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Systematic Review of Cadaveric Studies on Anatomic Posterior Cruciate Ligament Reconstruction: The Landmarks in Anatomic Posterior Cruciate Ligament Reconstruction

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Recently, several new techniques for anatomic posterior cruciate ligament reconstruction (PCLR) have emerged and are believed to restore the normal anatomy of the posterior cruciate ligament more accurately. Despite the latest trend, the optimal methods for anatomic PCLR remain controversial. The purpose of this research is to review surgical techniques for PCLR in cadaver studies and suggest consistent and reproducible technical criteria. For the review of the literature, MEDLINE and EMBASE were screened for articles on anatomic PCLR. Only basic science studies on PCLR performed on human cadavers and written in English were included. Seventeen studies were included in this systematic review. Only the tunnel positions, graft types, and surgical techniques were reported in the majority of the studies. There were many variations of the reported tunnel positions, graft types, and surgical techniques among the studies. In most studies, surgical techniques for consistent and reproducible anatomic PCLR were not explained clearly. Therefore, high level medical research should be encouraged in order to establish standard surgical techniques for anatomic PCLR.

Keywords: Posterior cruciate ligament, Reconstruction, Cadaveric study

Introduction

In recent years, more and more attention has been directed towards biomechanics of the anatomic posterior cruciate ligament reconstruction (PCLR). Past studies showed that PCLR would neither prevent the knee from developing osteoarthritis nor fully restore the normal knee kinematics[1]. However, during the past decade, there has been rapid development in surgical techniques for PCLR, such as the double-bundle technique[2-7]. Consistent and reproducible surgical techniques increase the possibility to replicate the native anatomy of the knee and facilitate anatomic PCLR. Basic science studies, for instance cadaver studies, have demonstrated benefits of anatomic PCLR, and thus have been used as a template when evaluating new surgical techniques. There is an expectation that more anatomic PCLR techniques will enable more accurate restoration of the intact knee kinematics and reduce the incidence of osteoarthritis after PCLR[2,8]. However, utilization of the term 'anatomic' with regard to PCLR can be misleading because some PCLR surgical techniques designed to better replicate the native anatomy can still be performed non-anatomically. A more specific definition of the anatomic PCLR has recently been proposed: the functional restoration of the knee laxity, graft force, and knee kinematics[2,9]. Such definition provides a means to evaluate currently published clinical trials and basic science studies on PCLR from the perspective of anatomic accuracy. Overall, there is a scant amount of data on anatomic PCLR, but research has been actively carried out on the confir-

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mation of ligament insertion sites, tunnel positioning techniques, graft types, and graft fixation methods. On the other hand, researches using anatomic landmarks, such as the medial intercondylar ridge, medial bifurcate ridge, and posterior edge of shelf, or regarding preoperative planning or imaging techniques for postoperative evaluation are rare. The purpose of this research was to review surgical techniques for anatomic PCLR in cadaver studies and to suggest consistent and reproducible technical criteria. Therefore, a descriptive analysis was performed on surgical data reports. We hypothesized that the description of surgical techniques in those reports would be insufficient and thus it would not be feasible to set up clinical settings for anatomic PCLR.

Methods

A systematic and descriptive review on surgical techniques for PCLR was undertaken. Clinical trials were excluded from this systematic review; cadaver studies on anatomic PCLR were included in this study. Only studies providing a description of surgical techniques and involving human cadavers were eligible for inclusion.

A systematic electronic search was performed using the MEDLINE via PubMed and EMBASE databases. Studies that were published between 1999 and 2013 were included. The search was carried out by 2 observers in 2013. The following key search terms were used in all fields: 'posterior cruciate ligament' OR 'PCL' AND 'anatomic' OR 'anatomical' AND 'reconstruction' OR 'surgery' AND '1999:2013'. The search was restricted to English. Review articles, studies that were covered by 2 databases, clinical studies, and animal studies were excluded. Selection of studies was done by reading the abstracts, and if necessary, the full texts. For inclusion into the review, two authors independently analyzed the full texts using the aforementioned criteria. Any disagreements between the 2 observers were discussed to reach an agreement. Finally, the reference lists of the selected studies were investigated to identify additional studies that had not been found through our electronic search.

There are no established criteria yet to determine whether a PCLR is performed anatomically or not. So we initially decided to include all papers in which the authors stated that the reconstructive surgical procedure was 'anatomic'. However, considering the recent emphasis on the concept of 'anatomic' PCLR, we deemed it would be unfair to include all PCLR papers. Therefore, we analyzed the anatomic degree of reconstruction in those studies based on the assessment of the insertion site of the footprint of posterior cruciate ligament, tunnel position, and anatomical landmarks (medial intercondylar ridge, medial bifurcate ridge, and posterior edge of shelf), since most authors did not state their technique was 'anatomic'. The anatomical landmarks are displayed in Table 1.

A descriptive review of the reports providing a variety of surgical data was performed with the utilization of a predefined standardized data sheet. The authors filled in a template regarding suggestions for anatomic PCLR, which was used for analysis

Table 1. Demographic and Surgical Data from Included Studies

Author	Placement of the tibial tunnel in PCL footprint
Year of publication	Proof of tunnel placement provided
Journal of publication	Placement of the femoral tunnel at fixed distance from anatomic structure
Visualization of the femoral insertion site	Placement of the tibial tunnel at fixed distance from anatomic structure
Visualization of the tibial insertion site	Graft type
Measurement of the femoral insertion site	Use of fluoroscopy
Measurement of the tibial insertion site	Use of navigation
Measurement of the dimensions of the femoral intercondylar notch	Femoral fixation method
Medial intercondylar ridge	Tibial fixation method
Medial bifurcate ridge	Use of a different tension pattern for the AL and PM bundle graft
Posterior edge of shelf	Use of postoperative radiography
Use of o'clock reference for femoral tunnel position	Use of postoperative MRI
Flexion angle during femoral drilling	Use of postoperative CT-scan
Placement of the femoral tunnel in PCL footprint	Use of postoperative 3D CT-scan

PCL: posterior cruciate ligament, AL: anterolateral, PM: posteromedial, MRI: magnetic resonance imaging, CT: computed tomography, 3D: three-dimensional.

of the studies (Table 1). The data sheet included a column for all data as well as an additional column for pooling more specific data. The analysis was not performed in a blinded fashion. The data were recorded as either 'reported' or 'not reported'. Also, the ratios of studies presenting certain data to the total included studies were calculated as percentages. Assessments on detailed procedures or methods were not performed. In addition, if an item was recorded as 'reported', more specific data were collected when possible for the purpose of pooling. Consensus was reached through discussion for any disagreements.

Results

There were 185 search results on MEDLINE via PubMed and 123 on EMBASE according to the aforementioned search criteria (Fig. 1). Of these 308 studies, 246 were excluded because the abstracts showed they did not meet the inclusion criteria. Most of the excluded studies were either clinical trials or not written in English. Of the remaining 62 papers, 17 papers were selected by both observers and the rest were excluded after discussion due to disagreement. Therefore, 17 papers were selected for final inclusion of the systematic review[2,7,9-23]. The results of 17 included studies are summarized in Table 2. The 45 studies were excluded mostly because the authors did not claim that their reconstructive technique was anatomic.

Whether certain surgical data were reported or not reported in the included papers is displayed in Table 3. Visualization indicates presenting diagrams or pictures showing how the femoral or tibial bone is attached in the study. The femoral and tibial insertion sites were visualized in approximately two-thirds of the included studies, whereas only 12% of anatomic studies investigated the actual insertion sites of the PCL. Regarding the use of the medial intercondylar ridge and the medial bifurcate ridge for femoral tunnel positioning, the posterior edge of shelf was rarely used for tibial tunnel positioning (Figs. 2 and 3). The anatomic positions of tunnels or footprints proposed in the studies are described in Table 2.

Seventy-eight percent and 61.7% of the studies included data on the tunnel placement in the femoral and tibial insertion sites, respectively. Seventy-eight percent of them also provided visual proof in their papers (Table 4). Imaging techniques were poorly used in these cadaveric trials: standard radiographs, computed tomography (CT), and three-dimensional CT were used in only 9.1% each. Magnetic resonance imaging was used in 18.2% and the use of other methods such as fluoroscopic images, computer graphics, or gross cadaveric dissection photographs were reported in 27.3%.

The positions of femoral and tibial tunnels were reported to be at a fixed distance from another anatomic structure in 66.5% and 55.9%, respectively. On the femoral side, the authors used the intercondylar roof, PCL insertion site, and the edge of the articular cartilage for guidance of femoral tunnel placement. On the tibial

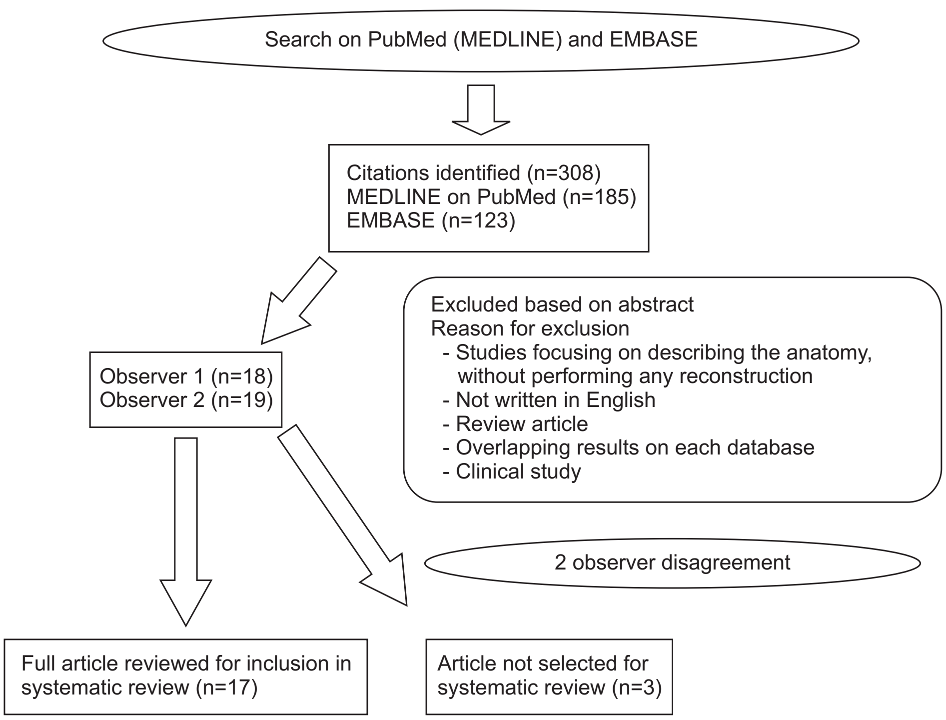

Fig. 1. Flow diagram for systematic review of the literature.

Table 2. Summary of the Included Studies

Author	Tunnel or footprint	Landmark	Image
Markolf et al.[2]	An AL tunnel was located at the anterolateral margin of the native ligament footprint	Not described	Diagrams
Stahelin et al.[7]	The entrance of the 2 femoral sockets: superior, 13mm below the top of the roof and 13 mm posterior to the border of the articular cartilage; inferior, 20 mm inferior and 8 mm posterior The tibial footprint was located approximately 1 cm below the joint	Intercondylar femoral roof, articular cartilage	Diagrams
Harner et al.[9]	The femoral and tibial tunnels were made: the anatomic insertion site of the ALB and PMB of the PCL	Not described	Diagrams, gross pictures
Lorenz et al.[10]	Femoral side The average geometric insertion points according to the modified quadrant method on the true lateral view: ALB, x=62%±3%/y=16%±6%; PMB, x=51%±5% and y=35%±7% Tibial side The common insertion point of the PCL was located: 51%±2% of the mediolateral diameter of the tibial plateau with respect to the lateral border; 13%±2% inferior to the medial tibia plateau with respect to the sagittal diameter of the tibial plateau	Not described	Radiographs, diagrams, gross pictures
Johannsen et al.[11]	Femur AP view ALB center was 34.1±3.0 mm and PMB center was 29.2±3.0 mm lateral to the most medial border of the medial femoral condyle Femur lateral view ALB center was 17.4±1.7 mm and PMB center was 23.9±2.7 mm posteroproximal to a line perpendicular to the Blumensaat's line that intersects the anterior margin of the medial femoral condyle cortex Tibia AP view ALB center was 0.2±2.1 mm and PMB center was 4.9±2.9 mm distal to the proximal joint line Tibia lateral view ALB center was 8.4±1.8 mm and PMB center was 2.5±1.5 mm superior to the champagne glass drop-off of the posterior tibia	Medial intercondylar ridge, posterior edge of shelf	Diagrams
Tsukada et al.[12]	The PCL anatomic footprint	Not described	Diagrams
Harner et al.[13]	Areas of the insertions of the PCL Femur: AL, 74±13 mm^2; PM, 69±12 mm^2 Tibia: AL, 70±26 mm^2; PM, 62±17 mm^2	Not described	Diagrams, gross pictures
Tompkins et al.[14]	The center of the femoral tunnel from the center of the native footprint: the outside-in technique, 4.9±2.2 mm; the inside-out technique, 5.3±2.0 mm There was no difference between the two techniques in the ability for femoral tunnel placement within the PCL femoral footprint	Medial femoral condyle, anterior articular surface, inferior articular surface	CT, 3D-CT
Ahn et al.[15]	The middle portion of the anatomic tibial insertion site of the PCL	Not described	Gross pictures, 3D-CT
Davis et al.[16]	Native femoral and tibial insertion sites	Blumensaat's line	Gross pictures, X-ray
Ettinger et al.[17]	The PCL anatomic footprint	Not described	Diagrams
Markolf et al.[18]	AL: the anterolateral margin of the native footprint PM: one of two locations within the footprint	Not described	Diagrams
Bergfeld et al.[19]	The PCL anatomic footprint	Not described	Diagrams
Markolf et al.[20]	A footprint-based reference was used for tunnel placement. Tunnel locations were described in terms of their position within footprint rather than fixed distance	Not described	Diagrams, gross pictures
Mejia et al.[21]	The PCL attachment location reference to a right knee coordinate system extended past the midline in the notch to 11:21±15 min	Femoral articular margin, intercondylar femoral roof	Diagrams, gross pictures
Forsythe et al.[22]	The average area of the PCL footprint was 209±33.82 mm^2: AL, 118±23.95 mm^2; PM: 90±16.13 mm^2	Medial intercondylar ridge, medial bifurcate ridge	Diagrams, gross pictures
Tajima et al.[23]	The mean surface areas on insertion sites: AL, 93.1±16.6 mm^2; PM, 150.8±31.0 mm^2 The mean length and width of insertion sites: AL, 7.8±1.5 mm and 9.2±1.6 mm; PM, 9.4±1.4 mm and 15.0±2.7 mm	Posterior intercondylar fossa	Diagrams, gross pictures

ALB: anterolateral bundle, PMB: posteromedial bundle, PCL: posterior cruciate ligament, AP: anteroposterior, AL: anterolateral, PM: posteromedial, CT: computed tomography, 3D: three-dimensional.

Table 3. Reporting of Surgical Data in Included Studies

Variable	Reported (%)	Not reported (%)
Visualization of the femoral insertion site	78.0	22.0
Visualization of the tibial insertion site	55.8	44.2
Measurement of the tibial insertion site	11.8	88.2
Measurement of the femoral insertion site	11.8	88.2
Measurement of the dimensions of the femoral intercondylar notch	11.8	88.2
Use of o'clock face for femoral tunnel position	22.3	77.7
Flection angle during femoral drilling	66.1	33.9
Placement of the femoral tunnel in PCL footprint	78.0	22.0
Placement of the tibial tunnel in PCL footprint	61.7	38.3
Medial intercondylar ridge	11.7	88.3
Medial bifurcate ridge	5.8	94.2
Posterior edge of shelf	5.8	94.2
Proof of tunnel placement provided	78.0	22.0
Placement of the femoral tunnel at fixed distance from anatomic structure	66.5	33.5
Placement of the tibial tunnel at fixed distance from anatomic structure	55.9	44.1
Graft type	71.2	28.8
Use of fluoroscopy	6.0	94.0
Use of navigation	0	100
Femoral fixation method	50.0	50.0
Tibial fixation method	50.0	50.0
Use of a different tension pattern for the AL and PM bundle grafts	66.5	33.5
Use of postoperative radiography	9.1	90.9
Use of postoperative MRI	18.2	81.8
Use of postoperative CT-scan	9.1	90.9
Use of postoperative 3D CT-scan	9.1	90.9

PCL: posterior cruciate ligament, AL: anterolateral, PM: posteromedial, MRI: magnetic resonance imaging, CT: computed tomography, 3D: three-dimensional.

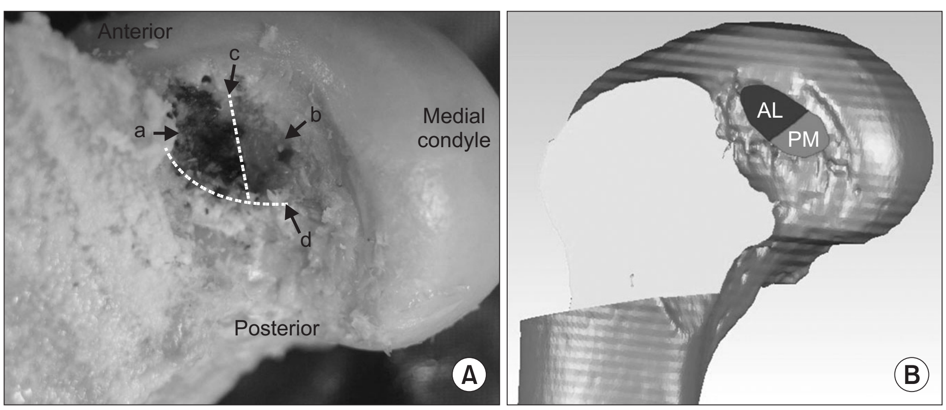

Fig. 2. Femoral footprint of the posterior cruciate ligament (imaging was reconstructed using Geomagic Software). (A) a: AL bundle, b: PM bundle, c: medial bifurcate ridge, d: medial intercondylar notch. (B) Femoral footprint at three-dimensional reconstructed imaging. AL: anterolateral, PM: posteromedial.

side, authors used the anterior margin of the tibia, the medial border of the tibial plateau, and the vertical distance from the tibial plane as reference points. No superior graft has been identified and graft fixation method was reported in approximately half of the included studies (Table 5).

In these studies, either single-bundle PCLR or double-bundle

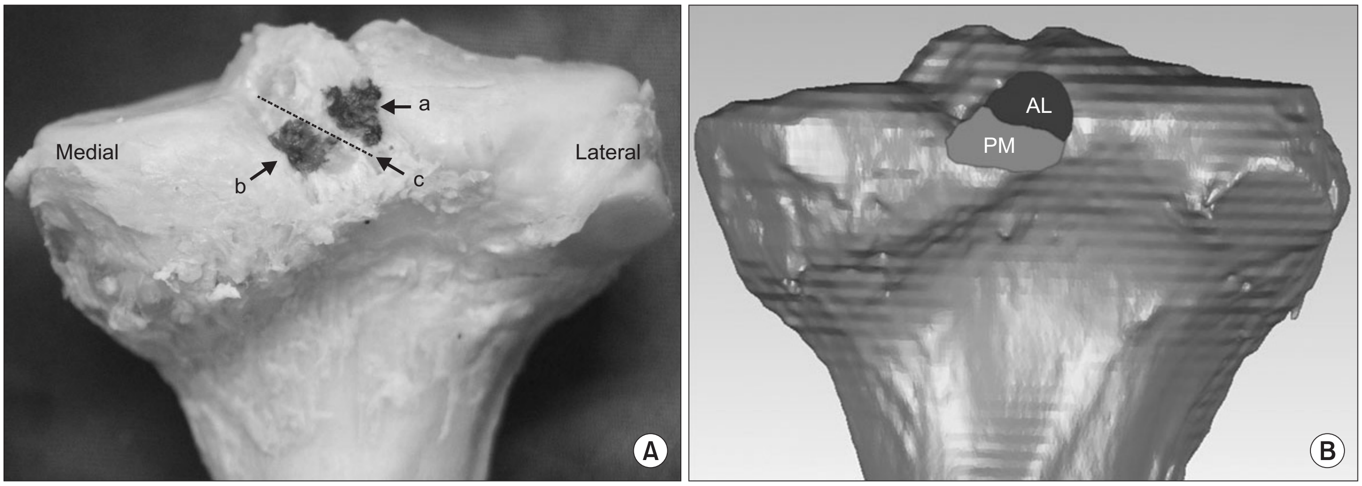

Fig. 3. Tibial footprint of posterior cruciate ligament (imaging was reconstructed using Geomagic Software). (A) a: AL bundle, b: PM bundle, c: posterior edge of shelf. (B) Tibial footprint at three-dimensional reconstructed imaging. AL: anterolateral, PM: posteromedial.

Table 4. Proof of Tunnel Placement in the Native Posterior Cruciate Ligament Footprint

Modality	Shown (%)	Not shown (%)
Diagram	54.5	45.5
Picture	36.4	63.6
Radiograph	9.1	90.9
Magnetic resonance imaging	18.2	81.8
Computed tomography	9.1	90.9
Three-dimensional computed tomography	9.1	90.9
Other	27.3	72.7
Multiple	27.3	72.7

Table 5. Fixation Methods Used for Anatomic Posterior Cruciate Ligament Reconstruction

Fixation method	Femoral side (%)	Tibial side (%)
Metal interference screw	11.8	11.8
Bio-absorbable interference screw	29.4	23.5
Staple	0	5.9
Screw/washer	0	29.4
Suture/post	11.8	5.9

PCLR was used as a tunnel reconstruction method, and superiority between the two methods could not be determined.

Discussion

The growing attention to anatomic PCLR has led to a recent increase in the number of basic science studies evaluating potential benefits and limitations of this technique. However, despite the outcomes of many studies, the true definition of anatomic PCLR has not yet reached a consensus. In this review, it was hypothesized that the description of surgical techniques would be insufficient to set up clinical settings for anatomic PCLR.

This review revealed that data for anatomic PCLR, such as the insertion site and tunnel position, are not sufficient despite the current increase in the number of PCL research. In many studies, femoral tunnel positions were not determined by referring to anatomic sites and the o'clock reference was used instead. However, the size and shape of the PCL insertion site, tibial plateau, and femoral intercondylar notch anatomy are different from patient to patient[21,22,24]. Therefore, the o'clock reference would not be beneficial for anatomic reconstruction because it provides a non-reproducible generic two-dimensional formula for tunnel placement. The o'clock reference was originally developed to be used with radiographs taken with the knee in extension, which can be quite reliable under this circumstance[25]. Later, it was also utilized for arthroscopic measurements without taking into consideration that the knee is flexed in this situation. Differences in the knee flexion angle and viewing portal have caused much confusion when using the o'clock description[26]. The mean tibial tunnel position in the studies we selected for review was 10–15 mm below the articular joint. In cadaveric studies and clinical trials, authors utilize various anatomical landmarks to describe the tibial insertion site[23,27-29]. However, these studies mostly used only one reference value, although at least two coordinates are necessary to define a geographical point, and more are needed for an accurate 3D mapping. Radiological studies also attempted to identify landmarks for definition of the PCL tibial insertion site[10,11]. However, they did not rely on identical reference points and did not distinguish between the anterolateral and posteromedial bundles[28]. As evidenced in this review, the accurate methods for tibial tunnel positioning have been rarely reported in many studies, demonstrating the need for a detailed description of the PCL fovea to establish consistent, reproducible anatomical landmarks for surgery.

The increased interest in anatomic PCLR has led to a great number of basic science studies evaluating potential benefits and limitations of this technique[2,7,9-23]. However, the true definition of anatomic PCLR has not reached a consensus, and therefore, the interpretation of 'anatomic' varies from study to study. The aim of many cadaver studies on PCLR is to study the effects of differences in reconstruction techniques and tunnel positions on the knee biomechanics[15,16,19,20]. Recent research furthermore puts its emphasis on comparisons of surgical methods and approaches for 'anatomic' PCLR[6,7,14,15,30]. As aforementioned in the present study, superiority between the single-bundle PCLR and double-bundle PCLR with regard to tunnel reconstruction could not be determined. So we believe this should be elucidated in further research. Basic science is the milestone for clinical research and ultimately treatment strategies. Providing detailed description of a surgical method helps readers make an appropriate interpretation of the study results and be assured that the reconstruction was indeed performed in an anatomic fashion. The ideal way to implement this would be to establish standards for describing anatomic techniques, encompassing all essential aspects needed to define anatomic PCLR. Authors, for their part, should strive to provide clear description of their methods using figures, pictures, and diagrams.

Overall, we found that a variety of surgical data were not presented in current cadaver studies on anatomic PCLR. The absence of certain data on surgical techniques does not necessarily imply certain procedures were not performed. However, the recent high standard of medical research requires accuracy when reporting methods and findings. Description of surgical techniques in clinical studies may be considered unimportant; however, it should be addressed in detail in cadaver studies considering that they are used as a template for clinical trials. Anatomic PCLR can be performed in many different ways, and such diversity of methods affects the study outcomes. As a result, in the absence of sufficient description of techniques, it should be difficult to interpret the outcomes and make comparisons with other studies.

There were several limitations of this systematic review. First, it was specifically focused on studies that report on anatomic PCLR techniques in cadaver models. Second, the search was limited to English papers available on MEDLINE via PubMed or EMBASE. Third, the data extraction was not performed in a blinded fashion. However, despite these limitations, we believe this systematic review provides a rare insight into the overall factors of anatomic PCLR and the current status of studies on the technique.

Most basic science studies regarding anatomic PCLR in cadavers do not provide detailed description of surgical techniques for consistent and reproducible anatomic PCLR. Therefore, we believe high level medical research should be encouraged in order to establish standard surgical techniques and delineate the definition of anatomic PCLR.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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