Original Article

Grid and Image Intensifier Improve Arthroscopic ACL Tunnel Position and Patient-Reported Outcomes

Sudeep Kumar, M.B.B.S., M.S., Anup Kumar, M.B.B.S., M.S., Ravi Kumar, M.B.B.S., M.S., Charan Teja KV, M.B.B.S., M.S., Mohammed Roshen AR, M.B.B.S., M.S., and Alapati Hari Venkata Bramesh, M.B.B.S., M.S.

Purpose: To evaluate the accuracy in the femoral and tibial tunnel placement after the use of fluoroscopy along with an indigenously designed grid method to assist in arthroscopic anterior cruciate ligament reconstruction as compared with the tunnel placement without using them and to validate the findings with computed tomography scan performed postoperatively along with assessing the functional outcome at a minimum of 3 years of follow-up. **Methods:** This was a prospective study conducted on patients who underwent primary anterior cruciate ligament reconstruction. Patients were included and segregated into a nonfluoroscopy (group B) and a fluoroscopy group (group A), and both had postoperative computed tomography scans so that femoral and tibial tunnel position could be evaluated. Scheduled follow-up occurred 3, 6, 12, 24, and 36 months' postoperatively. Patients were evaluated objectively with the Lachman test, measurement of range of motion, and functional outcome using patient-reported outcome measures, i.e., Tegner Lysholm Knee score, Knee injury and Osteoarthritis Outcome Score, and International Knee Documentation Committee subjective knee score. **Results:** A total of 113 subjects were included. There were 53 in group A and 60 in group B. The average location of femoral tunnel showed significant differences between the 2 groups. However, the variability in femoral tunnel location was significantly lower in group A as compared with group B for proximal—distal planes only. The average location of the tibial tunnel as per the grid of Bernard et al. showed significant differences in both the planes. The variability in tibial tunnel was greater in the medial—lateral plane as compared with the anterior—posterior plane. There was a statistically significant difference in mean value of the 3 scores among the 2 groups. The variability of the scores was greater in group B as compared with group A. None of the patient was reported as a failure. **Conclusions:** The results of our study suggests that fluoroscopy-guided positioning using a grid technique increases the accuracy of anterior cruciate ligament tunnel positioning with decreased variability and is associated with better patient-reported outcomes 3 years after surgery compared with tunnel positioning using landmarks. **Level of Evidence:** Level II, prospective, comparative therapeutic trial.

Arthroscopic anterior cruciate ligament reconstruction (ACLR) surgery, being one of the most commonly performed knee surgeries, has an average success rate of 90% as far as individual satisfaction and restoration of joint stability are concerned.[1] The prime objective of an ACLR is to restore joint biomechanics to obtain a stable joint with full range of motion and prevention of secondary cartilage and meniscal lesions.[2] Still, the literature has reported a re-rupture rate of 6.07%.[3] Among various causes responsible for graft failure, inaccurate tunnel placement is assumed to be one of the most important intraoperative variables and is directly influenced by the operating surgeon.[4]

Of late, much importance is being put on placing the anterior cruciate ligament (ACL) graft in a more anatomical location on the tibia and femur, thereby having graft in a more horizontal orientation, which is believed to provide better rotational and translational stability; in addition the rate of atraumatic graft rupture is lower after anatomical ACLR.[5] Arthroscopic surgeons, especially beginners, face a dilemma regarding the best method to determine appropriate

From the Department of Orthopaedics, AIIMS-Patna (S.K., A.K., C.T.K.V., M.R.A.R., A.H.V.B.); and Cisro Hospital (R.K.), Patna, Bihar, India.

The authors report that they have no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received July 21, 2022; revised manuscript received November 25, 2022; accepted December 1, 2022.

Address correspondence to Sudeep Kumar, M.B.B.S., M.S., Department of Orthopaedics, AIIMS-Patna, 101, Type 5, Block 1, AIIMS Residential Complex, Patna, Bihar, India, 801105. E-mail: drsudeeportho@gmail.com

2666-061X/22893

https://doi.org/10.1016/j.asmr.2022.12.001

intraoperative graft position,[6] as studies have confirmed significant variation in tunnel placement,[4] even in the hands of experts to the tune of 10% to 40%.[2]

To achieve an anatomical ACLR, the surgeon has to take reference of various arthroscopic and radiologic landmarks. Anatomic aids like femoral ACL footprint, residents ridge, and lateral bifurcate ridge undergo interindividual variability or are influenced by delay in injury and surgery.[7,8] Lately, image-assisted techniques for precise and definitive guidewire placement have been advocated and have been found to be less subjective.[9] Among these, intraoperative fluoroscopy has been proposed as a feasible method to improve the accuracy of guidewire placement, and its role in reducing variability in tunnel position is already documented.[10]

The purpose of this study is to evaluate the accuracy in femoral and tibial tunnel placement after use of fluoroscopy along with an indigenously designed grid method to assist in ACLR as compared with tunnel placement without using these and to validate the findings with computed tomography (CT) scanning done postoperatively along with assessing the functional outcome at a minimum of 3 years of follow-up. We hypothesized that intraoperative fluoroscopy and the indigenously designed grid method would allow accurate anatomical tunnel positioning during ACLR and would lead to better functional outcome as reported by various patient-reported outcome (PRO) measures.

Methods

This was an institute-based prospective study conducted on patients who underwent primary ACLR using quadruple looped hamstring autograft (semitendinosus and gracilis) between June 2016 and January 2019 in the Department of Orthopaedics. This research was approved by the institutional research board at the All India Institute of Medical Sciences Patna (IEC/AIIMS/PAT/116/2016).

In this study, we included patients aged between 18 and 45 years and with a confirmed diagnosis of ACL injury following clinicoradiologic evaluation with a minimum of 3 years of follow-up. The exclusion criteria included bilateral ACL tear, meniscal injury, associated ligament injury, such as medial collateral ligament, lateral collateral ligament, posterior cruciate ligament, or injury involving “posterolateral corner,” previous history of ACL repair or reconstruction, and those who refused to participate in the study. All included patients in the study provided written and informed consent.

All patients underwent ACLR performed by the senior author S.K. using quadruple looped hamstring autograft (semitendinosus and gracilis). Patients who underwent the procedure with the indigenously designed grid and intraoperatively fluoroscopy constituted group A, whereas patients who underwent the procedure without fluoroscopy constituted group B. It is important to emphasize that all patients in the nonfluoroscopy group underwent surgery before the first surgery in the fluoroscopy group.

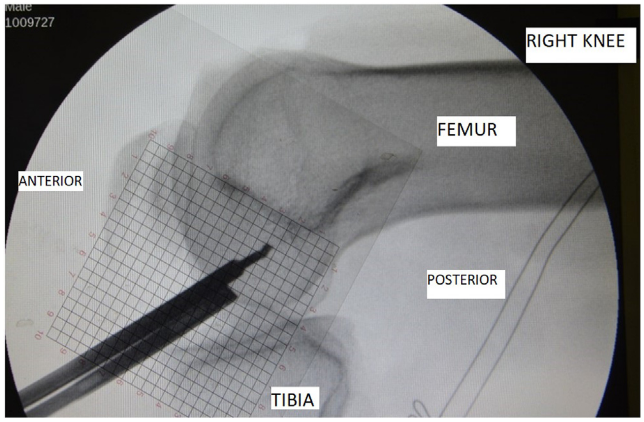

Fig 1. Intraoperative fluoroscopy image of lateral view of the right knee with the superimposed grid of Bernard et al.[15] along with Beath pin placement as per the recommendation of Bird et al.[12]

Data obtained from both the groups during the study included demographic data, 3-dimensional CT position of femoral tunnel in anteroposterior and proximal—distal planes, tibial tunnel in anteroposterior and mediolateral planes expressed in percentage, and PROs, measured using the Tegner Lysholm Knee (TLK) score, Knee injury and Osteoarthritis Outcome Score (KOOS), and International Knee Documentation Committee (IKDC) subjective knee score, measured at 3, 6, 12, 24, and 36 months. The 36-month results were used to compare the groups. All statistical calculations were made using Statistical Package for the Social Sciences (SPSS), version 21.0 (IBM Corp., Armonk, NY). The primary outcome in our study was to compare the variability of tunnel placement in both groups.

A surgical team headed by senior author S.K. performed all the surgeries. Diagnostic arthroscopy was performed and associated injury to meniscus or articular cartilage was noted. Ipsilateral semitendinosus and gracilis graft were harvested using longitudinal incision over “anteromedial” aspect of proximal tibia; the graft was prepared over a graft-preparation board and a FiberWire (Arthrex, Largo, FL) suture was used for preparing the tendon in all the cases. Quadrupled hamstring (semitendinosus and gracilis) was used in all the patients. The prepared tendon was sized, measurements noted, and graft pretensioned with a tensioning device over the graft preparation board.

In group B, through the standard anteromedial portal, a Beath pin was placed at the center of the femoral ACL footprint, keeping in mind the remnants of the native ACL. Similarly, the anterior horn of lateral meniscus

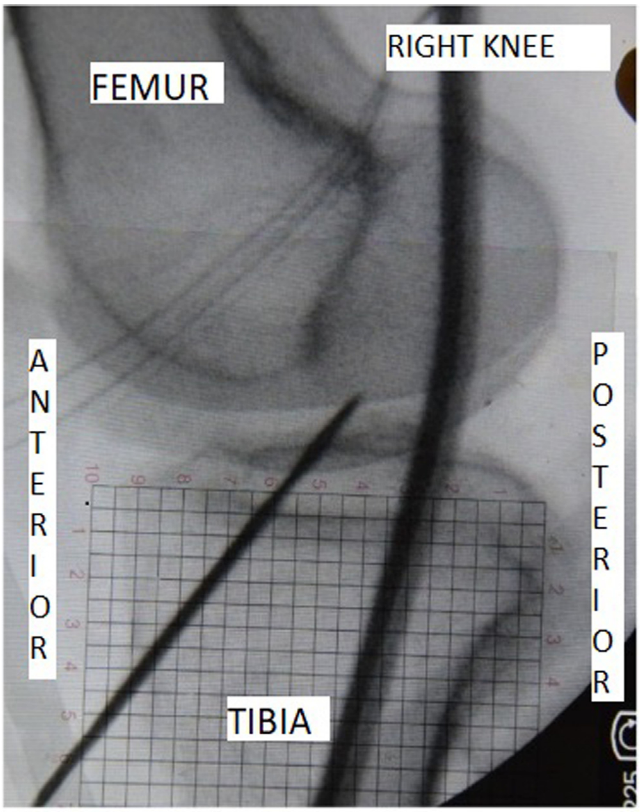

Fig 2. Intraoperative fluoroscopy image of the lateral view of knee with superimposed grid of Bernard et al.[15] over the proximal tibia along with Beath pin placement as per the recommendation of Amis and Jakob.[13]

and tibial end ACL remnant were used as references for tibia tunnel placement. In group A, we used the surgical technique as described by Kumar et al.[11] for accurate positioning of femoral and tibial tunnel using the indigenously made grid on a transparency sheet and C-arm. True lateral image of the knee is obtained intraoperatively and the indigenously designed grid containing 20 × 20 squares equidistant and an equal size of 5 mm on a transparent sheet is superimposed on the C-arm image by floor assistant. It is aligned on the intercondylar ridge and along the anteroposterior width of the lateral femoral condyle for femur. For the tibia, it is aligned over the proximal aspect along its maximum width in the anteroposterior direction (Figs 1 and 2).

The aim was to keep Beath pin at 27% in "proximal—distal" and 34% in the "anteroposterior" direction for the femur as described by Bird et al,[12] whereas for the tibia, the aim was to keep tunnel center at 43% in front—back[13] and 47% in "medial—lateral" planes from the medial cortex.[14]

The percentage of the position of the entry point (position of tip of pin) was determined on the grid (as described by Bernard et al.[15]). This image intensifier—guided method usually adds about 8 to 10 minutes' more duration to the surgical time. In all the cases, femoral tunnels were made using the anterior cruciate ligament portal. Cortical suspensory fixation with adjustable loop ENDOBUTTON (Smith & Nephew, Andover, MA) was used to fix the graft tendon to the femoral side, whereas aperture fixation with a bioabsorbable interference screw as appropriate to tunnel diameter was performed to fix the graft tendon to the tibial side in all the cases. The patient was made to stand with full weight-bearing from postoperative day 1 and start active knee mobilization along with quadriceps strengthening exercises. All patients followed similar standard hospital ACL rehabilitation protocol.

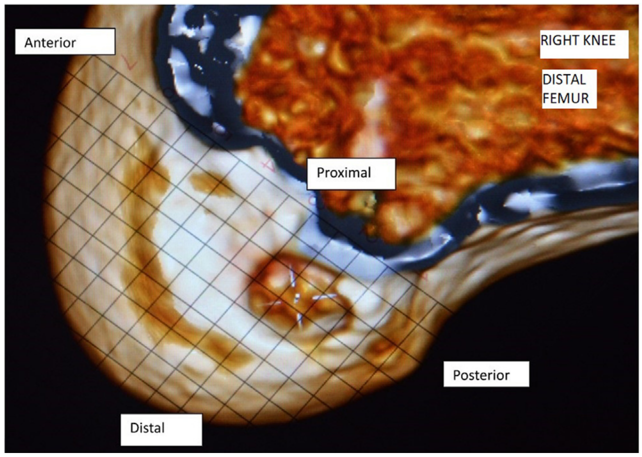

Fig 3. Postoperative 3-dimensional computed tomography of the lateral femoral condyle for evaluation of femoral tunnel position with the superimposed grid of Bernard et al.[15] so as to quantify tunnel position as per the recommendation of Bird et al.[12]

The 3D CT scan was performed on day 7 using a Siemens SOMATOM 256-slice CT scanner (Siemens, Munich, Germany) at 120 kv, mAs 256 in standard and bone algorithm with slice thickness of 1 mm. Three-dimensional reconstruction of the knee in the true lateral was made, and the proximal tibia, patella, and medial femoral condyle were removed so as to obtain an explicit view of the inner side of the lateral femoral condyle. With the image in true lateral, the indigenously designed transparency sheet with inbuilt grid was superimposed as described by Sirleo et al.,[16] and the tunnel center was measured using the quadrant method of Bernard et al.[15] Parameters were expressed in terms of percentage for "proximal—distal" and "anteroposterior" placement. For tibial tunnel position evaluation, the femur and patella were removed and image was placed such that tunnel could be viewed clearly and the center of tibia tunnel on the plateau was measured in "anteroposterior" and "medial—lateral" planes and expressed as a percentage (Fig 3 and 4) This assessment was performed by the senior author S.K. with aid from radiologist (M.D., radiodiagnosis)

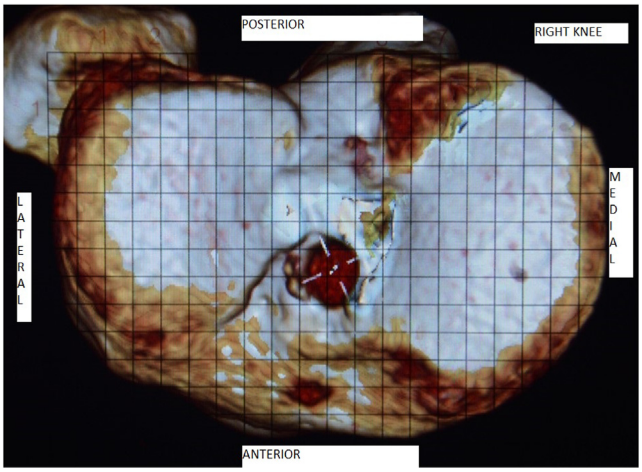

Fig 4. Postoperative 3-dimensional computed tomography of proximal tibia for evaluation of tibia tunnel position with the superimposed grid of Bernard et al.[15] so as to quantify tunnel position.

and the same author and team members (M.S., orthopaedics) followed the patients postoperatively.

Scheduled follow-ups were at 3, 6, 12, 24, and 36 months' postoperatively. Patients were evaluated objectively with the Lachman test, measurement of range of motion, and functional outcome, assessed using PRO measures, i.e., the TLK score, KOOS, and IKDC subjective knee score, all of which were validated.[17-20] In our study, failure was defined as a complaint of instability from the patient with clinically grade 2 or more in the Lachman test and at least grade 2 in pivot shift test and/or rupture requiring a revision surgery.

Results

A total of 113 patients who had attended our outpatient clinic and fulfilled inclusion criteria were prospectively included into the study. A total of 53 consecutive patients who underwent ACLR using intraoperative fluoroscopy along with an indigenously designed grid constituted group A, whereas another 60 consecutive patients who underwent ACLR without using fluoroscopy intraoperatively constituted group B. None of the participants in either group was excluded from the study.

The demographic data are summarized in Table 1 and show no significant differences between the 2 groups.

Table 1. Patient Characteristics of Both Groups

	Group A	Group B	*P* Value
No. of cases	53	60	
Age, y	28.26 ± 8.80	27.63 ± 5.94	.653
Sex, M/F	49/4	58/2	.319
Side, R/L	25/28	34/26	.313

F, female; L, left; M, male; R, right.

Table 2. Assessment of Femoral Tunnel Placement

Group	Anteroposterior Plane, %			Proximal–Distal Plane, %		
	A	B	*P* Value	A	B	*P* Value
Mean	29.66	21.88		30.98	42.22	
Max.	42.00	38.00		46.00	53.85	
Min.	14.28	11.76		25.00	26.00	
SD	6.00	5.35	<.001	4.36	6.40	<.001
Range	27.72	26.24		11	27.85	

SD, standard deviation.

Table 2 summarizes the variables of the femoral tunnel location among the groups. The mean location of femoral tunnel center in group A, evaluated after 3-dimensional CT, was 29.66 ± 6.00% and 30.98 ± 4.36% in the "anteroposterior" and "proximal–distal planes," respectively. Similarly in group B, the locations were 21.88 ± 5.35% and 42.22 ± 6.40% in the "anteroposterior" and "proximal–distal" planes, respectively. The average location of the femoral tunnel showed significant differences between the 2 groups, $P < .001$, in both measures. However, the variability in femoral tunnel location was significantly lower in group A as compared with group B for proximal–distal planes only.

Table 3 summarizes the coordinates of the tibial tunnel. In group A, the location of tibial tunnel center was 47.35 ± 2.75% and 41.34 ± 5.39% in the "medial–lateral" and "anteroposterior" planes, respectively. In group B, the location of tibial tunnel center was 45.95 ± 3.62% and 37.05 ± 4.57% in the "medial–lateral" and "anterioposterior" planes, respectively. The average location of the tibial tunnel as per the grid of Bernard et al. showed significant differences in both the planes, $P < .05$. The variability in tibial tunnel was greater in the medial–lateral plane as compared with the anteroposterior plane between the 2 groups.

Table 4 summarizes the PRO measures among the 2 groups at 36 months. In group A, the TLK, IKDC, and KOOS scores were 97.88 ± 1.35, 85.46 ± 1.78, and 96.43 ± 2.63, respectively. In group B, the TLK, IKDC, and KOOS scores were 86.88 ± 5.01, 68.78 ± 7.01, and 87.94 ± 7.62, respectively. There was statistically a significant difference in mean value of the 3 scores

Table 3. Assessment of Tibial Tunnel Location Variability

	Mediolateral Plane, %			Anteroposterior Plane, %		
Group	A	B	*P* Value	A	B	*P* Value
Mean	47.35	45.95		41.34	37.05	
Max.	53.00	52.78		50.00	50.00	
Min.	40.00	33.00		27.27	25.00	
Range	13.00	19.78		22.73	25.00	
SD	2.75	3.62	.025	5.39	4.57	.00

SD, standard deviation.

Table 4. Assessment of Functional Outcome Among Groups A and B

	TLK Knee Score			IKDC Knee Score			KOOS		
Group	A	B	*P* Value	A	B	*P* Value	A	B	*P* Value
Mean	97.88	86.881		85.46	68.78		96.43	87.94	
Max.	100	100		89.10	89.00		100	100	
Min.	95	73		79.30	44.80		88.70	63.20	
SD	1.35	5.01	<.001	1.78	7.01	.00	2.63	7.62	<.001
Range	5	27		9.80	44.20		11.30	36.80	

IKDC, International Knee Documentation Committee; KOOS, Knee injury and osteoarthritis outcome score; SD, standard deviation; TLK, Tegner Lysholm.

among the 2 groups, $P < .001$. The variability of the scores was greater in group B as compared with group A. None of the patients was reported as a failure in our study.

Discussion

The main finding of this study was that there was significant improvement in both the femoral and tibial tunnel position after the introduction of fluoroscopy in arthroscopic ACL reconstruction when compared with the nonfluoroscopy group. Second, intraoperative fluoroscopy assistance allowed the PRO measures to improve significantly and, lastly, there was also significant reduction in femoral tunnel variability especially in proximal–distal direction and sagittal plane tibia tunnel placement.

As the ideal location of femoral and tibial tunnel in ACL reconstruction is still contentious, and with numerous literature reports of variability in tunnel location irrespective of anatomical landmark used, there is growing interest in of the role of intraoperative fluoroscopy.[10] Excessive anteriorly placed femoral tunnel leads to high tension in the graft, which can restrict range of motion and eventually elongation or the ultimate failure of the graft.[21,22] A too-posterior position of femoral tunnel can cause impingement and loss of movement or rupture.[21,22]

Similarly, tibial tunnel placed >50% posteriorly along the tibial plateau can result in loss of flexion and a significant increase in the rupture rate as compared with the <50% group.[14] Anterior placement of the tibial tunnel can cause roof impingement in extension. Medial placement of tibial tunnel causes posterior cruciate ligament impingement.[23] A medially placed femoral tunnel can cause posterior cruciate ligament impingement of the ACL graft.[24]

Moloney et al.[25] in their cadaveric study revealed that even the experienced surgeons find it difficult to distinctly identify the ACL attachments with arthroscopy technique. An audit of tunnel position after ACL reconstruction found that 65% of femoral tunnels and 59% of the tibial tunnels were malpositioned in the sagittal plane.[4]

Our understanding of fluoroscopic-guided tunnel placement evaluated by CT is limited.

Among studies that evaluated effect of intraoperative fluoroscopy on tunnel positioning and validated the position with postoperative CT, Inderhaug et al.[26] found a significant improvement of femoral tunnel placement, which was seconded by Seo et al.,[10] who also found it to be feasible and effective in achieving consistency in femoral tunnel placement.

Sven et al.[2] investigated 112 cases of fluoroscopy-assisted ACL reconstruction and concluded that intraoperative fluoroscopy could determine the tunnel position more consistently and reliably. Kawakami et al.,[27] in their study, found the fluoroscopy group to have a femoral tunnel significantly closer to the "ideal" anatomic point. In addition, the timing of imaging after surgery is not standardized. We routinely got the CT scan done at day 7 after surgery. The radiation exposure for a CT of the knee is equivalent to 2 radiographs of the chest, which must be taken into consideration.[28]

Limitations

Our study has some limitations. We did not have an objective method to evaluate the rotational stability. Cost-effectiveness of using intraoperative fluoroscopy followed by postoperative 3D CT scan could not be ascertained. There was only one surgeon involved in the study. Because we did not perform a sample size calculation according to femoral tunnel position, there is a risk for a type II error.

Conclusions

The results of our study suggests that fluoroscopy-guided positioning using a grid technique increases the accuracy of ACL tunnel positioning with decreased variability and is associated with better PROs 3 years after surgery compared with tunnel positioning using landmarks.

References

1. Yu J, Garret WE. Femoral tunnel placement in anterior cruciate ligament reconstruction. *Oper Tech Sports Med* 2006;14:45-49.

2. Sven S, Maurice B, Marc B. Variability of tunnel positioning in fluoroscopic-assisted ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2015;23:2269-2277.
3. Pecora V. Determining the rate of ipsilateral and contralateral ACL rupture following ACL reconstruction surgery in males and females: A systematic review [Internet] [Thesis]. 2019. https://digitalrepository.salemstate.edu/handle/20.500.13013/737. Accessed October 17, 2022.
4. Topliss C, Webb J. An audit of tunnel position in anterior cruciate ligament reconstruction. *Knee* 2001;8:59-63.
5. Eliya Y, Nawar K, Rothrauff BB, Lesniak BP, Musahl V, de SA D. Anatomical anterior cruciate ligament reconstruction (ACLR) results in fewer rates of atraumatic graft rupture, and higher rates of rotatory knee stability: A meta-analysis. *J ISAKOS* 2020;5:359-370.
6. Brand MG, Daniel DM. Considerations in the placement of an intra-articular anterior cruciate ligament graft. *Oper Tech Orthop* 1992;2:55-62.
7. Ferretti M, Ekdahl M, Shen W, Fu FH. Osseous landmarks of the femoral attachment of the anterior cruciate ligament: An anatomic study. *Arthroscopy* 2007;23:1218-1225.
8. Brown CH, Spalding T, Robb C. Medial portal technique for single-bundle anatomical anterior cruciate ligament (ACL) reconstruction. *Int Orthop* 2013;37:253-269.
9. Shafizadeh S, Balke M, Wegener S, et al. Precision of tunnel positioning in navigated anterior cruciate ligament reconstruction. *Arthroscopy* 2011;27:1268-1274.
10. Seo SS, Kim CW, Lee CR, et al. Intraoperative fluoroscopy reduces the variability in femoral tunnel placement during single-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2020;28:629-636.
11. Kumar S, Kumar A, Kumar R. Accurate positioning of femoral and tibial tunnels in single bundle anterior cruciate ligament reconstruction using the indigenously made Bernard and hurtle grid on a transparency sheet and C-arm. *Arthrosc Tech* 2017;6:e757-e761.
12. Bird JH, Carmont MR, Dhillon M, et al. Validation of a new technique to determine midbundle femoral tunnel position in anterior cruciate ligament reconstruction using 3-dimensional computed tomography analysis. *Arthroscopy* 2011;27:1259-1267.
13. Amis AA, Jakob RP. Anterior cruciate ligament graft positioning, tensioning and twisting. *Knee Surg Sports Traumatol Arthrosc* 1998;6:S2-S12 (suppl 1).
14. Pinczewski LA, Salmon LJ, Jackson WFM, von Bormann RBP, Haslam PG, Tashiro S. Radiological landmarks for placement of the tunnels in single-bundle reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Br* 2008;90:172-179.
15. Bernard M, Hertel P, Hornung H, Cierpinski T. Femoral insertion of the ACL. Radiographic quadrant method. *Am J Knee Surg* 1997;10:14-21. discussion 21-22.
16. Sirleo L, Innocenti M, Innocenti M, Civinini R, Carulli C, Matassi F. Post-operative 3D CT feedback improves accuracy and precision in the learning curve of anatomic ACL femoral tunnel placement. *Knee Surg Sports Traumatol Arthrosc* 2018;26:468-477.
17. Salavati M, Akhbari B, Mohammadi F, Mazaheri M, Khorrami M. Knee injury and Osteoarthritis Outcome Score (KOOS); reliability and validity in competitive athletes after anterior cruciate ligament reconstruction. *Osteoarthritis Cartilage* 2011;19:406-410.
18. Crawford K, Briggs KK, Rodkey WG, Steadman JR. Reliability, validity, and responsiveness of the IKDC score for meniscus injuries of the knee. *Arthroscopy* 2007;23:839-844.
19. Higgins LD, Taylor MK, Park D, et al. Reliability and validity of the International Knee Documentation Committee (IKDC) Subjective Knee Form. *Joint Bone Spine* 2007;74:594-59.
20. Briggs KK, Lysholm J, Tegner Y, Rodkey WG, Kocher MS, Steadman JR. The reliability, validity, and responsiveness of the Lysholm score and Tegner activity scale for anterior cruciate ligament injuries of the knee: 25 years later. *Am J Sports Med* 2009;37:890-897.
21. Sommer C, Friederich NF, Müller W. Improperly placed anterior cruciate ligament grafts: Correlation between radiological parameters and clinical results. *Knee Surg* 2000;8:207-213.
22. Harner CD, Irrgang JJ, Paul J, Dearwater S, Fu FH. Loss of motion after anterior cruciate ligament reconstruction. *Am J Sports Med* 1992;20:499-506.
23. Howell SM, Hull ML. Checkpoints for judging tunnel and anterior cruciate ligament graft placement. *J Knee Surg* 2009;22:161-170.
24. Simmons R, Howell SM, Hull ML. Effect of the angle of the femoral and tibial tunnels in the coronal plane and incremental excision of the posterior cruciate ligament on tension of an anterior cruciate ligament graft: An in vitro study. *J Bone Joint Surg Am* 2003;85:1018-1029.
25. Moloney G, Araujo P, Rabuck S, et al. Use of a fluoroscopic overlay to assist arthroscopic anterior cruciate ligament reconstruction. *Am J Sports Med* 2013;41:1794-1800.
26. Inderhaug E, Larsen A, Waaler PA, Strand T, Harlem T, Solheim E. The effect of intraoperative fluoroscopy on the accuracy of femoral tunnel placement in single-bundle anatomic ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2017;25:1211-1218.
27. Kawakami Y, Hiranaka T, Matsumoto T, et al. The accuracy of bone tunnel position using fluoroscopic-based navigation system in anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2012;20:1503-1510.
28. Biswas D, Bible JE, Bohan M, Simpson AK, Whang PG, Grauer JN. Radiation exposure from musculoskeletal computerized tomographic scans. *J Bone Joint Surg Am* 2009;91:1882-1889.