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Changes in Bone Scans after Anterior Cruciate Ligament Reconstruction

A Prospective Study*

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Background: Whether anterior cruciate ligament reconstruction retards the progression of osteoarthrosis is not established. Bone scintigraphy can be useful for monitoring the course of osteoarthrosis. Bone scan findings are abnormal in the majority of patients with anterior cruciate ligament deficiency. Three uptake patterns can be distinguished.
Hypothesis: Reconstruction corrects the three abnormal bone scan patterns seen in patients with anterior cruciate ligament deficiency.
Study Design: Prospective cohort study.
Methods: We performed bone scintigraphy in 80 patients, before and 2 years after anterior cruciate ligament reconstruction.
Results: Reconstruction consistently corrected type 2 bone scan pattern (meniscus scan) but not type 1 and 3 patterns (osteoarthrosis and cartilage ulcer scan). Correction of all three patterns decreased among patients who had longer duration of anterior cruciate ligament deficiency and was more reliable for the combined uptake of all three patterns among patients who had less than 6 months of deficiency.
Conclusion: These findings indicate anterior cruciate ligament reconstruction protects the menisci. Reconstruction may be best performed within 6 months after injury.

Rupture of the ACL most often occurs in young patients[28]; it can cause varying degrees of disability[6] and is associated with the development of osteoarthrosis.[25] Anterior cruciate ligament reconstruction improves short-term knee function in most patients[17]; however, whether reconstruction retards the progression of osteoarthrosis after knee injury has not been established.[18,25] The reported prevalence of osteoarthrosis after ACL reconstruction ranges from 13% to 65% at 3 to 9 years, respectively.[18] However, only one study that examined the development of osteoarthrosis after ACL reconstruction was prospective in design.[7] Five years after the start of treatment, the authors of this study found a higher incidence of osteoarthrosis in patients who had undergone operative treatment than in patients who had nonoperative treatment. Among patients with osteoarthrosis, the findings of both radiographs and bone scintigraphy were abnormal.[7] The presence of abnormal bone scans after ACL reconstruction was confirmed in another study,[1] but the implications of both studies are uncertain. The reason for this uncertainty is that treatment methods were not randomized and bone scans were not performed prospectively. Scans were obtained only at follow-up, not at the start of treatment.

Bone scans appear to be useful for monitoring the course of osteoarthrosis. In contrast to radiographs, bone scans reportedly detect the early changes of osteoarthrosis.[27,38] In addition, bone scans can be used to predict progression in patients with established osteoarthrosis.[9] Whether this application is also relevant for ACL-deficient knees has not been examined. If so, the use of bone scan findings can be helpful in counseling patients and in assessing treatment methods for ACL deficiency.

Bone scans of ACL-deficient knees can enable the physician to interpret the functional changes that may precede structural changes. Bone scan findings are abnormal

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in approximately 80% of patients with ACL-deficient knees,[10,11,13,21] and three patterns of scan uptake can be distinguished (Table 1 and Figs. 1 through 3). We compared these patterns with structural changes (cartilage and meniscus status at arthroscopy) and found that structural changes alone did not explain all the scan patterns.[21] However, when the functional changes of ACL deficiency, for example, altered joint loading, were considered in addition to the structural changes, the unexplained scan patterns could be interpreted as the loss of osseous homeostasis that results from these functional changes.[21] This loss of homeostasis likely precedes meniscal lesions and osteoarthrosis.[16] As a consequence, correction of abnormal scan uptake after ACL reconstruction would indicate correction of the functional changes. At present, however, the effect of ACL reconstruction on abnormal scan uptake is unknown. Only one single case has been described in which bone scans were made before and after ACL reconstruction.[12] We sought to answer the question of whether ACL reconstruction corrects the three abnormal bone scan patterns seen in ACL-deficient knees.

MATERIALS AND METHODS

From April 1, 1997, to March 1, 1998, 109 patients with symptomatic unilateral ACL deficiency were admitted to the Onze Lieve Vrouwe Gasthuis in Amsterdam for reconstruction. Exclusion criteria for the study were an earlier operation or combined ligament instability of the ACL-deficient or the contralateral knee. Four patients refused to take part in the study, and 10 patients with combined ligament instability or who had undergone revision surgery of the ACL were excluded. The hospital's medical ethics committee approved the study, and all patients gave informed consent. Thus, a total of 95 patients (64 men and 31 women) were examined preoperatively by undergoing bone scintigraphy. The average age of the patients at the time of operation was 32 years (range, 16 to 57). The average duration of ACL deficiency before the operation was 43 months (range, 1 to 280), and the median duration was 18 months. Bone scan findings of these 95 patients were reported earlier.[21]

Before ACL reconstruction, a complete diagnostic arthroscopic examination was performed. Meniscal tears were repaired or excised. All ACL reconstructions were performed arthroscopically by one surgeon (CPvdH) with use of autologous bone-patellar tendon-bone grafts.

Cartilage and Meniscal Status

Cartilage degeneration was graded 0 to 4 during the arthroscopic examination: 0 for intact cartilage, 1 for softening, 2 for fibrillation, 3 for partial-thickness loss, and 4 for full-thickness loss.[31,35] Only partial meniscectomies were performed, and they were graded 0 for no meniscectomy, 1 when the central third of the meniscus was removed, 2 when the central and middle thirds were removed, and 3 when the central, middle, and capsular thirds were removed.

Bone Scans

Bone scans were obtained 1 to 3 days preceding ACL reconstruction by using 10 mCi technetium 99-hydroxy diphosphonate (99mTc). Scans were obtained directly after injection and repeated after 2 hours with a Siemens Orbiter single-detector camera (Siemens, Erlangen, Germany). Three or four views were obtained: anterior and posterior, and, on the basis of these views, additional medial or lateral views or both.

With use of the same protocol, bone scans were repeated a minimum of 2 years after ACL reconstruction (range, 24 to 28 months). Of the 95 patients, 4 refused to undergo the second scan, 6 could not be located, 2 were living abroad, 1 was pregnant, and 2 patients had undergone surgery during the 2-year period (1 had revision ACL reconstruction and 1 had a high tibial osteotomy). Thus, a total of 80 patients (84% of the original 95 patients) underwent a repeat scan 2 years after ACL reconstruction. The group of 15 patients who did not have a repeat scan was compared with the remaining 80 patients with regard to preoperative scan patterns, age, duration of ACL deficiency, arthroscopic findings, and subjective outcome. There were no significant differences between the two groups except that the group of 15 patients who did not have a repeat scan were younger (mean, 26 years compared with 32, $P = 0.02$).

In the following sections we report the findings of the 80 patients who underwent bone scintigraphy both before and after reconstruction. Bone scans were evaluated by three observers (TH, THPR, WKT) in consensus, without knowledge of the operative findings. The scans at follow-up were evaluated without knowledge of the scans before operation. A simplified Mooar classification was used (Table 1).[29] Intensity of uptake was graded 0 (normal) when it was not increased compared with the contralateral knee. Abnormal scans were graded 1 for a slight increase and 2 for a marked increase compared with the contralateral knee. Before the operation and at follow-up, 2.5% of contralateral knees (2 of 80) had abnormal scans. The following results are only for the ACL-deficient knees.

TABLE 1
Classification of Bone Scan Uptake Patterns in ACL-Deficient Knees[a]

Pattern	Illustration	Location in knee	Associated pathologic conditions
Type 1	Figure 1	Periarticular regions of femur, patella, and tibia	Osteoarthrosis
Type 2	Figure 2	Posterior rim of tibial plateau	Meniscal lesion
Type 3	Figure 3	Deep to subchondral surface	Cartilage ulcer, bone bruise, subchondral fracture

[a] Modified from Mooar et al.[29]

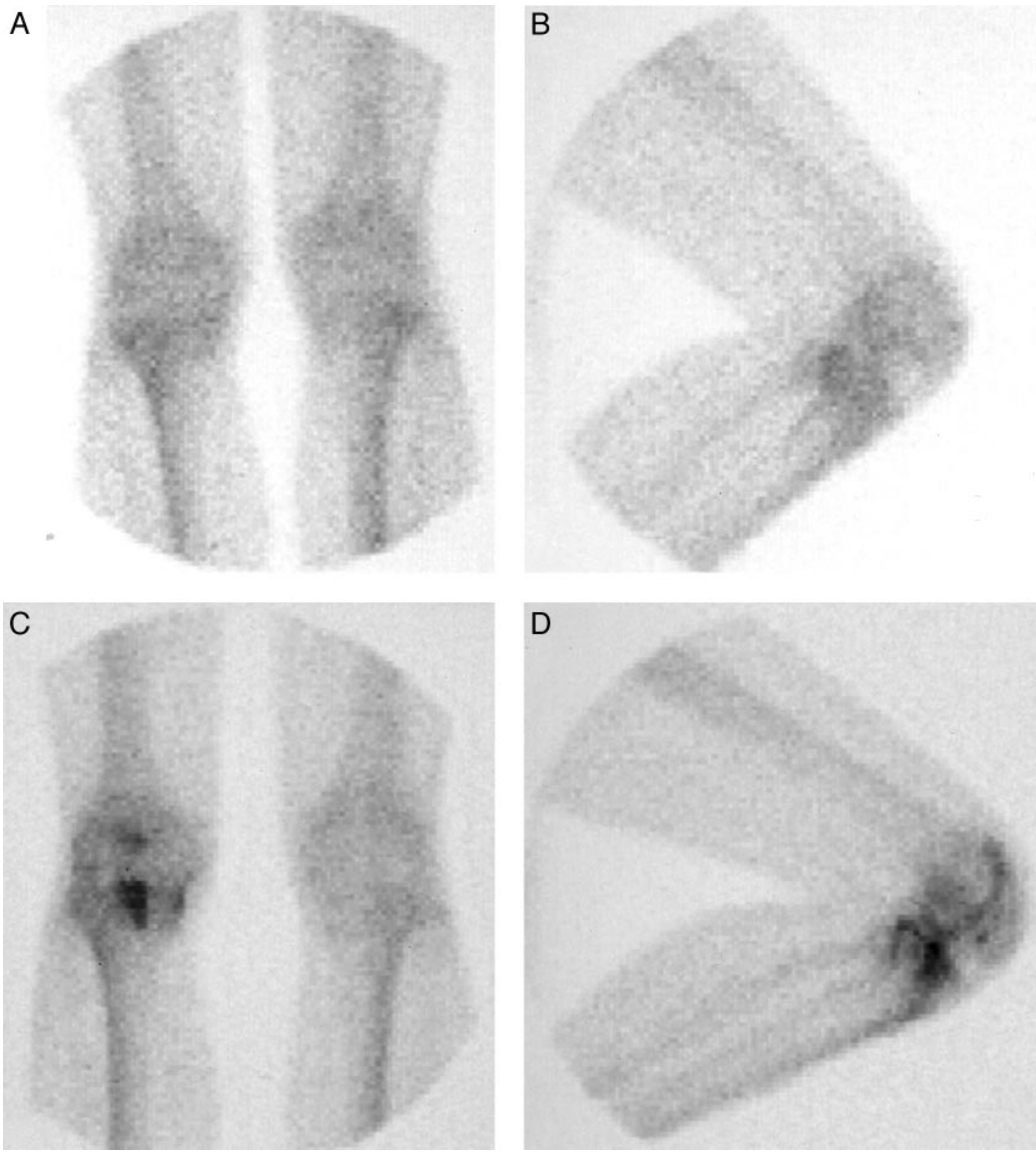

Figure 1. Bone scans of a 43-year-old patient who had ACL deficiency of the right knee for 40 months. A, normal AP bone scan before operation. B, normal lateral scan before operation. C, type 1 pattern (osteoarthrosis scan) 2 years after ACL reconstruction on an AP scan. D, type 1 pattern on a lateral scan.

Radiographs

Radiographs were obtained of both knees on the same days that bone scans were obtained, before and 2 years after ACL reconstruction. Posteroanterior and lateral weightbearing views were made with the knee in 0° and 30° of flexion, respectively.

Radiographs were not obtained from 4 of the 80 patients at the 2-year follow-up. Kellgren and Lawrence grading, as described by Petersson et al.,[34] was performed in consensus by three observers (TH, THPR, WKT). Grade 0 was assigned to normal knees, grade 1 for a minute osteophyte of doubtful significance, grade 2 for a definite osteophyte with an unimpaired joint space, grade 3 for moderate joint space diminution, and grade 4 when the joint space was greatly impaired or when moderate joint space diminution was seen with marked sclerosis of subchondral bone. Joint space diminution was determined by comparing the medial and lateral tibiofemoral joint spaces in one knee, or, if necessary, by comparing them with the contralateral knee.

Clinical Evaluation

At the 2-year follow-up, patients completed questionnaires that consisted of the subjective part of the International Knee Documentation Committee (IKDC) form.[20]

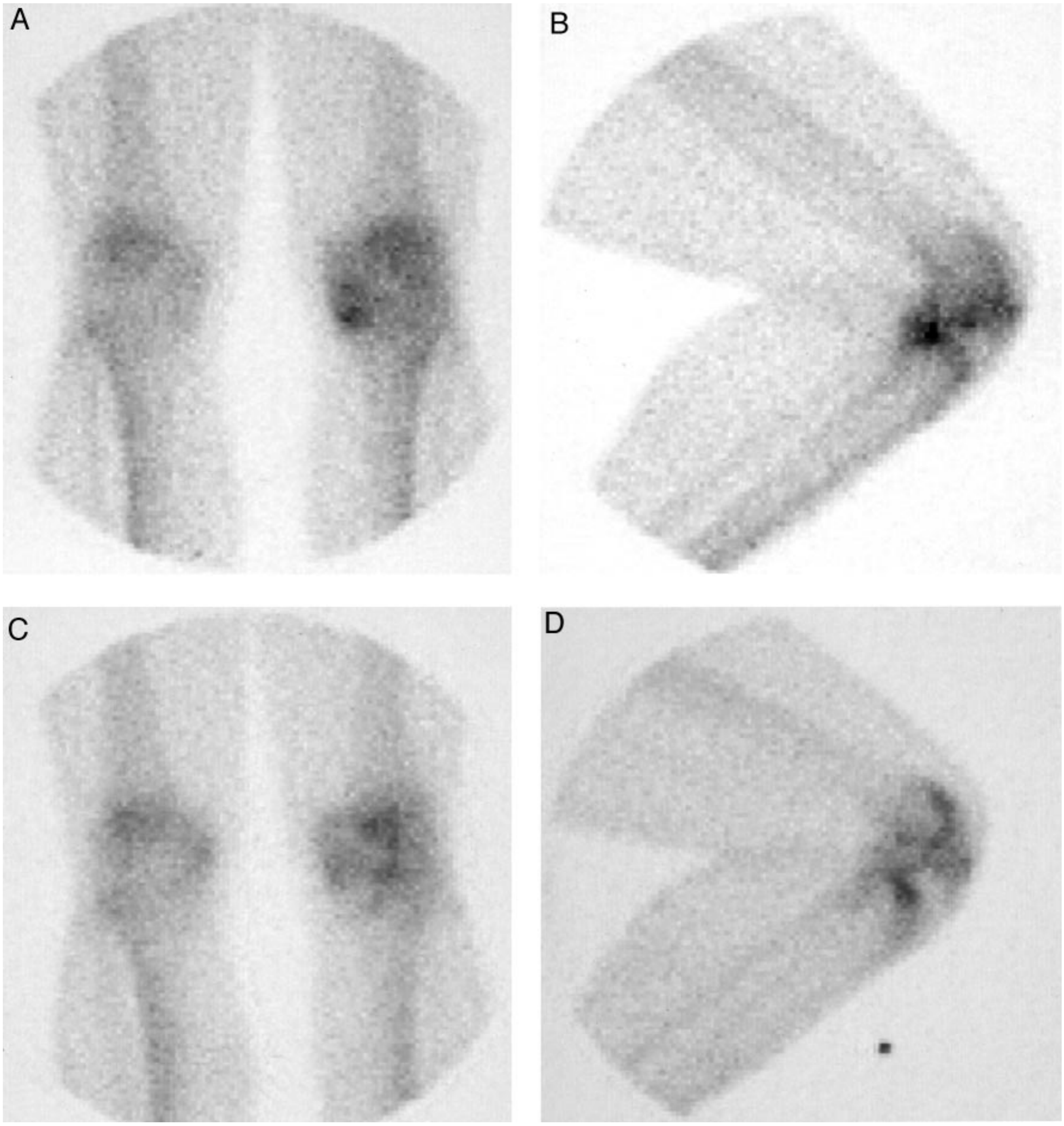

Figure 2. Bone scans of a 32-year-old patient who had 109 months of ACL deficiency of the left knee. A, preoperative AP bone scan with type 1 and type 2 pattern. B, preoperative lateral scan. C, AP bone scan 2 years after ACL reconstruction, with correction of type 2 (meniscus scan), but not of type 1 pattern (osteoarthrosis scan). D, lateral scan at 2 years after ACL reconstruction.

For evaluation of overall knee function, we asked the question, "How does your knee function?" Answers were categorized as 1, normal; 2, nearly normal; 3, abnormal; and 4, severely abnormal. Activity level, pain, instability (partial giving way), and effusion were similarly examined by asking the patients to respond to the corresponding questions of the IKDC form. Answers were categorized according to the IKDC scheme for activity levels: 1) jumping, pivoting, hard cutting, football, soccer; 2) heavy manual work, skiing, tennis; 3) light manual work, jogging, running; and 4) sedentary work, activities of daily living. Anterior laxity difference between the operated and contralateral knee was measured with a KT-1000 arthrometer (Medmetric Corp., San Diego, California) with use of a 133-N force.

Calculations

Overall scan uptake was calculated as the sum of uptake grades for type 1, 2, and 3 scans. The difference in scan uptake before operation and at follow-up was calculated for the three scan types separately and for their sum. The difference between uptake before operation and at follow-up was divided by the uptake before operation to obtain a measure of the degree of change of scan uptake independent of the grade of uptake before operation. This

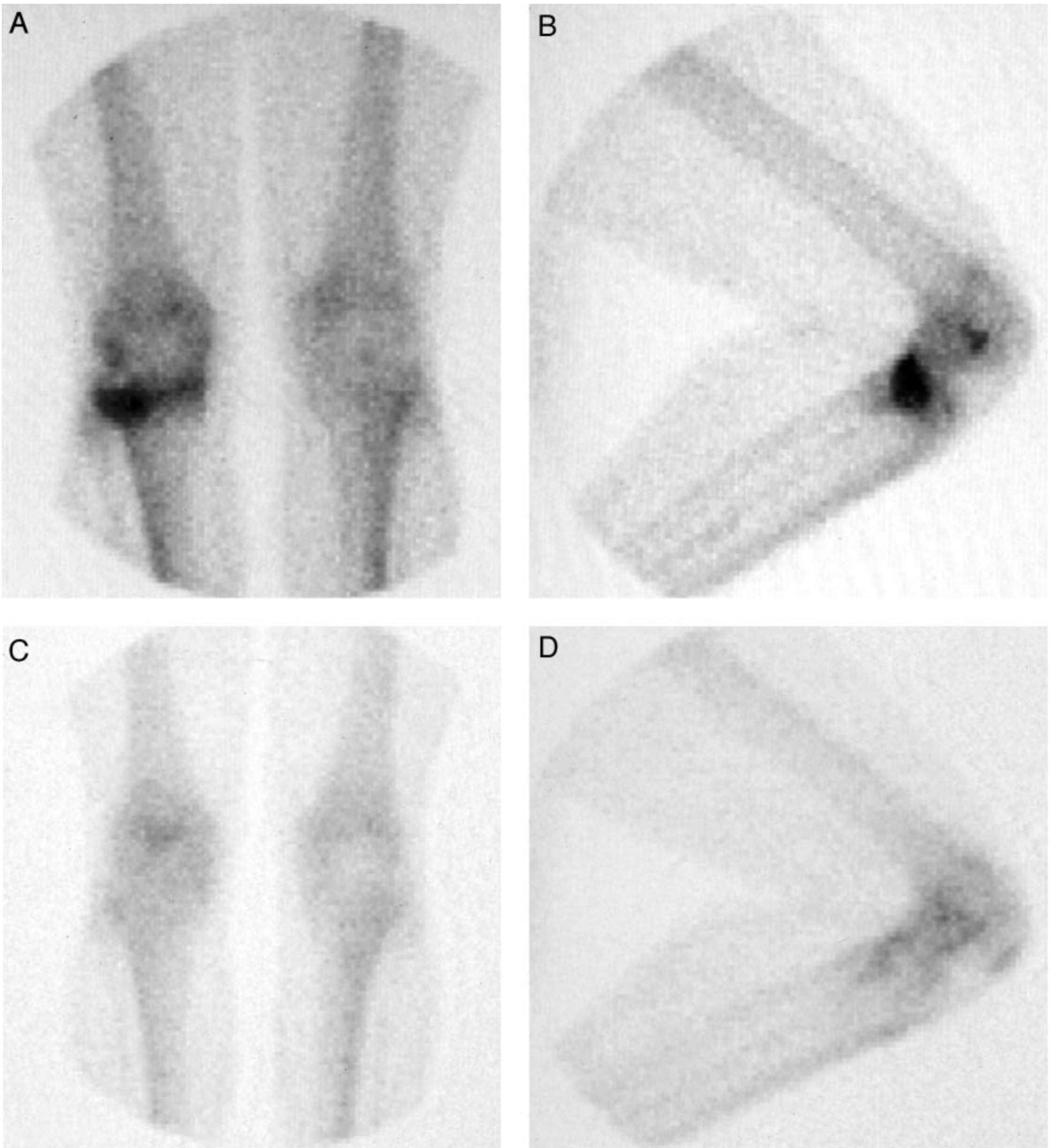

Figure 3. Bone scans of a 23-year-old patient who had 2 months of ACL deficiency of the right knee. A, AP bone scan before operation with type 3 pattern. B, lateral scan before operation. C, AP bone scan 2 years after ACL reconstruction, with correction of type 3 pattern (bone bruise and cartilage ulcer scans). D, lateral scan 2 years after ACL reconstruction.

figure gave an index value between 1 and −1. Negative values indicated an increase of uptake at follow-up, 0 indicated no change, and 1 indicated return to normal uptake (identical with the contralateral knee). When uptake was grade 0 before and after the operation, index value 0 (no change) was assigned. Index value −1 was assigned when uptake was grade 0 before and grade 1 or 2 after operation.

Statistical Analysis

Data are summarized as means and standard deviations. For statistical analysis, the five grades of cartilage damage were grouped into two categories (normal, chondropathy grade 0 to 2; and abnormal, chondropathy grade 3 to 4). Meniscal status was grouped into three categories (normal, both menisci intact; 1, partial meniscectomy of medial or lateral meniscus; and 2, partial meniscectomy of both menisci). For subjective outcome measures, we used the mean of the IKDC subjective categories for knee function, activity level, pain, effusion, and instability. We analyzed time (duration of ACL deficiency) in two ways. One was as a discontinuous variable in which we made subgroups on the basis of comparable sample size. The other was as a continuous variable for scatter plots. In addition, for scatter plots, time was transformed to log time to better approximate the Gaussian distribution.

For the subgroups of duration of ACL deficiency, we found no normalizing transformation for the ordinal data. Because of the small sample size, we used the Kruskal-Wallis nonparametric analog to the one-way analysis of variance to test for equality of scan uptake among groups of different duration of ACL deficiency. The Mann-Whitney test was used for differences in change of scan uptake between subjects in the 0- to 6-month and 1- to 2-year groups. This comparison was planned a priori and was the only comparison made between subgroups. Fisher's exact test was used to determine the differences in change of scan uptake between subgroups. Spearman's rank-order correlation coefficient was used to examine the relationship between subjective outcome, scan uptake, and radiographic and clinical findings.

Baseline characteristics were compared between the 80 patients in the study and the 15 patients lost to follow-up. An extension of the Wilcoxon rank test[5] was used to determine whether there was a trend among groups with different duration of ACL deficiency. Reported P values are two-sided. The nominal significance level was set at 0.05 for all tests. All data were analyzed by using Stata 6.0 software (Stata Inc., College Station, Texas).

RESULTS

In this study of 80 patients, we found that ACL reconstruction consistently corrected type 2 bone scan pattern (meniscus scan) but not type 1 and 3 patterns (osteoarthrosis and cartilage ulcer scan). Correction of all three patterns decreased among patients who had longer duration of ACL deficiency and was more reliable for the combined uptake of all three patterns among patients with less than 6 months of ACL deficiency.

Type 2 Scan (Meniscus Pattern)

Anterior cruciate ligament reconstruction had corrected 90% of the rate and 95% of the uptake of type 2 scans. Fifty-two of 80 patients had a type 2 scan before the operation, compared with 5 of 80 at follow-up ($P = 0.001$). The mean grade of uptake of type 2 scans in the 80 patients was 1.05 ± 1.07 before operation and 0.06 ± 0.24 at follow-up ($P < 0.0001$) (Fig. 4).

Type 2 scans were corrected irrespective of whether the meniscus had been found to be normal or abnormal (new or old tear or prior partial meniscectomy) during the arthroscopic procedure. Scan findings were normal in 18 of 20 patients who originally had a normal meniscus and in 29 of 32 patients who had had an abnormal meniscus ($P = 1$). In contrast, correction of type 2 scans was differentiated with regard to duration of ACL deficiency. Correction was complete in all patients who had less than 12 months of ACL deficiency; whereas, of those patients with more than 12 months of ACL deficiency, correction was incomplete in 5; 19 of 19 were corrected compared with 28 of 33, respectively. No type 2 scans had developed as a new finding at follow-up.

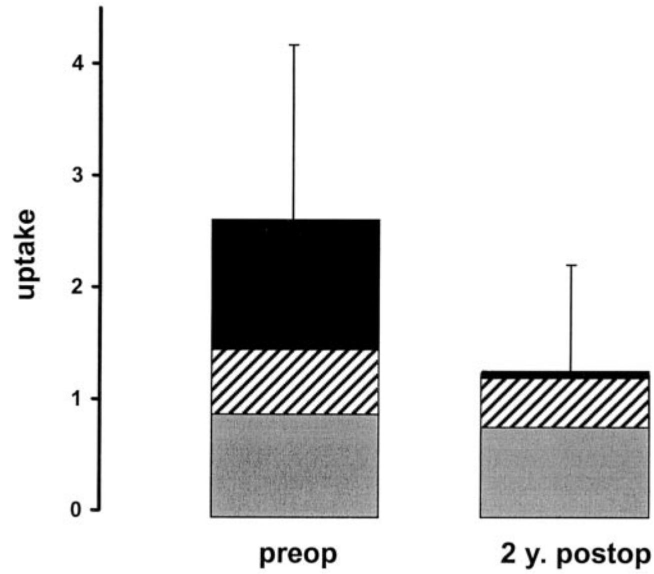

Figure 4. Mean grade of scan uptake in 80 patients. The difference in uptake between the preoperative (preop) and 2-year postoperative (2 y. postop) scans is significant for the sum of all three scan types ($P = 0.0001$) and for type 2 scan ($P < 0.0001$), but not for type 1 ($P = 0.07$) and 3 ($P = 0.25$) scans (Wilcoxon rank test). Gray bar, type 1; striped bar, type 3; black bar, type 2.

Type 1 Scan (Osteoarthrosis Pattern)

Overall, neither uptake nor rate of type 1 scan were corrected at follow-up. The mean grade of uptake of type 1 scan among 80 patients before operation was 0.94 ± 0.62 and 0.83 ± 0.78 at follow-up ($P = 0.07$) (Fig. 4). The rate of type 1 scan was unaltered because, although type 1 scan was corrected in 12 patients, it also developed as a new finding at follow-up in 11 patients who did not have this pattern before operation (Fig. 1). The rate before operation was 78% (62 of 80) and at follow-up was 76% (61 of 80) (Fig. 5).

The duration of ACL deficiency influenced change in type 1 scans in two ways. First, type 1 scans were corrected more reliably when the duration of ACL deficiency was less than 6 months. Five of 12 patients with correction had less than 6 months of ACL deficiency, compared with 8 of 50 patients without correction ($P = 0.06$). Second, in contrast to the previous finding, type 1 scans as a new finding at follow-up developed more frequently among patients with longer duration of ACL deficiency. Of the total of 11 "new" type 1 scans, 8 patients had had more than 3 years' duration and 3 had less than 3 years of ACL deficiency ($P = 0.009$). The seven patients with normal preoperative scans who did not develop type 1 scans all had less than 3 years of ACL deficiency.

The findings of corrected and new type 1 scans confirmed a trend in the overall group of 80 patients of decreased correction of type 1 scan uptake with longer duration of ACL deficiency (Fig. 6).

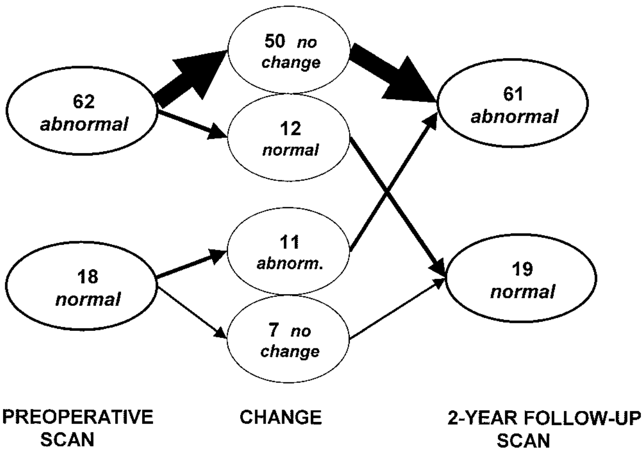

Figure 5. Changes in type 1 pattern (osteoarthrosis scan). For the preoperative scan, *abnormal* = type 1 scan and *normal* = no type 1 scan. Change indicates the change from normal to abnormal or vice versa at 2-year follow-up scan.

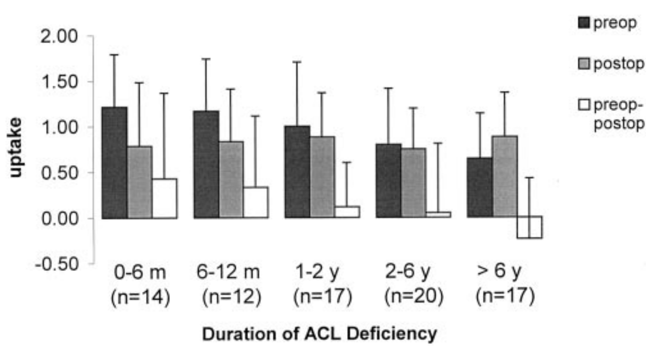

Figure 6. Mean grade of scan uptake of type 1 pattern (osteoarthrosis scan) in 80 patients before operation and at 2-year follow-up according to duration of ACL deficiency. The trend for decreasing correction with longer duration of ACL deficiency approached significance ($P = 0.06$).

Type 3 Scan (Cartilage Ulcer Pattern)

Overall, neither the uptake nor the rate of type 3 scans was corrected at follow-up. The mean grade of uptake of type 3 scan among 80 patients was 0.48 ± 0.78 preoperatively and 0.36 ± 0.70 at follow-up ($P = 0.25$) (Fig. 4). In the femur, type 3 scans had developed as a new finding at follow-up in two patients who did not have this pattern before operation. The rate before operation was 30% (24 of 80) and at follow-up was 23% (18 of 80) (Fig. 7).

Not all patients who had a type 3 scan had associated cartilage damage. For example, 3 of 10 patients with grade 2 uptake of a type 3 scan had normal cartilage (grade 0) identified during the arthroscopic procedure. All three patients had less than 3 months' duration of ACL deficiency, and all three had complete correction of a type 3 scan 2 years after ACL reconstruction. In general, type 3 scans were corrected more reliably when the cartilage had been identified as normal during the arthroscopic procedure. Eight of 14 patients who had chondropathy of

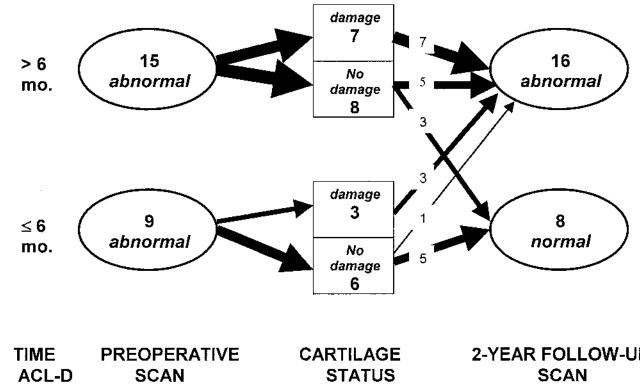

Figure 7. Changes in type 3 pattern (cartilage ulcer scan). Time ACL-D, duration of ACL deficiency. For the preoperative scans, *abnormal* = type 3 scan. For the cartilage status, *damage* = chondropathy grade 3 or 4 and *no damage* = chondropathy grade 2 or less. For 2-year postoperative scan, *normal* = no type 3 scan.

grade 2 or less had correction, compared with 0 of 10 who had chondropathy of grade 3 or 4 ($P = 0.04$).

In the tibia, three patients had a type 3 scan in the lateral plateau. Two of the scans had become normal at follow-up. No type 3 scans had developed as a new finding in the tibia at follow-up.

Influence of Duration of ACL Deficiency on Change in Scan Uptake

The correction of all three uptake patterns decreased with longer duration of ACL deficiency. Although overall scan uptake before operation was highest among patients with less than 6 months of ACL deficiency, these patients also had the largest correction of uptake at follow-up, in both absolute and index values (Table 2). When all three scan types were combined, we found a more reliable decrease of uptake in patients with less than 6 months of ACL deficiency. Among patients who had less than 6 months of ACL deficiency, uptake decreased in 93% of patients (13 of 14). In contrast, among patients with more than 10 months of ACL deficiency, 60% had a decrease (34 of 57), 23% had no change (index 0) (13 of 57), and 18% had an increase in uptake (index <0) (10 of 57) ($P = 0.015$) (Fig. 8). When only type 1 and 3 scans (osteoarthrosis and cartilage ulcer) were combined, we found more reliable correction of these uptake patterns for patients with less than 4 months of ACL deficiency. Eight patients had less than 4 months of ACL deficiency; six of the eight had a decrease and two had no change of uptake. Fifty-five patients with a type 1 or 3 pattern had more than 4 months of deficiency; 19 had a decrease, 19 had no change, and 17 had an increase of uptake. Similarly, correction of type 2 scans (meniscus) was seen more reliably when the duration of ACL deficiency was less than 12 months; 19 of 19 scans had corrected in knees with less than 12 months' ACL deficiency compared with 28 of 33 in knees with more than 12 months' ACL deficiency.

TABLE 2
Change in Overall Scan Uptake in 80 Patients

Duration of ACL deficiency	N	Scan uptake[a]			Index (A–B)/A
		Before operation (A)	2-year follow-up (B)	Difference (A–B)[b]	
0–6 months	14	3.79 ± 1.67	1.00 ± 0.78	2.79 ± 2.01[c]	0.74[c]
6–12 months	12	2.83 ± 1.64	1.25 ± 1.06	1.58 ± 1.62	0.56
1–2 years	17	1.88 ± 1.27	1.29 ± 1.10	0.59 ± 1.00	0.31
2–6 years	20	2.00 ± 1.41	1.05 ± 0.78	0.95 ± 1.28	0.48
>6 years	17	2.35 ± 1.87	1.65 ± 1.00	0.71 ± 1.46	0.30
Overall	80	2.49 ± 1.87	1.25 ± 0.95	1.24 ± 1.62	0.50

[a] Combined uptake of type 1, 2, and 3 bone scan patterns.
[b] $P = 0.01$ for difference among the five groups, by Kruskal-Wallis test.
[c] $P = 0.0009$ versus the group with 1- to 2-year ACL deficiency, by Mann-Whitney test.

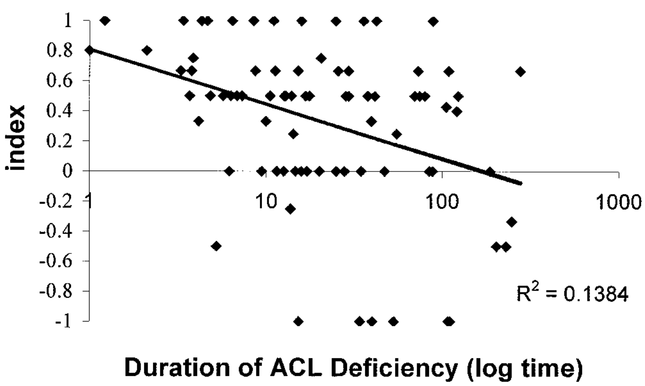

Figure 8. Correction of scan uptake decreases with duration of ACL deficiency. Scatter diagram shows index values for change in scan grade for type 1, 2, and 3 scan combined. Duration of ACL deficiency is shown as log time. The index is the ratio between the difference of pre- and postoperative scan grades and the preoperative scan grade. Duration of ACL deficiency and index value are correlated at $r = -0.364$ ($P = 0.009$).

Radiographic Findings

Before the operation, 48% of patients (38 of 80) had a narrower joint space in the medial than in the lateral compartment (Kellgren-Lawrence grade 3). A further 31% of patients (25 of 80) not only had a narrower joint space, but also had marked sclerosis of the subchondral layer of the medial tibial plateau (Kellgren-Lawrence grade 4, Fig. 9). At follow-up, six patients had an increase of one Kellgren-Lawrence grade and two patients had an increase of two grades. Among the 76 patients of whom radiographs were obtained, the Kellgren-Lawrence grade at follow-up correlated with scan uptake (Table 3) and duration of ACL deficiency ($r = 0.31$, $P = 0.007$).

Correlations at Follow-up

Arthroscopic findings (cartilage and meniscus status) were correlated with radiographic grade but had a stronger correlation with scan uptake at follow-up (Table 3). Subjective outcome was not correlated with any of the measured variables, but there was a trend toward correlation with scan uptake at follow-up (Table 3).

Figure 9. Weightbearing AP radiograph 2 years after ACL reconstruction showing Kellgren-Lawrence grade 4 with narrowing of the medial joint space and subchondral sclerosis.

DISCUSSION

The results of this study of 80 patients show that ACL reconstruction consistently corrected type 2 bone scan pat-

TABLE 3
Correlations among Five Variables in 76 of 80 Patients[a]

Variable	Cartilage/meniscus status[b]	At 2-year follow-up	
		Scan uptake[c]	K–L grade[d]
Subjective outcome	0.13 (0.28)	0.19 (0.096)	0.055 (0.65)
Duration of ACL deficiency	0.22 (0.06)	−0.15 (0.44)	0.31 (0.007)
Cartilage/meniscus status		0.47 (0.01)	0.36 (0.001)

[a] Spearman's rank-order correlations and (P values).
[b] Cartilage degeneration and meniscal tears as seen arthroscopically at ACL reconstruction.
[c] Combined uptake of type 1, 2, and 3 pattern.
[d] Kellgren-Lawrence radiographic grade.

terns (meniscus scan) but not type 1 and 3 patterns (osteoarthrosis and cartilage ulcer scan). Correction of all three patterns decreased with longer duration of ACL deficiency and was more reliable for the combined uptake of all three patterns among patients who had less than 6 months of ACL deficiency before reconstruction.

As an explanation of the consistent correction of the type 2 pattern we suggest that ACL reconstruction has a protective effect on the meniscus. Anterior cruciate ligament reconstruction likely reduces abnormal anterior tibial translation, correcting the high loads on the posterior tibial rim and its meniscus. We believe this correction of loading is reflected in the restoration of osseous homeostasis, as manifested by the correction of the bone scan uptake to normal. Findings of clinical and experimental studies support this explanation.[23,32] In clinical studies, a finding of an increasing rate of meniscal tears with longer ACL deficiency is unquestioned.[2] In experimental studies, ACL transection has been found to increase the load on the meniscal posterior horns, and ACL reconstruction corrects it. These findings and the consistent correction of the type 2 scan pattern, irrespective of the presence of a meniscal tear, fully agree with our earlier suggestion that bone scans can be used to visualize the changes in joint loading in patients with ACL deficiency.[21]

As an explanation of the lack of correction of type 1 and 3 patterns, we speculate that early osteoarthrosis can continue once it is beyond a certain stage, even if pathologic kinematics are assumed to have been corrected. Possibly, ACL reconstruction cannot restore the joint to homeostasis once a certain quantity of accumulated damage to cartilage and menisci is present. We examined four variables relevant to this speculation: scan uptake at follow-up, cartilage and meniscus status, duration of ACL deficiency, and radiographic grade (Table 3). The correlations between these variables support this speculation, with the strongest correlation found between scan uptake at follow-up and cartilage and meniscus status ($r = 0.47$, $P = 0.01$). In addition, the index value for change in scan uptake was correlated with duration of ACL deficiency ($r = -0.36$, $P = 0.009$) (Fig. 8).

Our speculation to explain the lack of correction of type 1 and 3 patterns may appear to contradict our explanation for the correction of the type 2 pattern. One would expect that, if ACL reconstruction preserves the remaining meniscus, it must also reduce the progression of osteoarthrosis. This expectation would be extrapolated from the findings of Neyret et al.[30] that osteoarthrosis after partial meniscectomy is more severe when the knee is ACL deficient. On the other hand, two reviews on osteoarthrosis after knee ligament injury have not confirmed the inference that if ACL reconstruction preserves remaining meniscus, it must also reduce the progression of osteoarthrosis.[18,25] Furthermore, in stable (ACL-sufficient) knees, a randomized study of partial versus total meniscectomy[19] and a matched-control study of meniscal repair versus meniscectomy[36] found no significant differences in degree of osteoarthrosis between these groups. Thus, there appears to be a lack of effect of meniscus-sparing operations on the progression of osteoarthrosis. This finding of lack of effect concurs with our finding of a lack of correction of type 1 and 3 patterns after ACL reconstruction.

We can compare our findings with those of only one other prospective study. In a case report, Dye and Chew[12] reported restoration of osseous homeostasis after reconstruction in a patient who had 20 months' duration of ACL deficiency (S. F. Dye, personal communication, 2000). Complete correction of uptake was rare in our study (12 of 71 patients). Moreover, 11 patients developed a type 1 pattern as a new finding at follow-up. Our results are in better agreement with those of another prospective study conducted by Dye et al.[14] of 34 patients with stable knees who were treated for meniscal tears. In that study, 58% of patients had an abnormal bone scan after the operation. Interestingly, 43% of the patients with abnormal bone scans developed Fairbank changes, compared with 5% of the patients who had normal scans ($P < 0.0001$).

An unexpected finding in our study was that 11 patients developed a type 1 pattern as a new finding at follow-up. We have no adequate explanation for this development. Suggested explanations could be mechanical or biologic in nature. Mechanical explanations include persistent pathologic kinematics or an overconstrained knee (P. A. Mooar, personal communication, 2000). Biologic explanations involve biochemical and genetic aspects of the inherent capability of the joint to restore homeostasis.[16] Of these possible explanations, we could only examine the values from KT-1000 arthrometer testing as an indicator for an overconstrained knee, but we found no such indication in the group of 11 patients (mean side-to-side laxity difference, 1.1 mm; range, −0.5 to +4).

A shortcoming of our study was that we included only patients who had operative treatment for symptomatic unilateral ACL deficiency. Perhaps patients with good functional outcome after nonoperative treatment have fewer scan abnormalities, as found in the study of Daniel et al.[7] However, in that study, scans were obtained only at follow-up, not at the start of treatment. We are currently examining patients who had nonoperative treatment in a longitudinal study that uses bone scans and gait analysis. Although we do not yet have longitudinal data on the rate of the three scan patterns in a control group with nonoperative treatment, we are confident that ACL reconstruction caused the correction of type 2 pattern for two reasons. First, type 2 pattern uptake decreased 95% (Fig. 4) ($P < 0.0001$), whereas uptake of type 1 and 3 patterns had not changed significantly. Second, although the rate of type 2 scans appeared to decrease with longer duration of ACL deficiency (from 73% with less than 1 year to 50% with more than 6 years of ACL deficiency), correction of this rate was differentiated. Complete correction occurred among the subgroups with less than 12 months of duration, although these subgroups actually had the highest rate before operation. Conversely, incomplete correction occurred in subgroups that had a longer duration and a lower rate before operation. We therefore believe that the decrease in the type 2 rate with increasing duration of ACL deficiency is not the explanation for the correction seen after ACL reconstruction. Rather, a decrease in the capacity to restore osseous homeostasis with longer duration of ACL deficiency may explain these differences between the subgroups.

Another shortcoming of our study was that 15 patients were lost to follow-up. Other than exclusion criteria for reasons related to the bone scan, we did not try to select a particular type of patient for this study and used consecutive patients. The 15 patients lost to follow-up were similar to the remaining 80 patients in preoperative scan patterns, duration of ACL deficiency, arthroscopic findings, and subjective outcome. Therefore, we do not believe the loss to follow-up influenced our findings in an important way. Nevertheless, it is clear that we examined mainly patients with chronic injuries. Only eight patients had less than 4 months of ACL deficiency. In retrospect, this may have been the most interesting group, specifically with regard to correction of type 1 and 3 scans (osteoarthrosis and cartilage ulcer scans). As a consequence, we believe that the bone scan and radiographic findings in this group related more to chronic instability than to the acute ACL rupture, as described earlier by Dye et al.[15] Evidence to support this belief is that, before operation, only three bone bruises (type 3 pattern of the tibia) were seen, whereas 79% of patients had a narrower joint space medially than laterally (Kellgren-Lawrence grade 3 and 4).

Bone scans are not commonly used to examine joint injuries, but we believe that bone scans, before and after ACL reconstruction, can be used to detect and monitor early osteoarthrosis. Uptake on bone scans of osteoarthrotic joints is assumed to reflect subchondral remodeling, although the biochemical pathway of radioisotopes in relation to osteoarthrosis has not been fully explained. Christensen[4] clarified the distribution of technetium-phosphate radioisotopes in patients and in two animal models. In the femoral heads of patients who underwent arthroplasty and in the bone of growing rats, distribution of the radioisotope was analogous to that of alkaline and acid phosphatase activity. But in rat bone, uptake was also present in areas of provisional calcification that did not have high alkaline phosphatase activity. Christensen concluded that, although the phosphatase enzymes themselves were not the target of the technetium-phosphate complexes, uptake on bone scans of osteoarthrotic joints reflects subchondral remodeling. An increasing amount of clinical data supports Christensen's conclusion and, in addition, suggests that bone scans can be used to detect early osteoarthrosis and to monitor its development. For detection of early osteoarthrosis, bone scan findings correlate with biochemical markers of osteoarthrosis[33,37] and with pain in radiographically normal knees at risk for osteoarthrosis.[26] For monitoring the development of osteoarthrosis, bone scan findings correlate with the degree of joint space narrowing[26] and with progression of the disease.[9,24] These reports are of findings in stable knees, but ACL transection in dogs and rabbits produces postoperative bone scan changes as early as 1 week.[3,27] Nevertheless, because diagnosis of osteoarthrosis is currently made with radiographs,[8] the definitive answer as to whether bone scans can detect and monitor early osteoarthrosis in ACL-deficient patients requires 5- and 10-year radiographic follow-up of the patient group reported in this study.

We used a simple score to evaluate the uptake of the bone scans. This method may make exact comparisons between groups more difficult, but it has the advantage that the overall pattern of uptake can be evaluated. By comparing with the other knee, a clear statement as to whether uptake was increased or not was always possible. In fact, this scoring method may have led to a stricter evaluation of uptake in the knee than if regions of interest were quantitatively evaluated.

An implication of our findings may be that ACL reconstruction is best done within 6 months of injury. For correction of type 1 and 3 patterns (osteoarthrosis and cartilage ulcer scans), this interval may be as short as 4 months. However, two important limitations apply to this implication. One is that we studied only symptomatic patients who were admitted for reconstruction. Such patients distort our perception of the spectrum of functional disability after ACL injury; the best "compensators" do not need an operation. Another limitation is that we studied only 14 patients who had less than 6 months' duration of ACL deficiency and only 8 patients with less than 4 months' duration. These limitations aside, what role remains for nonoperative treatment? If nonoperative therapy fails, progressive loss of meniscal tissue over time and possibly osteoarthrosis can be expected. If ACL reconstruction can reliably restore osseous homeostasis, it is likely to within the first few months of ACL deficiency. If so, it can be questioned whether nonoperative treatment can sufficiently improve the functional status within these first few months without relinquishing the opportunity for optimal reconstruction. Thus, there are two conflicting issues. One is ACL reconstruction within approximately 4 months of injury to prevent further damage to the menisci and cartilage. The other is nonoperative treatment of selected cases, for which a period longer than 4 months is likely needed to allow for evaluation of the result. We believe that, for resolution of both issues, prospective bone scans can add valuable new information.

In summary, in this study of 80 patients, we found that ACL reconstruction consistently corrected type 2 bone scan patterns (meniscus scan) but not type 1 and 3 patterns (osteoarthrosis and cartilage ulcer scans). Correction of all three patterns decreased with longer duration of ACL deficiency and was more reliable for the combined uptake of all three patterns among patients with less than 6 months of ACL deficiency.

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