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Computer Assistance in Arthroscopic Anterior Cruciate Ligament Reconstruction

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Accurate placement of the graft is considered one of the most important factors in anterior cruciate ligament surgery. However, reconstruction with contemporary guiding systems still can result in unacceptable graft placement variability. To improve the reproducibility of graft placement, intraoperative visual feedback was added to the arthroscopic technique. First, fluoroscopic visualization was added to evaluate guidewire placement before tunnel drilling. Second, computer graphic overlays were added to the fluoroscopic view. Three groups of patients were treated: 29 patients with arthroscopy, 53 patients with fluoroscopy added, and 50 patients with computer overlays added. Graft placement variability was reduced significantly with fluoroscopic visualization. Computer overlays resulted in additional significant reductions in graft placement variability. Simple visual enhancements seem to be useful in improving the accuracy of arthroscopic anterior cruciate ligament reconstruction.

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Anterior cruciate ligament reconstruction is the most frequently performed major orthopaedic procedure in the young adult population. Patients receiving a cruciate reconstruction at a mean age of 27 years will live an average of 50 to 60 more years. Thus, anterior cruciate ligament reconstruction should be considered a high precision procedure, requiring a durable reconstruction with excellent functional stability for this active and demanding population. Any improvements in the precision of graft placement likely will benefit the patient.

Numerous different methods of graft placement are endorsed. Some authors[9,10,18] advocate isometric placement, as described by Sapega et al[19] in a study on intraoperative isometry measurement. Recently, others have advocated more anatomic placement.[1,2,4,17] Anatomic reconstructions can be divided into two types: those based on the location of bony[7,16,20] or soft tissue[17] landmarks, and those based on measured parameters[11,12] derived from the intercondylar roof or soft tissue location. Most current anterior cruciate ligament instrumentation systems rely on intraarticular landmarks to guide tunnel placement.

The authors recently have begun characterizing parameters for graft placement using radiographic bony landmarks. The tibial attachment of the anterior cruciate ligament was found to have an average location of 46% ± 3% on a line extending from the anterior to posterior tibial cortices. For the femur, a consistent relationship was found between the intercondylar roof line (Blumensaat's line) and the nearly circular profile of the posterior and inferior contour of the lateral femoral condyle. In transepicondylar lateral radiographs, the center of this circular profile was located just beneath Blumensaat's line at 66% ± 5% of its anterior to posterior length, and the femoral insertion site was found consistently at ¼ of the circle radius posterior to the center of the circle. These studies provide consistently identifiable radiographic features on the tibia and femur that can be used for fluoroscopic guidance of anterior cruciate ligament graft placement (Figs 1, 2). The goal of the present study was to compare the variability of graft placement using conventional arthroscopic techniques with the variability of graft placement in cruciate reconstructions performed with additional radiographic and computer graphic visualization. It was hypothesized that radiographic and computer guidance based on consistently identifiable radiographic landmarks could be used to improve the reproducibility of graft tunnel placement in arthroscopic anterior cruciate ligament reconstruction.

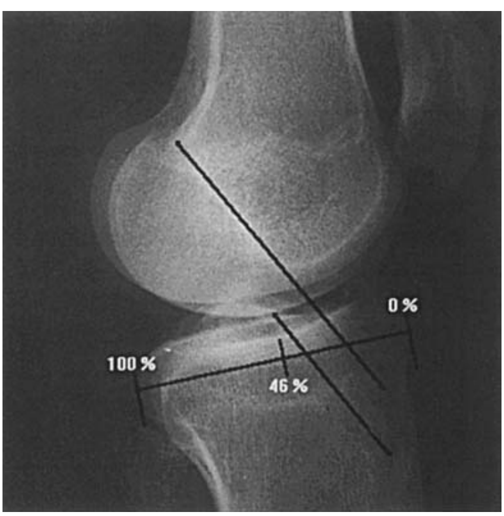

Fig 1. Preoperative hyperextension lateral radiographs with radiographic parameters for graft positioning.

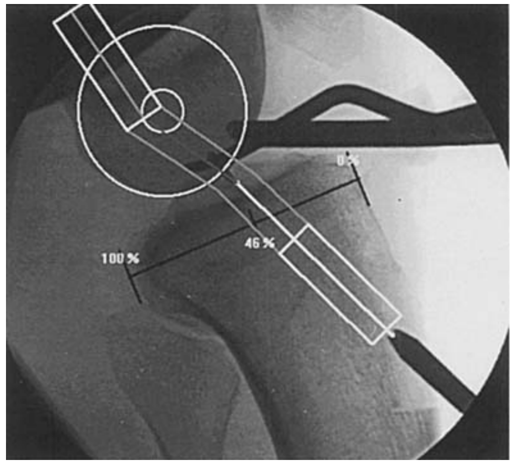

Fig 2. Intraoperative overlay (computer) image with virtual graft placement and tibial guiding instrumentation.

MATERIALS AND METHODS

A consecutive series study was performed to evaluate anterior cruciate ligament graft placement variability with the use of contemporary arthroscopic instrumentation, arthroscopy with lateral fluoroscopic guidance, and arthroscopy with computer graphics enhanced lateral fluoroscopy (all using an endoscopic technique). One surgeon (TVSK) performed 29 cases of arthroscopic anterior cruciate ligament reconstruction between April 1994 and July 1995. Fifty-three patients were treated with arthroscopy and lateral fluoroscopy by the same surgeon between March 1995 and October 1996. Between October 1996 and September 1997, 50 patients were treated by two surgeons (TVSK and RJJD) with arthroscopy and computer enhanced fluoroscopy. Placement of tunnel guidewires was recorded with fluoroscopy in the last two groups and compared with graft placement in postoperative radiographs from the first group. Graft to tunnel placement was assessed using the methods of Staubli and Rausching[20] for the tibia and Harner et al[8] for the femur.

During the procedure with computer assistance, fluoroscopic imaging is performed in the lateral plane. Optimal lateral positioning with overlapping condyles usually is acquired without any difficulty. The procedure is started with soft tissue removal, any required meniscal surgery, and harvesting of the patellar graft. A fluoroscopic image is taken after insertion of the tibial guiding instrumentation (Arthrex®, Arthrex Inc, Naples, FL) to determine instrument and knee position. In this image, the tibial entry point and aiming position and the most anterior and posterior points on the tibial cortex are identified. The instrument and knee position are modeled with graphic overlays (Fig 2) and can be tracked manually by the technician by moving the overlays with the mouse for each image. Movements of the patient can be accommodated by repositioning the overlays with the mouse. Next, the system is calibrated using the size of the hook of the guide instrument. After the graft dimensions are entered into the program, the computer displays the position of the graft in relation to the proposed entry point on the tibia (Fig 2). When the tibial entry point is too shallow, the virtual placement will show the distal bone block to extrude from the tibia (graft to tunnel mismatch). By adequately adjusting the tibial entry point, graft to tunnel mismatch can be avoided.

The program predicts the placement of the femoral drill tunnel on a fluoroscopic image (Fig 3) based on the position of the instrumentation. It is important to check the position of the tunnel and make certain no possible damage can occur to the posterior cortex. An intact posterior cortex is essential to provide sufficient tunnel strength for interference screw fixation. Finally, the graft is inserted and fixed with interference screws.

Software for this procedure was developed on a standard Intel Pentium computer (Intel Corporation, Santa Clara, CA) with Windows 95 (Microsoft Corporation, Redmond, WA) and a simple video capture board (Matrix Vision GmbH, Oppenweiler, Germany). The video capture board is used to acquire images directly from the video output of the fluoroscopic unit.

RESULTS

Graft placement variability was reduced significantly when fluoroscopy and computer assistance were used (Tables 1, 2). For the placement of the tibial portion of the graft, the standard deviation of the anteroposterior graft location decreased from 6% to 4% with the use of fluoroscopy and to less than 3% with the addition of computer assistance. For the femoral graft placement, the standard deviation decreased from 9% to 5% with the introduction of fluoroscopy and to 3% with computer assistance. Statistical analysis (F test) showed all differences among the three data sets to be significant ($p < 0.05$).

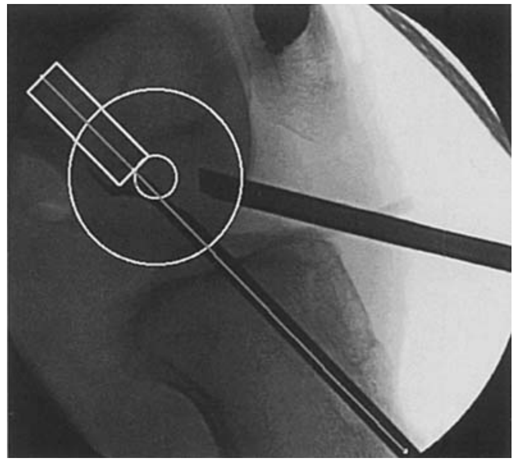

Fig 3. Intraoperative overlay (computer) image with virtual femoral drill hole and femoral guiding instrumentation.

DISCUSSION

Although many surgeons report satisfactory results with current anterior cruciate ligament reconstruction techniques, Kohn et al[14] recently showed a high incidence of inaccurate graft placement in a group of 24 experienced anterior cruciate ligament specialists performing arthroscopic reconstruction on human anatomic specimen knees. Kohn et al found inaccurate placement in 12 of 24 knees at the femoral site and in six of 24 knees at the tibial site. This provides convincing evidence that efforts should be made to reduce graft placement variability. The

TABLE 1. Radiographic Measurement of Drill Hole Placement in the Tibia

	Tibia		
Drill Hole Position	*Arthroscopy (n = 29)*	*Arthroscopy With Fluoroscopy (n = 53)*	*Arthroscopy With Fluoroscopy and Computer Assistance (n = 50)*
Mean (%)	45	46	46
Standard deviation (%)	5.9	4.2	2.7
Minimum (%)	37	38	38
Maximum (%)	60	58	51
Range (%)	23	20	13

goal of the present study was to evaluate the ability of enhanced intraoperative visualization to improve the repeatability of graft placement. Using proportional radiographic criteria for graft placement, it was found that fluoroscopy and computer enhanced fluoroscopy significantly reduced graft placement variability.

Enhanced intraoperative visualization can reduce graft placement variability. However, the present study does not address the issue of optimal graft location. Many authors[1,2,5,8,9,17,18,20] have tried to define optimal points or areas for graft insertion, but there is currently no consensus. The computer system used for this study allows the surgeon (or technician) to input the desired graft position and allows the surgeon to use general radiographic, anatomic, or proportional criteria, or permits individual placement based on the preoperative radiographs (Fig 1). In this study, preoperative hyperextension radiographs were evaluated for the possibility of graft impingement. In all but two cases, no problems were recognized with the use of these proportional parameters.

In addition to greater repeatability, computer enhanced visualization permits accurate calculation of tunnel and graft lengths. In 42 of 50 patients this permitted fixation of the tibial graft site with an interference screw, rather than a bone staple. Because painful staples often require removal, the use of intraoperative graft to tunnel length measurements (which permit intratibial attachment) may lower the frequency of reinterventions.

The use of fluoroscopy has been a major concern to many surgeons.[15] Some express concerns about radiation exposure; others fear the fluoroscopic equipment may obstruct the operation. Neither issue was problematic in this study. Goble[6] and Larson et al[15] reported positively on the routine use of fluoroscopy and its limited radiation exposure, and an in-

TABLE 2. Radiographic Measurement of Drill Hole Placement in the Femur

	Femur		
Drill Hole Position	*Arthroscopy (n = 29)*	*Arthroscopy With Fluoroscopy (n = 53)*	*Arthroscopy With Fluoroscopy and Computer Assistance (n = 50)*
Mean (%)	73	79	80
Standard deviation (%)	9.0	5.1	2.8
Minimum (%)	46	65	71
Maximum (%)	90	89	86
Range (%)	44	24	15

creasing number of training hospitals report using fluoroscopic feedback to monitor graft placement. Intraoperative images are superior for documenting graft location, eliminating the difficult task of identifying graft position from postoperative radiographs.[9] Increasing the accuracy of graft location assessment will facilitate outcome studies examining the relationships between graft location, function, and longevity.[8,13]

The introduction of new technology to the operating room inevitably leads to concerns about higher costs and increased complexity. The radiographic equipment used for this study is readily available in most hospitals where arthroscopy is performed, and the computer system was composed of inexpensive, off the shelf components. The visual nature of the task and software designed for simplicity, make it easy for any operating room technician to learn (typical training time is less than 2 hours).

Arguments for increasing surgical repeatability and finding optimal graft locations intuitively are appealing and compelling. However, the scientific evidence does not yet support definitive relationships between outcomes and repeatability of positioning, or the superiority of one optimal location versus another. Outcome studies, which already are underway, certainly will clarify these relationships. Regardless of these outcomes, however, the experience reported here clearly indicates that additional visualization techniques can improve significantly a surgeon's ability to place anterior cruciate ligament grafts in a desired location.

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