular (INTRA) groups

Stability test	No grade change		↑ 1 Grade		↑ 2 Grades	
	EXTRA	INTRA	EXTRA	INTRA	EXTRA	INTRA
Anterior drawer in neutral	7	1	7	7	1	2
Anterior drawer in 15° external rotation	3	1	11	8	1	1
Lachman test	4	1	8	9	3	0
Varus stress in 0° extension	12	9	3	1	0	0
Varus stress in 30° flexion	11	9	4	1	0	0
Valgus stress in 0° extension	5	7	10	3	0	0
Valgus stress in 30° flexion	9	6	6	4	0	0
Lateral pivot shift	7[a]	9[a]	8[b]	1[b]		

[a] Indicates a negative lateral pivot shift.
[b] Indicates a positive lateral pivot shift.

TABLE 4
Peak quadriceps and hamstring strength (foot-pounds) at 240 deg/sec

	Extraarticular (N = 15)			Intraarticular (N = 10)		
	Mean	Range	SD	Mean	Range	SD
Quadriceps						
Operated knee	73.77	36.40–130.51	23.91	48.51	0.73–82.48	27.31
Control knee	89.42	43.79–137.41	25.40	81.72	30.54–126.25	32.36
Hamstring						
Operated knee	62.67	26.29–102.22	22.53	52.98	8.27–76.16	22.94
Control knee	68.05	42.02–100.16	19.13	62.23	15.86–89.16	22.54

TABLE 5
Peak quadriceps and hamstring strength (foot-pounds) at 120 deg/sec

	Extraarticular (N = 15)			Intraarticular (N = 10)		
	Mean	Range	SD	Mean	Range	SD
Quadriceps						
Operated knee	121.19	56.72–183.17	33.99	85.38	12.41–134.71	40.42
Control knee	136.65	63.41–213.86	35.91	126.37	56.09–195.29	46.51
Hamstring						
Operated knee	96.78	60.26–151.95	30.22	82.03	18.32–111.67	34.07
Control knee	98.33	52.07–149.56	27.48	98.11	43.43–140.46	34.19

Strength

The quadriceps and hamstring data recorded from each subject's maximum work set are listed in Tables 4 and 5. The operated leg's quadriceps strength was significantly less than the control leg's quadriceps strength at 240 and 120 deg/sec for the extraarticular and intraarticular groups (Table 6). The hamstring strength of the intraarticular group's operated leg was significantly different than the control leg at both 240 deg/sec ($P < 0.05$) and 120 deg/sec ($P < 0.01$). There was no significant hamstring strength difference between the control and operated legs in the extraarticular group.

TABLE 6
Quadriceps and hamstring strength (foot-pounds): operated knee versus control knee

Speed (deg/sec)	Extraarticular (N = 15) t value	Intraarticular (N = 10) t value
Quadriceps, 240	4.82[a]	8.27[a]
Quadriceps, 120	3.00[b]	6.71[a]
Hamstrings, 240	1.81	2.99[c]
Hamstrings, 120	0.33	3.45[b]

[a] $P < 0.001$.
[b] $P < 0.01$.
[c] $P < 0.05$.

Functional activity score

The average functional activity scores of the extraarticular and intraarticular groups were 89.20 ± 7.34 and 73.80 ± 17.31, respectively. Subjects indicated their highest activity level attained before the onset of pain, swelling, and instability using the functional activity questionnaire. The extraarticular group reported functioning at significantly higher ($P < 0.05$) activity levels without symptoms of pain or swelling than the intraarticular group (Fig. 1).

No statistically significant relationship ($P < 0.05$) was found between the functional activity score and the time period from injury to surgery, injury to followup, or number of weeks of rehabilitation. There was no significant difference in the functional activity score, strength, or stability for subjects injuring their dominant versus nondominant leg. Neither surgical group showed a significant correlation between the functional activity score and symptoms of effusion, crepitus, or joint line tenderness. Although there was a significant difference ($P < 0.05$) between the intraarticular group's operated and control leg's flexion ROM, there was no significant correlation between flexion ROM and the functional activity score.

No statistically significant correlation was found between the functional activity score and the eight stability tests for either the extraarticular or intraarticular group ($P < 0.05$) (Table 7). No statistically significant correlation was found between quadriceps and hamstring strength and the functional activity score of the extraarticular group. Positive correlations were found between the intraarticular group's functional activity scores and quadriceps and hamstring strength parameters (Table 8).

Sports participation survey

The average sports activity level for the extraarticular and intraarticular groups were 2.93 ± 1.10 and 2.71 ± 0.99, respectively. No statistically significant difference was found between the two groups' average sports activity scores. Due to the limited number of subjects participating in each sport, results from the sports participation survey were reported for the entire subject population. A positive correlation was found between the functional activity score and the average sports score ($r = 0.78$, $P < 0.001$) for all 24 subjects. At the time of followup, 24 subjects participated in 13 different sports. Figures 2 and 3 illustrate the percent of participants at each activity level for the cutting and noncutting sports.

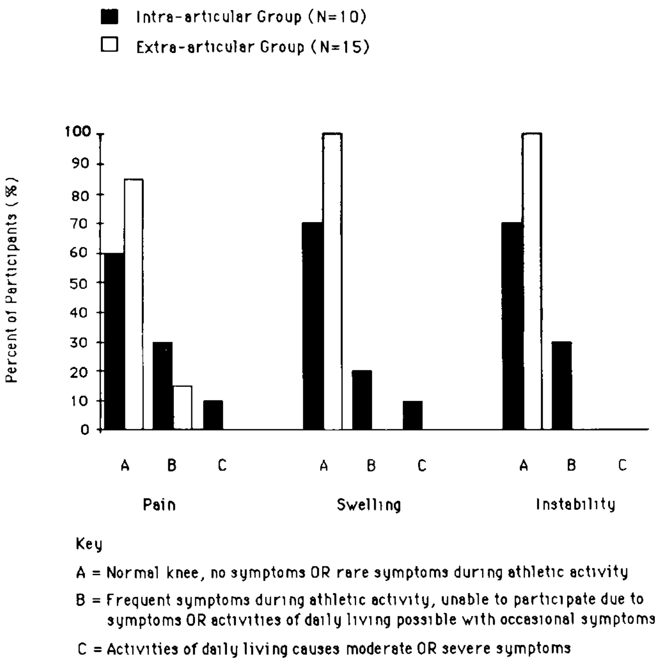

Figure 1. Percent of participants (%) versus the incidence of pain, swelling, and instability for the extraarticular ($N = 15$) and intraarticular ($N = 10$) groups.

TABLE 7

Correlation between the average functional activity score for the extraarticular ($\bar{x} = 89.20$) and intraarticular ($\bar{x} = 73.80$) groups and stability tests

Stability tests	Extraarticular ($N = 15$) r value	Intraarticular ($N = 10$) r value
Anterior drawer in neutral	−0.19625	0.24689
Anterior drawer in 15° external rotation	0.12154	0.39459
Lachman test	−0.15963	0.18678
Varus stress in 0° extension	−0.36192	−0.14618
Varus stress in 30° flexion	−0.36563	−0.14618
Valgus stress in 0° extension	−0.10982	0.21797
Valgus stress in 30° flexion	−0.26481	0.22628
Lateral pivot shift	−0.06407	0.62532

TABLE 8

Quadriceps (operated/control leg) and hamstring (operated/control leg) muscle strength (foot-pounds) versus functional activity score

Functional activity score versus (deg/sec):	Extraarticular ($N = 15$) r value	Intraarticular ($N = 10$) r value
Quadriceps, 240	0.5045	0.7916[a]
Quadriceps, 120	0.5031	0.7422[b]
Hamstrings, 240	−0.2875	0.7456[b]
Hamstrings, 120	−0.2700	0.7973[a]

[a] $P < 0.01$.
[b] $P < 0.05$.

Athletic participation was classified according to one of three categories: 1) competitive, 2) recreational, or 3) weekend athlete. There was no difference in the preinjury and follow-up participation levels for the extraarticular or intraarticular groups. For each sport, the percent of individuals who improved or returned to the same participation level, went down a participation level, and quit participating due to the injured knee is shown in Figures 4 and 5. More than 60% of the subjects participating in bicycling, weight lifting, swimming, racquetball, and softball were able to return to or improve their preinjury participation level. Sports with

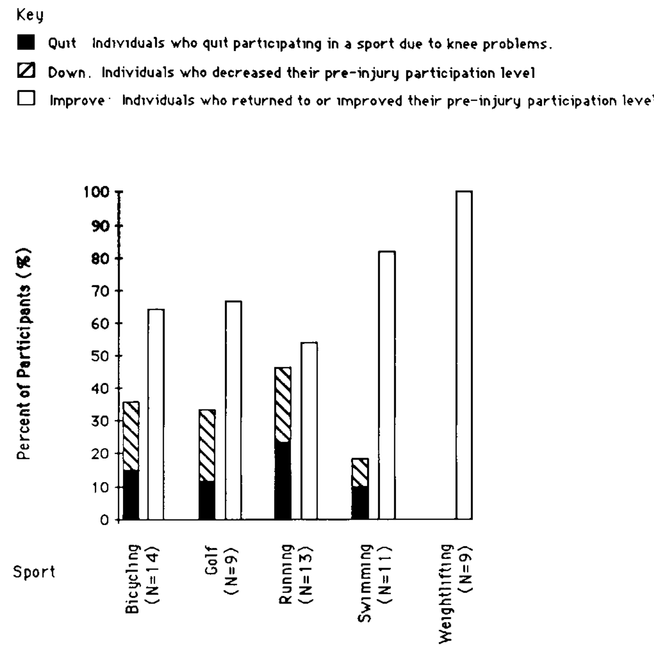

Figure 2. Percent of participants (%) versus activity level of noncutting sports.

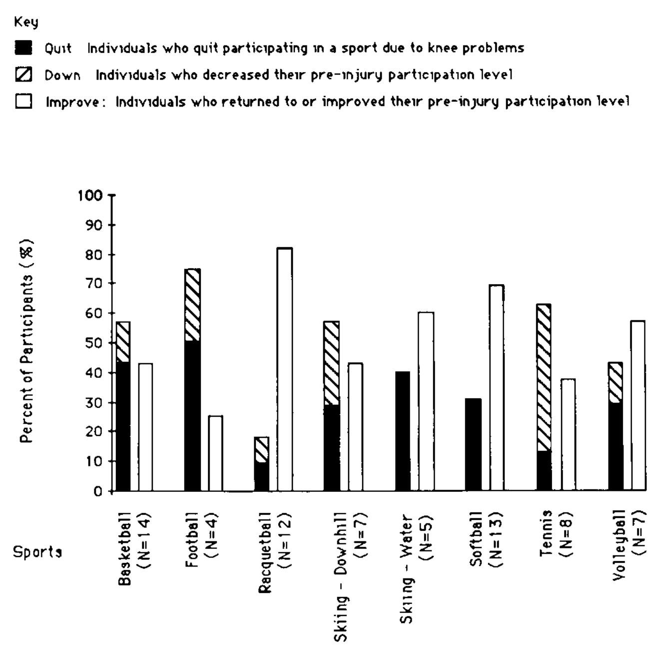

Figure 3. Percent of participants (%) versus level of cutting sports.

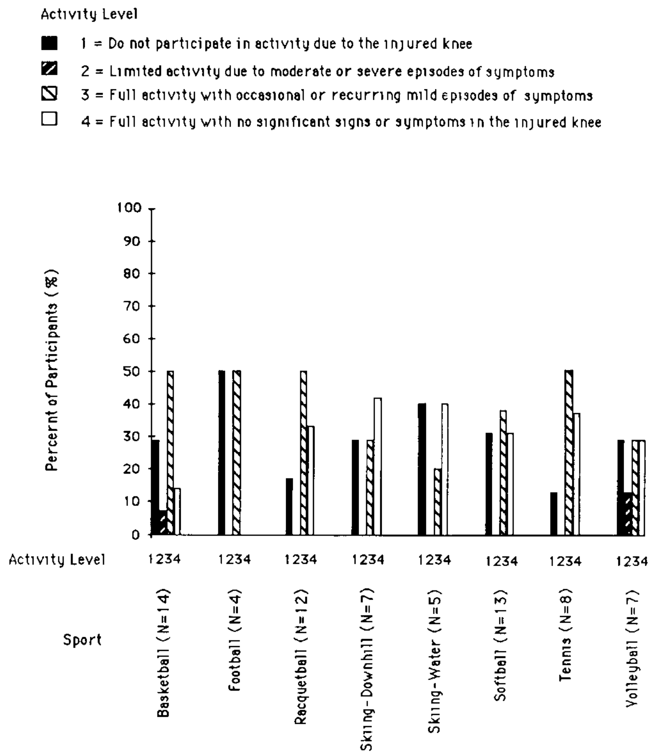

Figure 4. Percent of participants (%) who maintained or changed their preinjury participation level following ACL reconstruction in cutting sports.

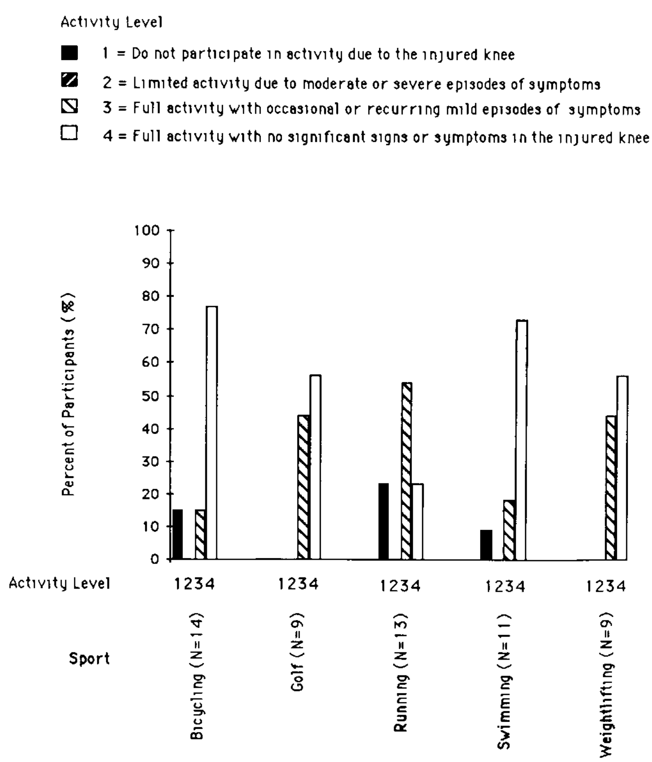

Figure 5. Percent of participants (%) who maintained or changed their preinjury participation level following ACL reconstruction in noncutting sports.

the largest percentage of decreased participation were football (87%), tennis (70%), downhill and water skiing (62%) and basketball (57%). Fifty percent or more of the individuals who decreased their preinjury sports participation levels in basketball, football, softball, and racquetball quit due to related knee problems.

DISCUSSION

One of the major treatment goals after ACL injury is to return to the individual to preinjury functional status. The major purpose of this study was to assess the relationship of functional status to static knee stability and dynamic muscular contraction in a surgically treated group of ACL-injured individuals. An additional goal was to compare this group's preinjury and postsurgery sports activity patterns. A better understanding of these relationships will help the clinicians assess the patient's prognosis and aid in devising individualized rehabilitation programs.

The results of this study indicate that there was a significant loss of stability in the operated knee as compared to the control knee. However, this instability had no statistically significant relationship with the subjects' functional activity level ($P < 0.05$). The functional rating questionnaire used in this study was patterned after that used by Lysholm et al.[12] Contrary to our results, they reported a significant correlation between functional loss and the presence of either a pivot shift sign and/or varus or valgus instability in knee extension. It is important to note that their population included subjects with combined ligament damage and subjects who were not surgically treated. Other studies using different functional rating systems have noted a positive relationship between stability and function.[11,14]

The integrity of static knee functional stability, as measured in this study, was the result of passive restraints offered mainly by the ligaments that surround the knee. The ability to function, on the other hand, is influenced by other structural factors in addition to ligamentous stability such as muscular strength, coordination, proprioception, and the integrity of the joint components (e.g., synovium, joint capsule, bursae). Walla et al.[18] found no significant relationship between passive stability and function, but noted a significant relationship between functional level and the hamstrings' ability to control tibial excursion. Passive tests of stability may not accurately predict joint responses during functional activities since ligaments act in conjunction with muscles to provide dynamic stability.

The quadriceps femoris and hamstring muscles are the major dynamic knee stabilizers. We expected that strong quadriceps femoris and hamstring musculature would be significantly related to functional status. In this study, a significant relationship between thigh muscle strength and functional status has been noted only in the intraarticular group. These results support previous findings in an intraarticular study[3] but conflict with previous findings in an extraarticular population.[16]

Further analysis of the data offers various explanations for the absence of a significant relationship between strength and function in the extraarticular group. It is interesting to note that the extraarticular group's quadriceps strength deficit was far less dramatic than the intraarticular group's. For example, at 240 and 120 deg/sec the extraarticular group's mean quadriceps strength ratios, operated to control leg, were 82.5% and 88.7%, respectively. The comparable figures for intraarticular group were 59.3% at 240 deg/sec and 67.6% at 120 deg/sec. Perhaps function related not only to a decrease in quadriceps strength, but also to the degree of that strength deficit. In addition, the extraarticular group did not show a significant loss of hamstring strength in the operated leg. The hamstrings may act to decrease the degree of anterior tibial excursion in the ACL deficient knee. The dynamic stability offered by this muscle group helped to positively influence the patient's functional status.

Walla et al.[18] have noted a positive relationship between the ability of the lateral hamstrings, the biceps femoris, to reflexively control anterolateral rotary instability and improve the individual's functional capacity. No significant relationship was found between isokinetic hamstring strength and functional ability. The ability of a muscle to prevent instability is determined by more than its force-producing capacity. Other factors that may affect the joint stabilizing ability of the muscles may include the speed in which the muscle responds to the unstabilizing force, the influence of muscle length to the tension generated, and the muscle's ability to resist fatigue. Further research is needed to delineate the components constituting the muscle's ability to stabilize a joint, and to determine the relative importance of these factors.

Giove et al.[8] found an interesting relationship between excessive strengthening of the hamstrings and function. Subjects whose hamstring strength was greater than or equal to the quadriceps strength of their involved limb returned to higher levels of sports participation than subjects whose hamstring strength was less than their quadriceps strength. In our study, subjects in the intraarticular group had approximately a 1:1 hamstring to quadriceps ratio. However, unlike the Giove et al. study, subjects in our study had a significant quadriceps strength deficit in their involved leg. Thus, our hamstrings to quadriceps ratios do not represent excessive hamstring strengthening. A valid correlation between the hamstring to quadriceps ratio and function cannot be made for our sample.

One of the most striking findings in this study was the difference in the functional activity score, specifically concerning the onset of pain and swelling, between the intraarticular and extraarticular surgical groups. The intraarticular group complained of significantly greater degrees of pain and swelling during activity (Fig. 1). Intraarticular ACL reconstruction is a more invasive surgical technique than extraarticular reconstruction and may have caused residual internal scarring in the knee joint which contributed to this difference.

Warren and Marshall[19] compared functional results between subgroups who had received various extraarticular and intraarticular procedures. No one surgical procedure was more successful in returning individuals to their preinjury status. The discrepancy between the results of Warren and Marshall[19] and this study may be due to the use of different functional activity scales which can produce varying results. In addition, the intraarticular group had losses in quadriceps and hamstrings strength in the operated leg which has been shown to influence function.[3,16]

Two possible interpretations may explain the relationship between the symptoms of pain and swelling and the strength deficits. First, loss of strength may result in decreased dynamic knee stability leading to complaints of pain and swelling. Second, subjects experiencing pain with activity will typically function at a lower activity level which can lead to or perpetuate decreased muscle strength. Further research is needed to determine the cause and effect relationship between these factors.

A more recent innovation in analyzing the functional status of the individual patient is the use of a sports participation survey. This survey is used to assess the patients' preinjury and postinjury participation levels in conjunction with the sports activities pursued. In this study, many individuals in both surgical groups decreased their sports participation level due to their injury (Figs. 4 and 5).

The limitation in sports activities was most evident in the cutting sports: football, tennis, downhill skiing, water skiing, and basketball (Fig. 3). Giove et al.[8] reported similar limitations in sports of football and basketball while also noting great limitations in volleyball and racquetball. One distinct characteristic common among these sports is that cutting, turning, and lateral movements are required during participation. It is not surprising that subjects with ACL injury have difficulty in these cutting sports since anteromedial or anterolateral instability would hinder the execution of a side-step or cross-over cut, respectively.[1] Furthermore, the lateral pivot shift and reverse lateral pivot shift motions are reproduced during cutting and pivoting motions.[10] In short, dynamic muscular stabilizers, as well as the stabilization offered by surgical intervention, may not be sufficient to limit the unstabilizing forces that occur during cutting maneuvers.

The successful return to cutting versus noncutting sports should be considered when advising the ACL-injured athlete. In contrast to sports requiring a high degree of cutting, few individuals participating in sports that do not require a high degree of cutting (i.e., bicycling, golf, swimming, and weight lifting) decreased their preinjury sports participation level or quit due to associated knee problems (Fig. 5). This finding is in agreement with previous results.[8]

Rehabilitation specifically aimed at increasing the hamstrings' ability to control tibial excursion may offer the joint stabilization necessary for cutting. In rehabilitation, the hamstrings are trained by resisted knee flexion exercises. Andriacchi et al.[2] reported that ACL deficient individuals cut with the knee and hip in a position of greater flexion. They proposed that this compensation may be used to place the biceps femoris in a more effective mechanical position to stabilize internal tibial rotation and an anterior drawer. As previously discussed, Walla et al.[18] showed that functional return did not relate to hamstring strength but was related to the hamstrings' ability to contact reflexively. Therefore, the focus in rehabilitation should include more than resisted knee flexion. Rehabilitation should also include resisted tibial internal and external rotation as well as reflex training of the medial and lateral hamstrings to decrease anteromedial rotary instability and anterolateral rotary instability, respectively.

Two other points of interest were found through the sports participation survey. First, the subjects in the two surgical groups did not differ significantly in their ability to return to sports. This indicates that, in respect to this one specific evaluation method, the intraarticular procedure is no more beneficial than the extraarticular technique in returning the individual to athletic participation. More research in this area is needed using a larger subject population as well as a control group to attain a better assessment of the effects of these two surgical procedures on sports participation.

In addition, a significant positive correlation ($P < 0.001$) was noted between the functional activity and sports participation scores. This finding, although not surprising, raises the possibility that the ability to function in daily activities may be a reliable predictor of successful return to sports activities. In the clinical setting a common component of the evaluation used prior to return to sports is assessment of whether functional activities are symptom-free prior to return to sport. Our results indicate that this practice should continue.

CONCLUSIONS

Defining the relationship between objective strength and stability on the operated leg and subjective functional outcome may help determine areas to emphasize in treatment and long-term progressive therapy of patients with ACL injuries. Despite a high percentage of subjects with objective signs of anterior instability, a more important factor influencing function was quadriceps and hamstring muscle strength in the involved limb. For the intraarticular group, as the thigh muscle strength on the operated leg approximated that of the control leg, the subjects' functional activity score increased. The specific role the hamstrings may play in providing dynamic stability of the knee was not investigated in this study. However, considering the importance of increased isokinetic strength in returning individuals to their preinjury activity level, further investigation is warranted.

Determining preinjury and present sports participation levels are important in assessing a patient's successful return to athletics. Reporting the individual's present participation level does not indicate full recovery. The average sports participation level at followup was not significantly different from preinjury level in this study. The sports that were played at the time of followup were not always the same sports played prior to injury. Twenty-five percent of the subjects who were active in sports involving cutting motions quit due to knee problems. Subjects engaged in sports with less cutting motions reported full activity with few symptoms of pain, swelling, and/or instability. However, some individuals were able to participate in new sports, including cutting sports, on a regular basis at followup. Further investigation examining the amount of cutting and twisting movements involved in different sports is important to: 1) determine the varying forces placed on the knee and, 2) how the compromised knee responds to these forces.

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