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Surgical Precision of Femoral Tunnel Placement in Anterior Cruciate Ligament Reconstruction: a Systematic Review

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Surgical Precision of Femoral Tunnel Placement in Anterior Cruciate Ligament Reconstruction: a Systematic Review

Dissertação de candidatura ao grau de Mestre em Medicina, submetida ao Instituto de Ciências Biomédicas Abel Salazar da Universidade do Porto

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Declaration of Scientific Integrity

I, Maria Inês Morais Couto, a student enrolled in the Integrated Master's Program in Medicine at the Institute of Medicine and Biomedical Sciences, University of Porto, hereby declare that, in accordance with paragraph a) of article 14 of the University of Porto's Code of Ethical Conduct, this dissertation embodies my perspectives, research efforts and interpretations at the time of submission. By presenting this project, I affirm that it contains the results of my original research and contributions, which have not been previously submitted to this or any other institution. Additionally, I confirm that all references to other authors comply with citation rules and are appropriately cited in the text, while also being listed in the references section. This dissertation does not include any material protected by copyrights laws. I acknowledge that plagiarism is considered a serious academic offense.

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Aqueles que passam por nós, não vão sós.

Deixam um pouco de si, levam um pouco de nós.

Antoine de Saint-Exupéry

Dedication

Chegando ao final desta longa jornada, é com muita gratidão que devo reconhecer aqueles que me levaram e fizeram destes 6 anos um percurso tão bonito e singular.

À minha mãe, que apoiou incondicionalmente todos os passos dados, relembrando a coragem e a felicidade do desafio e da mudança.

Ao meu pai, por ser um abrigo de tranquilidade e por me ensinar que não existe nada mais libertador que ultrapassar os mais difíceis obstáculos.

Às minhas irmãs, por me ancorarem à realidade e por serem apoio e honestidade, continuamente.

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Abstract

Introduction: Femoral tunnel misplacement is considered to be a significant contributor to anterior cruciate ligament reconstruction (ACLR) failure. Any minor discrepancy in the positioning of the femoral attachment site can lead to a mismatch between the tension and elongation changes of the graft. This serves to illustrate the importance of both precision and accuracy of the chosen surgical technique. The purpose of this systematic review was to assess the precision of viewing strategies, localization strategies and drilling techniques employed in femoral tunnel placement in ACLR. Furthermore, the clinical outcomes, operative time and operative cost of each technique were also evaluated.

Materials and Methods: PubMed, Scopus and Web of Science databases were searched by two reviewers to identify relevant literature on ACLR and the techniques employed in femoral tunnel placement. The precision of each surgical technique was quantified utilizing the Bernard-Hertel quadrant method, with particular focus on the value of the standard deviation for tunnel positioning in each axis of the grid, which allowed to calculate the corresponding coefficient of variation, adjusted to the sample mean and to the population size.

Results: A total of 24 articles were included in this review. These described the surgical protocol employed for each group of patients, encompassing a viewing strategy, a localization strategy and a drilling technique. A total of 15 distinct combinations of techniques were observed, which enabled the patients to be divided into comparable groups. Overall, the combination of a transseptal (TS) portal viewing technique, an estimation-based localization strategy and an anteromedial (AM) portal drilling technique, as well as the combination of an anterolateral (AL) portal viewing strategy, an offset guide localization strategy and an accessory anteromedial (aAM) portal drilling technique emerged as the most precise surgical protocols included in this systematic review. Nevertheless, the protocol comprising a TS portal, an offset guide and an aAM portal techniques has the potential to be the most precise combination for femoral tunnel placement.

Conclusion: The precision of the proposed protocol should be evaluated, while also exploring its correlation with clinical outcomes and its impact on operative time and cost.

Keywords: Anterior Cruciate Ligament; Reconstruction; Surgical Techniques; Femoral Tunnel

Resumo

Introdução: O mal posicionamento do túnel femoral é um fator significativo que contribui para o insucesso da reconstrução do ligamento cruzado anterior (LCA). Qualquer discrepância no posicionamento da inserção femoral pode resultar num desfasamento entre as alterações de tensão e o alongamento do enxerto. Isto revela a importância tanto da precisão, como da exatidão da técnica cirúrgica escolhida. O objetivo desta revisão sistemática foi avaliar a precisão das estratégias de visualização, de localização e de perfuração utilizadas na colocação do túnel femoral na reconstrução do LCA. Adicionalmente, foram também avaliados os resultados clínicos, o tempo operatório e o custo de cada técnica.

Materiais e Métodos: As bases de dados PubMed, Scopus e Web of Science foram pesquisadas por dois revisores para identificar literatura relevante sobre a reconstrução do LCA e as várias técnicas utilizadas na colocação do túnel femoral. A precisão de cada técnica cirúrgica foi quantificada utilizando o método dos quadrantes de Bernard-Hertel, com particular enfoque no desvio padrão para o posicionamento do túnel em cada eixo, que permitiu calcular o coeficiente de variação correspondente, ajustado à média da amostra e ao tamanho da população.

Resultados: 24 artigos foram incluídos nesta revisão. Estes descreveram o protocolo cirúrgico utilizado em cada grupo de doentes, englobando uma estratégia de visualização, uma estratégia de localização e uma técnica de perfuração. Foram observadas 15 combinações distintas de técnicas, o que permitiu dividir os pacientes em grupos comparáveis. De modo geral, a combinação de uma técnica de visualização pelo portal transeptal (TS), de localização baseada em estimativa e de perfuração pelo portal anteromedial (AM), bem como a combinação de uma estratégia de visualização pelo portal anterolateral (AL), de localização com um *offset guide* e de perfuração pelo portal anteromedial acessório (aAM) revelaram-se os protocolos cirúrgicos mais precisos incluídos nesta revisão sistemática. Contudo, o protocolo que inclui o portal TS, um *offset guide* e o portal aAM tem o potencial de ser o mais preciso para a colocação do túnel femoral.

Conclusão: A precisão do protocolo proposto deverá ser avaliada, explorando simultaneamente a sua correlação com os resultados clínicos e o seu impacto no tempo e custo operatórios.

Palavras-Chave: Ligamento Cruzado Anterior; Reconstrução; Técnicas Cirúrgicas; Túnel Femoral

Abbreviations

3D – Three-Dimensional

3D-CT – 3D-Computed Tomography

aAM – Accessory Anteromedial

ACL – Anterior Cruciate Ligament

ACLR – Anterior Cruciate Ligament Reconstruction

aCV – Adjusted Coefficient of Variation

AL – Anterolateral

AM – Anteromedial

BH – Bernard-Hertel

CT – Computed Tomography

CV – Coefficient of Variation

DB – Double-Bundle

DCM – Deep Cartilage Margin

DS – Deep-Shallow

HL – High-Low

IKDC – International Knee Documentation Committee

JBI – Joanna Briggs Institute

MINORS – Methodological Index for Non-Randomized Studies

MRI – Magnetic Resonance Imaging

NOS – Newcastle-Ottawa Scale

OA – Osteoarthritis

OI – Outside-In

PL – Posterolateral

SB – Single-Bundle

SD – Standard Deviation

TS – Transseptal

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Introduction

Anterior cruciate ligament (ACL) tears are highly prevalent, particularly among younger and more active individuals. Annually, approximately 200 000 ACL ruptures occur in the United States [1-3] and, globally, over 70% of these injuries are the result of non-contact mechanisms, such as sudden deceleration combined with changes in direction, pivoting or landing with the knee in nearly full extension [3, 4]. Other mechanisms responsible for ACL tears include contact or traumatic injuries, which are typically characterized by a force applied anteriorly to a fixed lower leg [3, 5]. Patients with an ACL rupture usually present themselves with knee pain, swelling, hemarthrosis and instability during activity. The majority of these injuries are commonly associated with the involvement of the collateral ligaments, subchondral bone and menisci [3, 4, 6], which might result in a reduction of the quality of life [1, 3], a decline in activity levels [3, 7] and an elevated risk of developing secondary osteoarthritis (OA) in the knee [3, 8-10]. However, when compared with meniscal injury alone, the ACL rupture has been demonstrated to result in radiographic changes at a younger age than meniscal tear. This indicates the importance of the ACL in knee health [11]. Furthermore, it has been demonstrated that 20-50% of knees with an ACL deficiency develop OA within 10 years of the injury [3, 8, 11]. The diagnosis of an ACL tear is confirmed with imaging techniques, such as Magnetic Resonance Imaging (MRI), which can also help to assess other related injuries [3, 12]. There are also clinical scores, such as the Lysholm or the International Knee Documentation Committee (IKDC) scores, that help to quantify the disability caused by knee ligament injuries and to evaluate the results of treatment [13].

In young adults who wish to resume pre-injury activity, ACL surgical reconstruction is considered to be the gold standard treatment, given that non-operative management frequently results in suboptimal functional outcomes [14-18]. Anterior cruciate ligament reconstruction (ACLR) entails the replacement of the torn ligament with a graft made from tendons or ligaments, which is positioned in pre-drilled holes. This procedure is typically performed arthroscopically, usually within a year of the initial injury [3, 19]. There are three main types of grafts used in ACLR: autografts (derived from the patient's body), allografts (sourced from cadaveric donors) or synthetic ligament substitutes. The most utilized graft is the hamstrings tendons (semitendinosus and gracilis) from the injured limb. An alternative graft is the bone-patella tendon-bone or the quadriceps grafts [3, 20]. The current standard technique for ACLR is arthroscopic single-bundle (SB) reconstruction, although double-bundle (DB) reconstruction is considered to restore the natural anatomy of the ACL more closely. An anatomic reconstruction has the potential to reduce the likelihood of graft failure, pain, instability and early OA [21-24]. Nevertheless, DB reconstruction is more technically demanding and invasive than SB reconstruction, which is why it is not considered the preferred technique [25-29].

During ACLR, the accuracy of the femoral and tibial tunnels' anatomically positioned placement is of paramount importance in restoring stability and preventing impingement or graft failure, with particular importance attached to the femoral tunnel [30-37]. Any minor discrepancy in the positioning of the femoral insertion site can result in maladjustment between the tension and elongation changes of the graft [24, 36]. This illustrates the importance of precision (in terms of the proximity of femoral tunnels when produced with the same technique in different patients) in addition to accuracy (in terms of the technique's capacity to place the femoral tunnel in relation to the optimal position). One of the most widely accepted methods for measuring the coordinates of the femoral tunnel and its deviation on a lateral radiograph is the Bernard-Hertel (BH) quadrant method, which can be employed either intraoperatively or postoperatively [38-43]. The placement of the femoral tunnel may vary depending on the viewing strategy, localization strategy and drilling technique employed by the surgeon [44]. Multiple studies have individually reported and compared the accuracy of the various strategies to determine the most accurate procedure for ACLR. However, to our knowledge, the evaluation of the precision of these methodologies has never been compiled and analyzed comprehensively before.

Therefore, the purpose of this systematic review was to examine the precision of femoral tunnel placement in ACLR across a range of viewing strategies, localization strategies and drilling techniques. In addition, the clinical outcomes, operative time and operative cost of each technique were also evaluated.

Materials and Methods

This systematic review was conducted in accordance with the *Preferred Reporting Items for Systematic Review and Meta-Analyses* (PRISMA) guidelines [45] and was submitted to the *Prospective Register of Systematic Reviews* (PROSPERO) database.

Search Strategy and Study Eligibility

A comprehensive search of the PubMed, Scopus and Web of Science bibliographic databases was conducted to identify relevant literature on ACLR and the various techniques employed in femoral tunnel viewing, localization and drilling. No date restrictions were applied. The search terms included were “anterior cruciate ligament”, “reconstruction”, “surgical techniques” and “femoral tunnel”. The Supplementary File I provides a detailed description of the complementary search strategy employed for each database.

This review encompasses articles written in English and patients of any age, who have undergone ACLR. It includes all surgical techniques for primary ACLR and femoral tunnel placement, with the exception of transtibial drilling technique, since several authors have demonstrated that this technique may not be capable of placing the graft in a position that is proximate to the anatomic center of the ACL footprint in the femoral condyle. Consequently, the native ACL oblique orientation is not replicated, which may result in a graft that is unable to provide the desire tibial rotation [46-53]. The exclusion criteria for this review were as follows: (1) revision ACLR, (2) transtibial drilling technique, (3) tibial tunnel placement, (4) double-bundle ACLR, (5) ACL repair surgery, (6) ACLR techniques tested in animals, (7) no confirmation as a percentage ratio of femoral tunnel positioning using BH quadrant method, (8) review studies, (9) case series and (10) editorials/opinion pieces.

Study Screening

The Rayyan platform [54] was employed to facilitate the independent screening of titles and abstracts of articles extracted, following the literature search, by two reviewers. Subsequently, the included studies underwent full-text screening for study eligibility in accordance with the inclusion and exclusion criteria mentioned above. Any disagreements that arose during the process were resolved through consensus between the two reviewers. If no consensus was reached, a senior reviewer was consulted to resolve any discrepancies.

Quality Assessment

A total of 15 cohort studies, 5 case series studies, 2 randomized-controlled trials and 2 non-randomized studies were included in this review. The quality of the cohort studies was evaluated using the Newcastle-Ottawa Quality Assessment Scale (NOS) [(55)], the case series studies with the Joanna Briggs Institute (JBI) Critical Appraisal Checklist [(56)], the randomized-controlled trials using the Jadad Scale [(57)] and the non-randomized studies with the Methodological Index for Non-Randomized Studies (MINORS) Checklist [(58)].

Data Abstraction

The data extraction process was conducted by a single reviewer, with the results being checked by another reviewer in a cross-over manner. The relevant information abstracted included the authors, year of publication, country of the study, study design and corresponding level of evidence, number of subjects enrolled, patient's demographics, average of time between intervention and follow-up, ACLR surgical protocol (including viewing strategy, localization strategy and drilling technique for femoral tunnel placement), technology intervention descriptions, graft type and tunnel placement outcomes (measured by the BH quadrant method). In addition, data was collected on other outcomes, including clinical outcomes (with record of the Lysholm and the IKDC scores, pre and postoperatively), operative time and operative cost.

Femoral Tunnel Placement Precision Measurement

The term "precision" refers to the closeness of measurements and can be indicative of the reproducibility of a surgical technique. Consequently, in this systematic review, the precision of each surgical technique for femoral tunnel placement in ACLR was quantified utilizing the BH quadrant method, with particular focus on the value of the standard deviation (SD) for tunnel positioning in each axis of the grid (deep-shallow (DS) and high-low (HL)). To eliminate the effect of different anatomy between patients (for example, different-sized femurs), only SD values expressed as a percentage ratio were considered. With the mean and the SD values of each femoral tunnel position's coordinate, the coefficient of variation (CV) was calculated (CV = (SD/sample mean) *100) and then adjusted to the number of patients of each group (adjusted $CV = CV/\sqrt{n}$), to evaluate the precision of each surgical technique, adjusted to the mean and to the size of the population.

It can be postulated that a lower adjusted CV (aCV) value would indicate a reduced dispersion of femoral tunnel positions, thereby signifying a more precise positioning of the femoral tunnel. Inderhaug, E. *et al.* (2015) [35] presented the 95% confidence interval instead of the SD value for the tunnel position's coordinates. Therefore, the SD value for aCV calculation was estimated using a method proposed by Wan, X. *et al.* (2014) [59]. The patients included in this systematic review were then divided into different comparable groups, with the mean aCV value for the DS and the HL coordinates calculated to facilitate comparison between each cohort of patients. Subsequently, with the mean aCV values corresponding to each group of comparable patients, a three-dimensional (3D) graphic was generated using the RStudio 2024.04.1 – Build 748 (Windows) program to illustrate the patients undergoing the same surgical protocol, encompassing the same viewing, localization and drilling techniques, as well as its precision. Some articles did not provide a comprehensive description of the surgical protocol, merely outlining the surgical technique under analysis. Consequently, the results extracted from these studies were interpreted separately.

Results

Literature Search

A total of 7345 articles were identified through the literature search, with 2085 from PubMed, 2833 from Scopus and 2427 from Web of Science. Following the removal of 3851 duplicate studies, 3494 studies were subjected to title and abstract screening, with 3411 deemed irrelevant. A total of 83 articles underwent full-text screening for final eligibility. Of these, 56 studies were excluded, primarily due to the absence of the BH quadrant method for measuring femoral tunnel placement, but also due to a lack of specification regarding femoral tunnel positioning and the failure to express this as a percentage ratio. Furthermore, 3 articles were also excluded due to the inability to access them, despite repeated attempts to contact the authors via email. In total, 24 articles [24, 29, 35-37, 53, 60-76] were included in this systematic review.

A flowchart illustrating the systematic search methodology is presented in Appendix I, Figure 1.

Study Quality

Among the 24 studies included in this systematic review, only 13 provided an indication of the level of evidence related to the article. Of these, one was classified as Level II evidence [53], 8 were classified as Level III evidence [35, 36, 62-64, 67, 69, 70] and 4 were classified as Level IV evidence [24, 43, 74, 75]. The level of evidence corresponding to the other articles [29, 37, 60, 61, 65, 66, 68, 71-73, 76] was not indicated in the article itself, in the supplementary files or by the authors in any other manner. Among the 15 cohort studies, only one [62] was deemed to have poor quality, while the remaining were considered to have good quality [24, 29, 35, 36, 53, 60, 61, 64, 67, 69, 71-73, 75]. Of the 5 case series studies, 2 [37, 66] were classified as having medium-high quality and the remaining 3 [43, 70, 74] were considered to have high quality. The 2 randomized-controlled studies [65, 76] and the 2 non-randomized studies [63, 68] were all considered to have good quality.

The quality assessment process of each type of study included in this review is presented in Appendix II, Tables I, II, III and IV.

Study and Intervention Characteristics

A total of 1478 patients were included in this systematic review. Considering only the manuscripts with the anthropometric data available, we found that the majority of the patients were male (71,82% of 873 patients), the age of participants ranged from 13 to 62 years (845 patients) and the average time between ACLR and follow-up ranged from the day of intervention to 36 months postoperatively (1166 patients).

All 24 included studies performed single-bundle ACL reconstruction. Of these, 14 studies [29, 35, 53, 61, 63-65, 67-69, 71, 73, 74, 76] employed a hamstring tendon (semitendinosus and gracilis) autograft, 1 [43] used only a semitendinosus autograft, 2 [36, 70] prepared a hamstring or a quadriceps autograft, 2 [37, 75] used a hamstring tendon autograft or an allograft, 1 [72] employed a bone-patellar tendon-bone graft, 1 [66] study used a bone-patellar tendon-bone autograft or an Achilles tendon allograft or a tibialis anterior tendon allograft and, lastly, 3 [24, 60, 62] articles lacked a comprehensive description of the type of graft used in femoral tunnel placement.

In terms of the viewing strategies employed for femoral tunnel placement, 417, 652, 35 e 144 patients were subjected to anteromedial (AM), anterolateral (AL), posterolateral (PL) and transseptal (TS) portal technique, respectively.

Regarding the localization strategies, estimation based on anatomic landmarks (namely the remnants of native ACL, resident's ridge and bifurcate ridge), offset guide, ruler, fluoroscopy, 3D-printed navigation templates and computer-assisted navigation were techniques employed in 916, 298, 60, 137, 22, and 26 patients, respectively.

Finally, in relation to the drilling techniques, the femoral tunnel was drilled through an AM portal in 499 patients, an accessory anteromedial portal (aAM) in 455 patients and using the outside-in (OI) technique in 417 patients.

A detailed description of each study is provided in Appendix III, Table V.

Femoral Tunnel Placement Precision

In order to assess the precision of each surgical protocol implemented for femoral tunnel placement in ACLR, the results were divided into comparable groups of patients, according to the overall description of the surgical protocol.

The 3D-graphic generated to illustrate the patients undergoing the same protocol and, therefore, facilitate the organization of these results is illustrated in Appendix IV, Figure 2.

Viewing Strategy

The results regarding the viewing strategies employed in the included articles of this systematic review were divided into four comparable groups of patients.

i. Group V1 – AM Portal vs. PL Portal vs. TS Portal vs. AL Portal

All studies included in this cohort comprised patients who underwent estimation based on anatomic landmarks as the localization strategy, in conjunction with an AM portal drilling technique, with the only variation being the viewing strategy.

In their respective studies, Pansard, E. *et al.* (2015) [(24)] and Jin, A. H. *et al.* (2016) [(60)] described the use of an AM portal viewing technique and obtained an aCV for the DS/HL coordinates of the femoral tunnel position of 4.47/5.96 and 6.97/3.56, respectively, with a mean aCV of 5.72/4.76. Jin, A. H. *et al.* (2016) [(60)] also described the use of a PL and a TS portal viewing technique and obtained an aCV for the DS/HL coordinates of 6.41/3.11 and 1.37/0.95, respectively. As for Weijie, L. *et al.* (2022) [(36)], Takanori, I. *et al.* (2017) [(70)] and Eun-Kyoo, S. *et al.* (2014) [(73)], these researchers described the use of an AL portal viewing technique and obtained an aCV for the DS/HL coordinates of 3.13/2.52, 3.32/4.69 and 4.63/6.10, respectively, with a mean aCV of 3.69/4.44.

In conclusion, the TS portal viewing strategy demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, indicating that it was the most precise in this cohort of patients.

ii. Group V2 – AL Portal vs. AM Portal

This cohort included patients who underwent estimation based on anatomic landmarks as the localization strategy, in conjunction with an aAM portal drilling technique.

In their respective studies, Jae-Ang, S. *et al.* (2015) [(62)] and Kwang, W. L. *et al.* (2014) [(66)] described the use of an AL portal viewing technique and obtained an aCV for the DS/HL coordinates of 3.19/2.69 and 1.79/1.71, respectively, with a mean aCV of 2.49/2.20. As for Silva, A. *et al.* (2011) [(53)], Young-Soo, S. *et al.* (2013) [(63)] and Yasutaka, T. *et al.* (2017) [(72)], these researchers described the use of an AM portal viewing technique and obtained an aCV for the DS/HL coordinates of 3.70/2.45, 0.57/0.42 and 3.01/3.39, respectively, with a mean aCV of 2.43/2.09.

In conclusion, the AM portal viewing strategy demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, by a minimal difference, indicating that it was the most precise in this cohort of patients.

iii. Group V3 – TS Portal vs. AL Portal vs. AM Portal

This cohort of patients demonstrated inconsistency with regard to the mean aCV for the DS/HL coordinates of the femoral tunnel position. Only patients who underwent estimation based on anatomic landmarks as the localization strategy, in conjunction with an OI drilling technique were included.

In their respective study, Seung, H. L. *et al.* (2019) [37] described the use of a TS portal viewing technique and obtained an aCV for the DS/HL coordinates of 2.62/2.00. As for Dhong, W. L. *et al.* (2018) [67] and Jin, A. H. *et al.* (2013) [61], these researchers described the use of an AL portal viewing technique and obtained an aCV for the DS/HL coordinates of 1.06/0.66 and 3.35/4.40, respectively, with a mean aCV of 2.21/2.53. Finally, Pansard, E. *et al.* (2015) [24], Jae-Ang, S. *et al.* (2015) [62], Young-Soo, S. *et al.* (2013) [63] and Seung-Suk, S. *et al.* (2019) [75] described the use of an AM portal viewing technique and obtained an aCV for the DS/HL coordinates of 3.61/5.78, 3.10/3.09, 0.93/0.70 and 3.21/4.46, respectively, with a mean aCV of 2.71/3.51.

In conclusion, the AL and the TS portals demonstrated the lowest mean aCV for the DS and for the HL coordinate of the femoral tunnel position, respectively, indicating that these protocols were the most precise in this cohort of patients for these measurements.

iv. Group V4 – AL Portal vs. AM Portal

The final cohort also demonstrated inconsistency with regard to the mean aCV for the DS/HL coordinates and comprised patients who underwent ruler localization strategy, in conjunction with an AM portal drilling technique.

Mhaskar, V. A. *et al.* (2020) [76] compared the use of an AL portal versus an AM portal viewing technique and obtained an aCV for the DS/HL coordinates of the femoral tunnel position of 3.48/4.18 and 4.79/4.12, respectively.

In conclusion, the surgical protocol using the AL portal as the viewing strategy demonstrated the lowest mean aCV for the DS coordinate, while the use of an AM portal demonstrated the lowest mean aCV for the HL coordinate of the femoral tunnel position, indicating that these protocols were the most precise in this cohort of patients for these measurements.

It is also important to note that out of the six most precise surgical protocols, the one which consists of a TS portal viewing strategy, an estimation based on anatomic landmarks and an AM portal drilling technique was the most precise overall, with the lowest mean aCV for both coordinates of the femoral tunnel position.

A comprehensive account of the results for each cohort of patients regarding viewing strategies for femoral tunnel placement in ACLR is presented in Appendix V, Table VI.

Localization Strategy

Similarly to the previous section, the results regarding the localization strategies employed in the included articles of this systematic review were divided into four comparable groups of patients.

i. **Group L1 – Estimation vs. Offset Guide vs. 3D-Printed Template vs. Ruler**

This cohort comprised patients who underwent an AL portal viewing strategy, in conjunction with an AM portal drilling technique.

In their respective studies, Takanori, I. *et al.* (2017) [70], Eun-Kyoo, S. *et al.* (2014) [73] and Weijie, L. *et al.* (2022) [36] described the use of an estimation based on anatomic landmarks localization strategy and obtained an aCV for the DS/HL coordinates of the femoral tunnel position of 3.32/4.69, 4.63/6.10 and 3.13/2.52, respectively, with a mean aCV of 3.69/4.44. Weijie, L. *et al.* (2022) [36], in conjunction with Weiler, A. *et al.* (2017) [43] and Hrishikesh, P. *et al.* (2017) [29] also described the use of an offset guide localization strategy and obtained an aCV for the DS/HL coordinates of 2.50/2.10, 2.88/2.46 and 2.30/0.80, respectively, with a mean aCV of 2.56/1.79. As for Dejian, L. *et al.* (2020) [65], this researcher studied the use of a 3D-printed navigation template localization strategy and obtained an aCV for the DS/HL coordinates of 3.24/4.80. Finally, Mhaskar, V. A. *et al.* (2020) [76], studied the use of a ruler localization strategy and obtained an aCV for the DS/HL coordinates of 3.48/4.18.

In conclusion, the offset guide localization strategy demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, indicating that it was the most precise in this cohort of patients.

ii. **Group L2 – Estimation vs. Fluoroscopy**

The subsequent cohort included patients who underwent an AM portal viewing strategy, in conjunction with an OI drilling technique.

In their respective studies, Pansard, E. *et al.* (2015) [24], Jae-Ang, S. *et al.* (2015) [62], Young-Soo, S. *et al.* (2013) [63] and Seung-Suk, S. *et al.* (2019) [75] described the use of an estimation based on anatomic landmarks localization strategy and obtained an aCV for the DS/HL coordinates of 3.61/5.78, 3.10/3.09, 0.93/0.70 and 3.21/4.46, respectively, with a mean aCV of 2.71/3.51. Seung-Suk, S. *et al.*

(2019) [75] also described the use of a fluoroscopy localization strategy and obtained an aCV for the DS/HL coordinates of 1.74/2.46.

In conclusion, the fluoroscopy localization strategy demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, indicating that it was the most precise in this cohort of patients.

iii. Group L3 – Estimation vs. Offset Guide

All studies included in this cohort comprised patients who underwent an AL portal viewing strategy, in conjunction with an aAM portal drilling technique.

In their respective studies, Jae-Ang, S. *et al.* (2015) [62] and Kwang, W. L. *et al.* (2014) [66] described the use of an estimation based on anatomic landmarks localization strategy and obtained an aCV for the DS/HL coordinates of 3.19/2.69 and 1.79/1.71, respectively, with a mean aCV of 2.49/2.20. As for Shafizadeh, S. *et al.* (2014) [74], this researcher described the use of an offset guide localization strategy and obtained an aCV for the DS/HL coordinates of 0.91/1.11.

In conclusion, the offset guide localization strategy demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, which indicates that it was the most precise in this cohort of patients.

iv. Group L4 – Ruler vs. Estimation

The final cohort comprised patients who underwent an AM portal viewing strategy and an AM portal drilling technique.

In their respective study, Mhaskar, V. A. *et al.* (2020) [76] described the use of a ruler localization strategy and obtained an aCV for the DS/HL coordinates of 4.79/4.12. As for Jin, A. H. *et al.* (2016) [60] and Pansard, E. *et al.* (2015) [24], these researchers described the use of an estimation based on anatomic landmarks localization strategy and obtained an aCV for the DS/HL coordinates of 6.97/3.56 and 4.47/5.96, respectively, with a mean aCV of 5.72/4.76.

In conclusion, the ruler localization strategy demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, indicating that it was the most precise in this cohort of patients.

It is also important to note that out of the four most precise surgical protocols, the one that uses an AL portal viewing strategy, an offset guide localization strategy and an aAM portal drilling technique was the most precise overall, with the lowest mean aCV for both coordinates of the femoral tunnel position.

A comprehensive account of the results for each cohort of patients regarding localization strategies for femoral tunnel placement in ACLR is presented in Appendix VI, Table VII.

Drilling Technique

The results regarding the drilling techniques employed in the included articles of this systematic review were divided into four comparable groups of patients.

i. Group D1 – AM Portal vs. OI vs. aAM Portal

In the initial cohort, which comprised patients who underwent an AL portal viewing strategy, in conjunction with an estimation based on anatomic landmarks localization strategy, the results demonstrated inconsistency with regard to the mean aCV for the DS/HL coordinates of the femoral tunnel position.

In their respective studies, Takanori, I. *et al.* (2017) (70), Eun-Kyoo, S. *et al.* (2014) (73) and Weijie, L. *et al.* (2022) (36) described the use of an AM portal drilling technique and obtained an aCV for the DS/HL coordinates of the femoral tunnel position of 3.32/4.69, 4.63/6.10 and 3.13/2.52, respectively, with a mean aCV of 3.69/4.44. As for Dhong, W. L. *et al.* (2018) (67) and Jin, A. H. *et al.* (2013) (61), these researchers described the use of an OI drilling technique and obtained an aCV for the DS/HL coordinates of 1.06/0.66 and 3.35/4.40, respectively, with a mean aCV of 2.21/2.53. Finally, Jae-Ang, S. *et al.* (2015) (62) and Kwang, W. L. *et al.* (2014) (66) described the use of an aAM portal drilling technique and obtained an aCV for the DS/HL coordinates of 3.19/2.69 and 1.79/1.71, respectively, with a mean aCV of 2.49/2.20.

In conclusion, the OI and the aAM portal drilling techniques demonstrated the lowest mean aCV for the DS and the HL coordinates of the femoral tunnel position, respectively, indicating that these protocols were the most precise in this cohort of patients for these measurements.

ii. Group D2 – OI vs. aAM Portal vs. AM Portal

The subsequent cohort included patients who underwent an AM portal viewing strategy, in conjunction with an estimation based on anatomic landmarks localization strategy.

In their respective studies, Jae-Ang, S. *et al.* (2015) (62), Pansard, E. *et al.* (2015) (24), Seung-Suk, S. *et al.* (2019) (75) and Young-Soo, S. *et al.* (2013) (63) described the use of an OI drilling technique and obtained an aCV for the DS/HL coordinates of 3.10/3.09, 3.61/5.78, 3.21/4.46 and 0.93/0.70, respectively, with a mean aCV of 2.71/3.51. Young-Soo, S. *et al.* (2013) [63], along with Silva, A. *et al.* (2011) [53] and Yasutaka, T. *et al.* (2017) [72], also described the use of an aAM portal drilling technique and obtained an aCV for the DS/HL coordinates of 0.57/0.42, 3.70/2.45 and 3.01/3.39, respectively, with a mean aCV of 2.43/2.09. Finally, Jin, A. H. *et al.* (2016) [60] and Pansard, E. *et al.* (2015) [24] described the use of an AM portal drilling technique and obtained an aCV for the DS/HL coordinates of 6.97/3.56 and 4.47/5.96, respectively, with a mean aCV of 5.72/4.76.

In conclusion, the aAM portal drilling technique demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, indicating that it was the most precise in this cohort of patients.

iii. Group D3 – AM Portal vs. aAM Portal

This cohort comprised patients who underwent an AL portal viewing strategy and an offset guide localization strategy.

In their respective studies, Weijie, L. *et al.* (2022) [36], Weiler, A. *et al.* (2017) [43] and Hrishikesh, P. *et al.* (2017) [29] described the use of an AM portal drilling technique and obtained an aCV for the DS/HL coordinates of 2.50/2.10, 2.88/2.46 and 2.30/0.80, respectively, with a mean aCV of 2.56/1.79. Shafizadeh, S. *et al.* (2014) [74] described the use of an aAM portal drilling technique and obtained an aCV for the DS/HL coordinates of 0.91/1.11.

In conclusion, the aAM portal drilling technique demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, indicating that it was the most precise in this cohort of patients.

iv. Group D4 – AM Portal vs. OI

The final cohort included patients who underwent a TS portal viewing strategy, along with an estimation based on anatomic landmarks localization strategy.

In their respective studies, Jin, A. H. *et al.* (2016) [60] and Seung, H. L. *et al.* (2019) [37] studied the efficacy of an AM portal and an OI drilling techniques, respectively. Each researcher obtained an aCV for the DS/HL coordinates of 1.37/0.95 and 2.62/2.00.

In conclusion, the AM portal drilling technique demonstrated the lowest mean aCV for both coordinates of the femoral tunnel position, indicating that it was the most precise in this cohort of patients.

It is also important to note that out of the five most precise surgical protocols, the one which consists in an AL portal viewing strategy, an offset guide localization strategy and an aAM portal drilling technique, and the one which combined a TS portal viewing technique, an estimation-based localization strategy and an AM portal drilling technique were the most precise overall, with the lowest mean aCV for the DS and the HL coordinates of the femoral tunnel position, respectively.

A comprehensive account of the results for each cohort of patients regarding drilling techniques for femoral tunnel placement in ACLR is presented in Appendix VII, Table VIII.

Other Findings

Some authors did not provide a comprehensive description of the entire surgical protocol under which some groups of patients were subjected. Consequently, the results extracted from these studies had to be interpreted separately.

Inderhaug, E. *et al.* (2015) [35] studied the use of an estimation based on anatomic landmarks versus the use of fluoroscopy as localization strategies, while both groups used an aAM portal drilling technique. No description of the viewing strategy employed was provided. The results demonstrated that the use of the first technique allowed for a more precise positioning of the femoral tunnel along the DS axis of the BH quadrant, with an aCV of 1.36 versus 1.79 of the second technique. Nevertheless, the fluoroscopy-based localization strategy reported a more precise positioning of the tunnel in the HL axis, with an aCV of 2.29 versus 2.59 of the estimation based on anatomic landmarks strategy.

Osti, M. *et al.* (2015) [64] studied the use of an aAM portal versus the OI drilling techniques, while both groups used fluoroscopy as the location strategy. No description of the viewing strategy employed was provided. The results demonstrated that the use of the first technique allowed for a more precise positioning of the femoral tunnel along the DS axis of the BH quadrant, with an aCV of 5.35 versus 8.84 of the second technique. Nevertheless, the use of an OI drilling technique reported a more precise positioning of the tunnel in the HL axis, with an aCV of 6.15 versus 6.66 of the aAM portal drilling technique.

Kosy, J. D. *et al.* (2020) [68] studied the use of an AL versus an AM portal viewing strategy, while both groups used estimation based on anatomic landmarks as the location strategy. No description of the drilling technique employed was provided. The results demonstrated that the use of the first technique allowed to obtain an aCV for the DS/HL coordinates of 3.29/3.49 versus 5.28/5.19 of the second technique. Therefore, the use of an AL portal revealed to be more precise as a viewing strategy than the AM portal.

Wayne, Y. X. F. *et al.* (2022) [(71)] studied the use of a computer-assisted navigation versus an estimation based on anatomic landmarks localization strategies. No description of the viewing strategy or the drilling technique employed was provided. The results demonstrated that the use of the first technique allowed for a more precise positioning of the femoral tunnel along the DS axis of the BH quadrant, with an aCV of 2.99 versus 3.71 of the second technique. Nevertheless, the use of an estimation based on anatomic landmarks localization strategy reported a more precise positioning of the tunnel in the HL axis, with an aCV of 2.68 versus 3.23 of the computer-assisted navigation as the localization strategy.

Two group of patients described in two different articles were deemed to be non-comparable to any other cohort of patients. Still, it is important to document their outcomes in the same manner. Man, K. S. *et al.* (2019) [(69)] investigated the efficacy of an offset guide localization strategy, in conjunction with an aAM portal drilling technique. No description of the viewing strategy employed was provided. The aCV obtained for the DS and for the HL coordinate of the femoral tunnel position was of 3.02 and 2.64, respectively. Lastly, Dejian, L. *et al.* (2020) [(65)] examined the use of an AL portal viewing strategy, in conjunction with an AM portal drilling technique. No description of the localization strategy employed was provided. The aCV obtained for the DS and for the HL coordinate of the femoral tunnel position was of 2.79 and 3.61, respectively.

A comprehensive account of these findings is presented in Appendix VIII, Table IX.

Clinical Outcomes

Six articles assessed clinical evaluation of patients included in each study, using clinical scores such as the Lysholm and the IKDC (subjective) scores, among others. The mean value of these scores was analyzed in order to identify any variations. Hrishikesh, P. *et al.* (2017) [(29)] reported an improvement of 52.23 in the mean Lysholm score and of 49.23 in the mean IKDC score, 12 months postoperatively. This improvement was observed in patients who had undergone a surgical protocol for femoral tunnel placement that included an AL portal viewing strategy, an offset guide localization strategy and an AM portal drilling technique. In the same time frame, Dejian, L. *et al.* (2020) [65] compared the use of a 3D-printed navigation template localization strategy to conventional surgery, with both groups using an AL portal viewing strategy and an AM portal drilling technique. The results demonstrated a significant improvement in the mean Lysholm score of 34.37 in the conventional group and 35.32 in the 3D group. In terms of the IKDC score, the conventional group and the 3D group demonstrated an improvement in the mean value of 40.10 and 41.37, respectively. Finally, Wayne, Y. X. F. *et al.* (2022) [71] compared the use of a computer-assisted navigation localization strategy to the estimation based on anatomic landmarks. This article only calculated the Lysholm score and demonstrated an improvement of 32.90 in the conventional group and 29.03 in the navigated group, 12 months postoperatively. When the three articles are considered collectively, the first article mentioned above reported the most significant improvement in both scores.

Three additional articles did not specify the timing of the score's calculation postoperatively, rendering them incompatible for comparison with the aforementioned studies. Dhong, W. L. *et al.* (2018) [67] employed an AL portal viewing strategy, an estimation based on anatomic landmarks localization strategy and an OI drilling technique. This approach resulted in a post-operative improvement of 21.10 for the Lysholm score and 22.10 for the IKDC score. Seung, H. L. *et al.* (2019) [37] used a TS portal viewing strategy, an estimation based on anatomic landmarks localization strategy and an OI drilling technique. This surgical protocol for femoral tunnel placement resulted in a post-operative improvement of 36.90 in the mean value for the Lysholm score and of 40.30 in the mean value for the IKDC score. Finally, Yasutaka, T. *et al.* (2017) [72] employed an AM portal viewing strategy, an estimation based on anatomic landmarks localization strategy and an aAM portal drilling technique, and demonstrated an improvement of the mean Lysholm score of 32.00 postoperatively. The final article did not calculate the IKDC score.

A comprehensive summary of the clinical outcomes of each article is presented in Appendix IX, Table X.

Operative Time and Cost

Only 3 out of the 24 included studies reported data pertaining to the operative time and cost of ACLR, specifically in relation to the surgical technique under analysis.

Dejian, L. *et al.* (2020) [65] observed a reduction in intraoperative positioning time with the use of a 3D-printed positioning tool (3.30 ± 1.00 minutes) in comparison to conventional surgery (5.90 ± 1.80 minutes). Additionally, the same report indicated that the preparation of the individualized navigation templates, following the collection of the MRI data, required approximately six hours, with an estimated cost of 42.00 United States dollars per patient.

Wayne, Y. X. F. *et al.* (2022) [71] demonstrated that the mean duration of surgery was significantly longer when the Orthopilot navigation system was employed (109 minutes) compared to conventional surgery (91 minutes).

Finally, Seung-Suk, S. *et al.* (2019) [75] demonstrated that the operation time was longer in the group that used intraoperative fluoroscopy to localize the femoral tunnel position (61.30 ± 5.20 minutes) than in the non-fluoroscopy group (55.50 ± 4.50 minutes).

Discussion

As previously stated, accurate and precise placement of the femoral tunnel in ACLR is of paramount importance to the success of the procedure. The term "accuracy" is used to describe the proximity of the femoral tunnel placement to the ideal anatomic location. Bird *et al.* [77] reported that this location is 27% along the DS axis and 34% along the HL axis of the grid. While it is important to accurately hit the target location, precision ensures that the surgeon can reliably place the femoral tunnel in the optimal position every time, resulting in more consistent patient outcomes. Consequently, precision in femoral tunnel placement allows standardization of the procedure across surgeons and institutions. This reproducibility is of crucial importance in order to achieve comparable surgical outcomes and to reduce variability in patient recovery times, while at the same time minimizing the risk of complications [30, 31]. Furthermore, even minor discrepancies can result in suboptimal outcomes [24, 36] and significant variation in tunnel placement can lead to inadequate graft tensioning, abnormal joint kinematics and potentially increased wear and tear on the joint structures, whereas precise placement can ensure that the reconstructed ligament functions similarly to the native ACL, which is essential for the longevity of the reconstruction and to reduce the risk of re-injury [30]. In addition, each patient's anatomy is unique and precision allows the femoral tunnel to be tailored to these individual anatomical differences. Patients are also more likely to return to their pre-injury level of activity and sports participation when the procedure is performed with high precision [78]. This highlights the importance of investigating the precision of surgical techniques for femoral tunnel placement and determining which are more reproducible.

Regarding the viewing strategies studied in this systematic review, the TS portal technique demonstrated the highest precision in Group V1, when compared to the AM, AL and PL portals, while utilizing an estimation-based localization strategy and an AM portal drilling technique. The anterior arthroscopic portal is not an optimal approach for visualizing the ACL footprint at the femoral site, as it may result in the loss of the remaining ACL due to blockage caused by the remnants or the ridge of the medial wall of the lateral femoral condyle. Conversely, a TS portal has high accuracy and reproducibility. Furthermore, the apex of the deep cartilage margin (DCM) can be the sole landmark that can be seen with an ACL femoral footprint [79]. In the TS approach, the femoral footprint of the ACL and the apex of the DCM are consistently visible in the anterior upper and middle compartments, with no other anatomical structures visible [80]. This may be a reason why this viewing portal demonstrated enhanced precision in femoral tunnel placement.

In Group V2, the AM portal technique reported the highest precision when compared to the AL portal, while utilizing an estimation-based localization strategy and drilling the femoral tunnel through an aAM portal. The AM portal is employed for the purpose of visualizing the lateral intercondylar notch wall and for the marking of the ACL insertion sites. The portal allows for unobstructed viewing of the lateral intercondylar notch, eliminating the need for "notchplasty" or "wallplasty" procedures. This is in contrast to the AL view, where the notch is obscured by the femoral condyle [81]. Another potential risk factor for tunnel mispositioning is image distortion, which may occur when peripheral regions are altered, particularly when the viewing angle is not straight. This can result in a more medial view of the lateral wall, which may contribute to tunnel malplacement [82]. This appears to justify the increased precision observed in this group, when using the AM portal as the viewing strategy.

In regard to Group V3, the AL and the TS portals demonstrated the highest precision for tunnel placement along the DS and the HL axes of the BH quadrant, respectively, when compared to the AM portal. This was achieved through the utilization of an estimation-based localization strategy and an OI drilling technique. The TS approach allows for direct visualization of the posterior 2/3 of the ACL stump, the DCM, and the entire height of the notch, which may facilitate precise localization of the tunnel in the HL coordinate. Nevertheless, the inability to observe the anterior 1/3 of the lateral condyle may justify a less precise location in the DS coordinate [80].

Finally, in Group V4, the AL and the AM portals demonstrated the highest precision for tunnel placement along the DS and the HL axes of the BH quadrant, respectively. This was achieved through the utilization of a ruler localization strategy and an AM portal drilling technique. The techniques analyzed exhibited a minimal disparity along the HL axis, yet the AL view with the utilization of a ruler appeared to achieve superior precision along the DS axis. This may be attributed to a reduced degree of interference between the arthroscope and the guide pin/drill when utilizing the AL portal for visualization, in comparison with both being inserted through the medial side. The use of a ruler serves to ensure the precision of the more tangential view of the AL view [83].

A comparison of the various visualization portals reveals that the TS portal offers the most direct and unobstructed view of the ACL insertion in the lateral femoral condyle. This may be indicative of the enhanced precision of the femoral tunnel positioning when utilizing this particular visualization method.

On the other hand, an analysis of the localization strategies observed in this systematic review revealed that the offset guide was the most precise technique in Group L1, when compared to the use of an estimation based on anatomic landmarks, a ruler and a 3D-printed template, while using an AL portal viewing strategy and an AM portal drilling technique. The use of an offset guide enables the surgeon to maintain a stable and focused grip during the insertion of the guide pin, prior to drilling. This may, therefore, reduce the variability induced by a free-hand technique, as observed in the estimation and ruler strategies (69). With regard to the 3D-printed templates technique, although it expected potential, it did not exhibit enhanced precision when compared to the remaining strategies.

In Group L2, the fluoroscopic localization strategy demonstrated superior precision to the estimation-based technique, when using an AM portal viewing strategy and an OI drilling technique. This can be attributed to the fact that surgeons can be successfully guided with fluoroscopy to create more consistent femoral tunnels during ACLR (84).

As in Group L3, the offset guide localization strategy reported the highest precision when compared to the estimation-based one, while using an AL portal viewing strategy and an aAM portal drilling technique. The estimation of the ACL femoral tunnel location by anatomic landmarks relies on a free-hand technique to insert the guide pin, and thus offset guides are shown to be more precise. Therefore, the use of offset guides appears to reduce the operator-depending variability in guide wire positioning, in comparison to estimation-based calculations (69).

Lastly, in Group L4, the ruler strategy was found to be more precise than the estimation based on anatomic landmarks, when using an AM portal as the viewing and the drilling techniques. Both strategies are based on the proper placement of the femoral tunnel through direct visualization of the lateral wall and positioning of the guide pin. However, the use of a ruler allows for a more precise location due to the difficulty of identifying anatomical landmarks for surgeons (32).

The results of this evaluation indicate that the use of a more stable and easily positioned instrument, such as the offset guide, to determine the drilling position, rather than free-hand techniques in handling guide wires or larger instruments such as 3D-printed guides, may result in improved precision in femoral tunnel placement.

In regard to the drilling techniques for femoral tunnel placement observed in this systematic review, the OI and the aAM portal demonstrated the highest precision for tunnel placement along the DS and the HL axes of the BH quadrant, respectively, in Group D1. This was achieved through the use of an AL portal viewing strategy and an estimation-based localization strategy. These drilling techniques achieved similar levels of precision, exceeding that of the AM portal. This is due to the fact that, with the AM portal, the drill is positioned more obliquely to the lateral wall of the notch, increasing the risk of posterior cortex blowout and reducing tunnel placement's precision (85).

In Group D2, the aAM portal showed the highest precision, when compared to the use of the OI or the AM portal drilling techniques, while employing an AM portal viewing strategy and an estimation based on anatomic landmarks localization strategy. A similar outcome was observed in Group D3, when compared to the AM portal, while the femoral tunnel position was viewed through an AL portal and located with an offset guide. The aAM portal is typically located just superior to the medial joint line, approximately 2 cm medial to the medial border of the patellar tendon (86). This ensures that the optimal angle for drilling the femoral tunnel is maintained, thereby reducing the risk of injury to the cartilage of the medial femoral condyle. The anterior approach to drilling is also more direct than the OI approach, allowing for better control. Additionally, the aAM approach is less tangential to the condyle wall than the AM portal (81). This may be indicative of the enhanced precision of the aAM portal drilling technique, in comparison to the remaining strategies.

Finally, in Group D4, the AM portal drilling technique was found to be more precise than the OI technique, while using a TS portal viewing strategy and an estimation-based localization strategy. It can be postulated that the reduced precision of the OI technique may be attributable to the increased difficulty in positioning the aiming guide on the femur to guide the guidewire, given the surgeon's position while visualizing through the TS portal. However, there is currently no way of demonstrating this.

Therefore, considering the various drilling techniques observed in this review, it can be posited that the aAM portal approach represents the most precise drilling technique. This may be due to its user-friendliness for the surgeon in handling the instruments, its reduced tangentiality to the notch wall, thereby reducing migration from the desired location, and its frontal alignment with the anatomical insertion of the ACL.

In light of the aforementioned considerations, it can be postulated that the most precise surgical protocol for femoral tunnel placement in ACLR would be one that combined a TS portal viewing strategy, an offset guide localization strategy and an aAM portal drilling technique. However, this surgical protocol was not observed among the included studies in this review. Therefore, when analyzing the 3D-graphic illustrated in Appendix IV, Figure 2, it becomes evident that the most precise surgical protocol for femoral tunnel placement along the DS axis of the BH quadrant included in this study is the one which combines an AL portal viewing strategy, an offset guide localization strategy and an aAM portal drilling technique, while the combination of a TS portal viewing strategy, an estimation-based localization strategy and an AM portal drilling technique has demonstrated to be the most precise one for placing the femoral tunnel along the HL axis of the grid. The two most precise protocols presented in this paper represent the most closely related combinations to the proposed one.

The remaining articles included in this systematic review were deemed to be non-comparable for the viewing strategies, localization strategies and drilling techniques employed in femoral tunnel placement, since they did not provide a comprehensive description of the surgical protocol implemented. Consequently, any critical analysis and discussion of their results was precluded.

It is also important to consider that other factors outside the surgical procedure can influence the precision of femoral tunnel placement in ACLR. This could explain the observed variation in the results obtained in different groups of patients subjected to the same combination of viewing, localization and drilling techniques. Some of these factors include the surgeon's experience and skill. It is anticipated that surgeons with more advanced training and a greater number of ACL surgeries performed will be able to achieve more precise tunnel placement. It is also necessary to consider patient-specific factors, such as anatomical variability (for example, the size and shape of the femur) and bone quality (patients with poor bone quality, such as those with osteoporotic bone, for example, can make precise drilling more challenging, while also affecting the stability of the tunnel). Simultaneously, there are a number of intraoperative factors that are not directly related to the surgical protocol that can also influence the procedure's precision. These include the quality of the equipment, the competence of the support staff, the anesthesia, and the positioning of the patient during the surgery. These factors must be taken into account when analyzing the results of this systematic review.

Limitations

It should be noted that this systematic review is subject to certain limitations. First, only 15 of the 60 possible combinations between the four viewing strategies, the five localization strategies and the three drilling techniques included in this study were observed. This may introduce a degree of bias into our conclusions, as there may be a surgical protocol with even greater precision that was not identified in the selected patients. Second, some surgical protocols were tested in a limited number of studies. Consequently, it is possible that these surgical protocols may be considered the most or least precise, solely because of the aforementioned factors that might also influence the procedure's precision, for example. Third, the results obtained in the remaining articles that were deemed non-comparable could not be discussed. Nevertheless, these results may be pertinent and the absence of discussion of their results may also introduce some bias into our conclusions. Fourth, a limited number of studies included in this review reported results regarding the patient's clinical outcomes, as well as the operative cost and operative time of the surgical protocol under analysis. This precludes a more accurate and comprehensive discussion of the results, as they were not truly representative of the population included in this review.

Conclusion

In ACLR, the precision of surgical protocols employed for femoral tunnel placement is of equal importance to their accuracy. Precision, which refers to the consistency and reproducibility of a procedure, is essential for ensuring that the surgical outcomes are reliable and uniform across different patients and surgeons. While accuracy guarantees that the femoral tunnel is correctly placed anatomically, precision ensures that this placement is consistently achieved, thereby minimizing variability and enhancing the predictability of the surgical results. Therefore, as reproducibility is a fundamental aspect of effective surgical practice, it is crucial to guarantee the precision of a surgical protocol before attempting to ascertain its accuracy. This is necessary to ensure that the optimal target is consistently achieved on each occasion.

The proposed surgical protocol, which combines a TS portal viewing strategy, an offset guide localization strategy and an aAM portal drilling technique for femoral tunnel placement, has been identified as potentially the most precise approach, according to the findings of this systematic review. In the future, further studies should be conducted to assess the variability in femoral tunnel placement when this protocol is employed, in comparison to other established methods. High-precision protocols will exhibit minimal variation, indicating that the procedure can be reliably reproduced and allowing the development of guidelines and training programs that enable all surgeons to replicate the success of the most experienced practitioners.

Future research should also evaluate the impact of this protocol on patient recovery, knee stability and long-term joint function. This should be accomplished by means of objective and subjective clinical scoring, both pre- and post-operatively. An understanding of this correlation will facilitate the validation of the protocol's effectiveness and its establishment as a standard practice in ACLR. In addition to clinical outcomes, it is essential to consider the practical aspects of surgical protocols, such as operative time and cost. It is recommended that future studies assess whether the increased precision of the TS portal, offset guide and aAM portal combination is related to more efficient surgeries and better resource management.

In conclusion, the precision of the proposed protocol should be evaluated in order to ascertain its correlation with clinical outcomes and to assess its impact on operative time and cost. This will ensure that this potentially superior method is validated and that, ultimately, it improves the standard of care in ACLR.

Appendix

Appendix I.

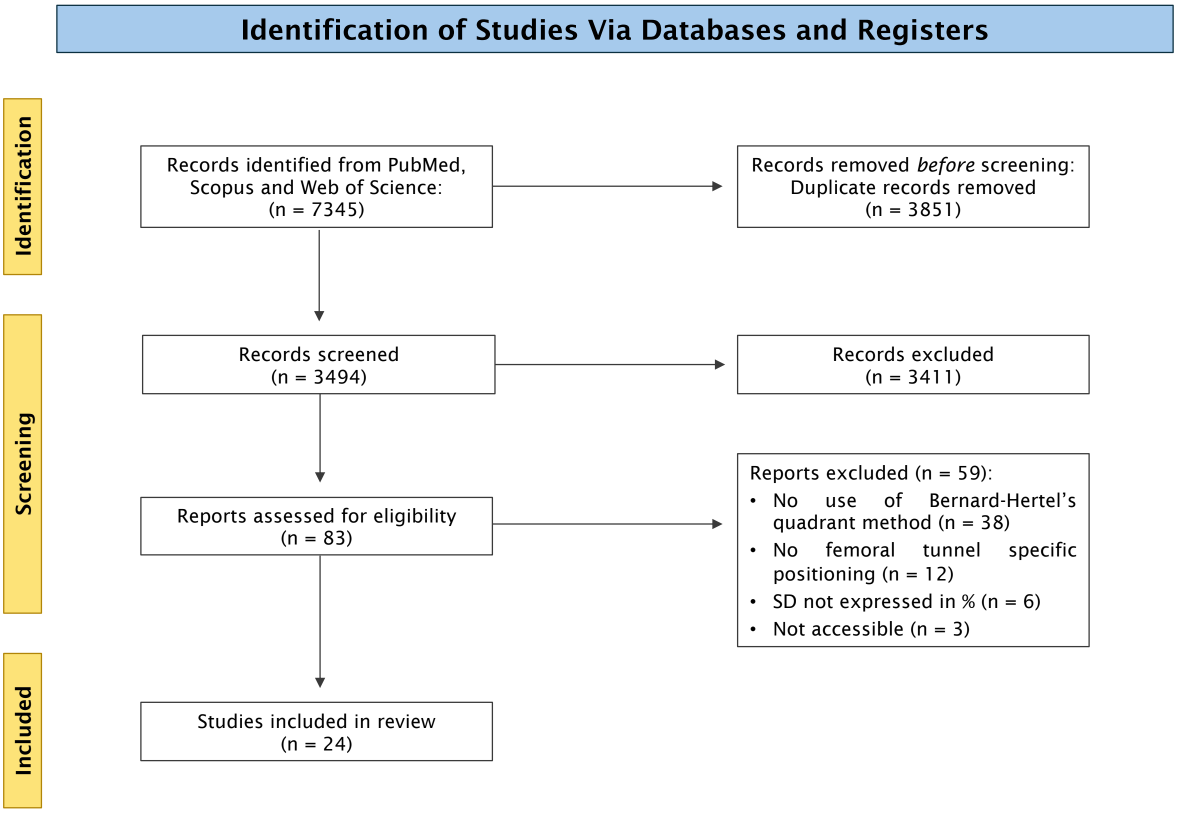

Figure 1 PRISMA flowchart of systematic search

Appendix II.

Table I Summary of the Newcastle-Ottawa Quality Assessment Scale scores of the Cohort Studies included in the systematic review

Newcastle-Ottawa Quality Assessment Scale for Cohort Studies										
Authors	**Year of Publication**	**Selection**				**Comparability**	**Outcome**			**Quality Assessment**
		Item 1	**Item 2**	**Item 3**	**Item 4**	**Item 1**	**Item 1**	**Item 2**	**Item 3**	
Silva, A. *et al.* (53)	2011	1	1	1	1	1	1	1	1	Good Quality
Jin, A. H. *et al.* (61)	2013	1	1	1	1	1	1	1	1	Good Quality
Eun-Kyoo, S. *et al.* (73)	2014	1	1	1	1	2	1	1	1	Good Quality
Pansard, E. *et al.* (24)	2015	1	1	1	1	1	1	1	1	Good Quality
Jae-Ang, S. *et al.* (62)	2015	1	1	1	1	0	1	1	1	Poor Quality
Osti, M. *et al.* (64)	2015	1	1	1	1	2	1	1	1	Good Quality
Inderhaug, E. *et al.* (35)	2015	1	1	1	1	1	1	1	1	Good Quality
Jin, A. H. *et al.* (60)	2016	1	1	1	1	1	1	1	1	Good Quality
Hrishikesh, P. *et al.* (29)	2017	1	1	1	1	2	1	1	1	Good Quality
Yasutaka, T. *et al.* (72)	2017	1	1	1	1	2	1	1	1	Good Quality
Dhong, W. L. *et al.* (67)	2018	1	1	1	1	2	1	1	1	Good Quality
Man, K. S. *et al.* (69)	2019	1	1	1	1	2	1	1	1	Good Quality
Seung-Suk, S. *et al.* (75)	2019	1	1	1	1	2	1	1	1	Good Quality
Weijie, L. *et al.* (36)	2022	1	1	1	1	2	1	1	1	Good Quality
Wayne, Y. X. F. *et al.* (71)	2022	1	1	1	1	2	1	1	1	Good Quality

Table II Summary of the Joanna Briggs Institute Critical Appraisal Checklist scores of the Case Series included in the systematic review

Joanna Briggs Institute Critical Appraisal Checklist for Case Series													
Authors	**Year of Publication**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**	**Quality Assessment**
Kwang, W. L. *et al.* (66)	2014		x	x			x	x	x	x	x	7	Medium-High Quality
Shafizadeh, S. *et al.* (74)	2014		x	x	x	x	x	x	x	x	x	9	High Quality
Weiler, A. *et al.* (43)	2017	x	x	x	x		x	x	x	x	x	9	High Quality
Takanori, I. *et al.* (70)	2017	x	x	x		x	x	x	x	x	x	9	High Quality
Seung, H. L. *et al.* (37)	2019	x	x	x			x		x	x	x	7	Medium-High Quality

Table III Summary of the Jadad Scale scores of the Randomized-Controlled Trials included in the systematic review

Jadad Scale for Quality Assessment of Randomized-Controlled Trials						
Authors	**Year of Publication**	**Randomization**	**Double-Blinding**	**Withdrawals and Dropouts**	**Total**	**Quality Assessment**
Dejian, L. *et al.* [65]	2020	2	0	1	3	Good Quality
Mhaskar, V. A. *et al.* [76]	2020	2	0	1	3	Good Quality

Table IV Summary of MINORS Checklist scores of the Non-Randomized Studies included in the systematic review

Methodological Index for Non-Randomized Studies (MINORS) Checklist															
Authors	**Year of Publication**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**	**Quality Assessment**
Young-Soo, S. *et al.* [63]	2013	2	1	2	2	1	2	2	2	0	1	1	2	18	Good Quality
Kosy, J. D. *et al.* [68]	2020	2	2	1	2	1	2	2	1	1	2	1	2	19	Good Quality

Appendix III.

Table V Summary of the characteristics of the included studies in the systematic review

Authors	Year of Publication	Level of Evidence	Surgical Protocol for Femoral Tunnel Placement			Population Size	Gender Distribution	Mean Population Age	Age Spread	Graft Type	Technology Used	Average of Interval of Time Between Intervention and Follow Up	Quality Assessment
			Viewing Strategy	Localization Strategy	Drilling Technique								
Silva, A. *et al.* (53)	2011	II	Anteromedial Portal	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	20 patients	-	28.10 ± 7.00 years	-	Hamstring tendon autograft	-	On the same day of ACLR	NOS: Good Quality
Young-Soo, S. *et al.* (63)	2013	III	Anteromedial Portal	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	73 patients	-	30.00 years	15 to 53 years	Hamstring tendon autograft	-	3 days	MINORS: Good Quality
					Outside-In	38 patients	-	33.00 years	16 to 53 years				
Jin, A. H. *et al.* (61)	2013	-	Anterolateral Portal	Estimation based on anatomic landmarks	Outside-In	35 patients	29 male and 6 female	29.77 ± 10.11 years	17 to 48 years	Hamstring tendon autograft	-	3 to 4 days	NOS: Good Quality
Eun-Kyoo, S. *et al.* (73)	2014	-	Anterolateral Portal	Estimation based on anatomic landmarks	Anteromedial Portal	30 patients	-	-	-	Hamstring tendon autograft	-	At 2 and 6 weeks	NOS: Good Quality
Shafizadeh, S. *et al.* (74)	2014	IV	Anterolateral Portal	Offset Guide	Accessory Anteromedial Portal	112 patients	71 male and 41 female	27.00 years	13 to 47 years	Hamstring tendon autograft	Intraoperative fluoroscopy	-	JBI Critical Appraisal Tool: High Quality
Kwang, W. L. *et al.* (66)	2014	-	Anterolateral Portal	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	32 patients	26 male and 6 female	31.90 years	16 to 54 years	Autogenous bone-patellar tendon-bone graft, Achilles tendon allograft and tibialis anterior tendon allograft	-	Within 2 weeks	JBI Critical Appraisal Tool: Medium-High Quality
Pansard, E. *et al.* (24)	2015	IV	Anteromedial Portal	Estimation based on anatomic landmarks	Outside-In	20 patients	16 male and 4 female	30.00 ± 8.80 years	15 to 48 years	-	-	3 weeks to 1 year	NOS: Good Quality
					Anteromedial Portal	20 patients	17 male and 3 female	29.70 ± 10.50 years					
Inderhaug, E. *et al.* (35)	2015	III	-	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	48 patients	-	31.50 ± 11.10 years	-	Hamstring tendon autograft	-	4 to 8 weeks	NOS: Good Quality
				Fluoroscopy		33 patients	-				Intraoperative fluoroscopy		
Jae-Ang, S. *et al.* (62)	2015	III	Anterolateral Portal	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	50 patients	-	-	-	-	-	2 to 6 weeks	NOS: Poor Quality
			Anteromedial Portal	Estimation based on anatomic landmarks	Outside-In	53 patients	-						
Osti, M. *et al.* (64)	2015	III	-	Fluoroscopy	Accessory Anteromedial Portal	32 patients	-	32.93 ± 10.32 years	15 to 59 years	Hamstring tendon autograft	Intraoperative fluoroscopy	2 days	NOS: Good Quality
					Outside-In	32 patients	-						
Jin, A. H. *et al.* (60)	2016	-	Anteromedial Portal	Estimation based on anatomic landmarks	Anteromedial Portal	36 patients	-	-	-	-	-	1 week	NOS: Good Quality
			Posterolateral Portal			35 patients	-						
			Transseptal Portal			35 patients	-						
Weiler, A. *et al.* (43)	2017	IV	Anterolateral Portal	Offset Guide	Anteromedial Portal	55 patients	30 male and 25 female	34.30 ± 10.40 years	15 to 52 years	Semitendinosus graft	-	-	JBI Critical Appraisal Tool: High Quality
Hrishikesh, P. *et al.* (29)	2017	-	Anterolateral Portal	Offset Guide	Anteromedial Portal	43 patients	41 male and 2 female	31.16 ± 7.73 years	-	Hamstring tendon autograft	-	6, 12 and 24 months	NOS: Good Quality
Takanori, I. *et al.* (70)	2017	III	Anterolateral Portal	Estimation based on anatomic landmarks	Anteromedial Portal	24 patients	5 male and 19 female	45.50 ± 16.70 years	-	Hamstring or quadriceps autograft	-	8 to 12 weeks	JBI Critical Appraisal Tool: High Quality
Yasutaka, T. *et al.* (72)	2017	-	Anteromedial Portal	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	30 patients	-	27.00 ± 9.00 years	-	Bone-patellar tendon-bone graft	-	2 weeks	NOS: Good Quality
Dhong, W. L. *et al.* (67)	2018	III	Anterolateral Portal	Estimation based on anatomic landmarks	Outside-In	50 patients	32 male and 18 female	27.20 ± 7.30 years	-	Hamstring tendon autograft	-	On the same day of ACLR and at 6, 9, 12, 24, and 36 months	NOS: Good Quality
Seung, H. L. *et al.* (37)	2019	-	Transseptal Portal	Estimation based on anatomic landmarks	Outside-In	109 patients	89 male and 20 female	30.50 ± 12.10 years	14 to 59 years	Hamstring tendon autograft and allograft	-	18 to 30 months	JBI Critical Appraisal Tool: Medium-High Quality
Man, K. S. *et al.* (69)	2019	III	-	Offset Guide	Accessory Anteromedial Portal	25 patients	18 male and 7 female	30.00 ± 7.60 years	-	Hamstring tendon autograft	-	-	NOS: Good Quality
Seung-Suk, S. *et al.* (75)	2019	IV	Anteromedial Portal	Fluoroscopy	Outside-In	40 patients	36 male and 4 female	29.50 ± 9.50 years	-	Hamstring tendon autograft or tibialis tendon allograft	Intraoperative fluoroscopy	7 days	NOS: Good Quality
				Estimation based on anatomic landmarks		40 patients	36 male and 4 female	26.50 ± 9.10 years			-		
Kosy, J. D. *et al.* (68)	2020	-	Anterolateral Portal	Estimation based on anatomic landmarks	-	30 patients	19 male and 11 female	29.00 years	19 to 62 years	Hamstring tendon autograft	-	At 3 and 6 months	MINORS: Good Quality
			Anteromedial Portal	Estimation based on anatomic landmarks		17 patients	12 male and 5 female	32.00 years	19 to 57 years				
Dejian, L. *et al.* (65)	2020	-	Anterolateral Portal	-	Anteromedial Portal	19 patients	11 male and 8 female	26.80 ± 4.50 years	-	Hamstring tendon autograft	-	12 to 15 months	Jadad Scale: Good Quality
				3D-Printed Navigation Template		22 patients	12 male and 10 female	25.30 ± 3.70 years			3D-printed positioning tool		
Mhaskar, V. A. *et al.* (76)	2020	-	Anterolateral Portal	Ruler	Anteromedial Portal	30 patients	18 male and 12 female	26.70 years	19 to 41 years	Hamstring tendon autograft	-	Within 1 week	Jadad Scale: Good Quality
			Anteromedial Portal			30 patients	23 male and 7 female	27.60 years	18 to 43 years				
Weijie, L. *et al.* (36)	2022	III	Anterolateral Portal	Estimation based on anatomic landmarks	Anteromedial Portal	57 patients	42 male and 15 female	27.00 years	20 to 50 years	Hamstring or quadriceps autograft	-	-	NOS: Good Quality
				Offset Guide		63 patients	44 male and 19 female	25.00 years	20 to 48 years				
Wayne, Y. X. F. *et al.* (71)	2022	-	-	Computer-Assisted Navigation	-	26 patients	-	-	18 to 45 years	Hamstring tendon autograft	Orthopilot navigation system	Within 12 months	NOS: Good Quality
				Estimation based on anatomic landmarks		34 patients	-				-		

Appendix IV.

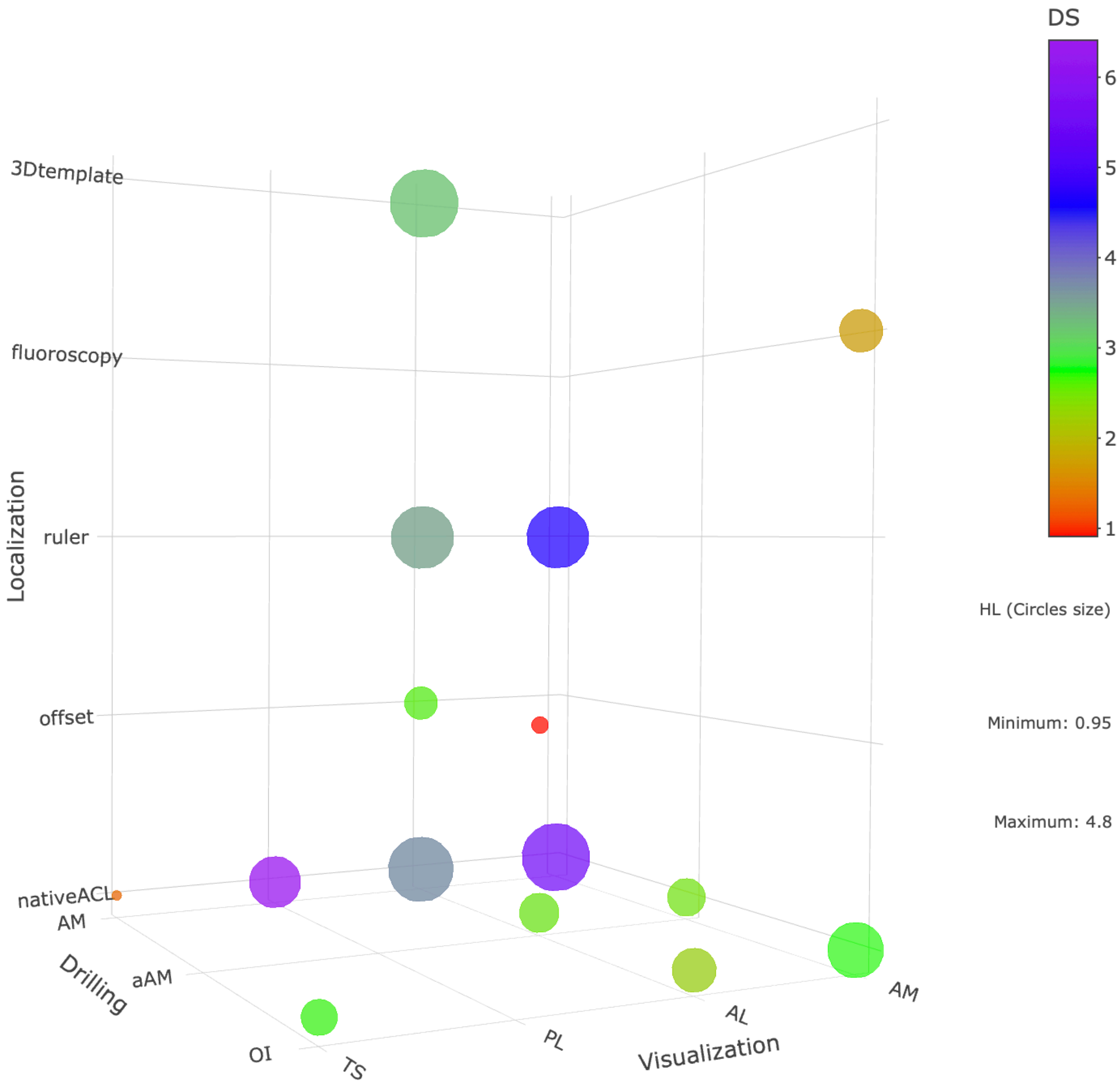

Figure 2 Three-dimensional graphic generated to illustrate the patients included in the systematic review who underwent the same surgical protocol, encompassing the same viewing (AM – anteromedial, AL – anterolateral, PL – posterolateral, TS – transseptal), localization and drilling (AM – anteromedial, aAM – accessory anteromedial, OI – outside-in) techniques, as well as its precision, which was quantified by the mean aCV for the Deep-Shallow (DS) (circles' colors) and for the High-Low (HL) (circles' size) coordinates of the femoral tunnel position. Available in https://rpubs.com/sspereira/1189356

Appendix V.

Table VI Summary of the results regarding the precision of the **viewing strategies** for femoral tunnel placement in ACLR employed in the studies included in the systematic review

Authors	Year of Publication	Population Size (n)	Viewing Strategy	Localization Strategy	Drilling Technique	Bernard-Hertel Quadrant Method		Adjusted CV (DS)	Adjusted CV (HL)	Mean aCV (DS)	Mean aCV (HL)
						Mean DS ± SD	Mean HL ± SD				
Group V1 - AM Portal vs. PL Portal vs. TS Portal vs. AL Portal											
Pansard, E. *et al.* [24]	2015	20	Anteromedial Portal	Estimation based on anatomic landmarks	Anteromedial Portal	30.00 ± 6.00	30.00 ± 8.00	4.47	5.96	5.72	4.76
Jin, A. H. *et al.* [60]	2016	36				19.28 ± 8.06	24.84 ± 5.30	6.97	3.56		
Jin, A. H. *et al.* [60]	2016	35	Posterolateral Portal			19.04 ± 7.22	22.11 ± 4.07	6.41	3.11	6.41	3.11
Jin, A. H. *et al.* [60]	2016	35	Transseptal Portal			28.44 ± 2.30	32.06 ± 1.80	1.37	0.95	1.37	0.95
Weijie, L. *et al.* [36]	2022	57	Anterolateral Portal			32.60 ± 7.70	28.40 ± 5.40	3.13	2.52	3.69	4.44
Takanori, I. *et al.* [70]	2017	24				24.00 ± 3.90	33.50 ± 7.70	3.32	4.69		
Eun-Kyoo, S. *et al.* [73]	2014	30				29.60 ± 7.50	34.40 ± 11.50	4.63	6.10		
Group V2 - AL Portal vs. AM Portal											
Jae-Ang, S. *et al.* [62]	2015	50	Anterolateral Portal	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	31.00 ± 7.00	42.00 ± 8.00	3.19	2.69	2.49	2.20
Kwang, W. L. *et al.* [66]	2014	32				26.70 ± 2.70	30.00 ± 2.90	1.79	1.71		
Silva, A. *et al.* [53]	2011	20	Anteromedial Portal			26.00 ± 4.30	34.70 ± 3.80	3.70	2.45	2.43	2.09
Young-Soo, S. *et al.* [63]	2013	73				37.00 ± 1.80	31.00 ± 1.10	0.57	0.42		
Yasutaka, T. *et al.* [72]	2017	30				29.70 ± 4.90	39.30 ± 7.30	3.01	3.39		
Group V3 - TS Portal vs. AL Portal vs. AM Portal											
Seung, H. L. *et al.* [37]	2019	109	Transseptal Portal	Estimation based on anatomic landmarks	Outside-In	24.10 ± 6.60	24.00 ± 5.00	2.62	2,00	2.62	2.00
Dhong, W. L. *et al.* [67]	2018	50	Anterolateral Portal			33.20 ± 2.50	40.90 ± 1.90	1.06	0.66	2.21	2.53
Jin, A. H. *et al.* [61]	2013	35				24.71 ± 4.90	27.08 ± 7.05	3.35	4.40		
Pansard, E. *et al.* [24]	2015	20	Anteromedial Portal			31.00 ± 5.00	34.80 ± 9.00	3.61	5.78	2.71	3.51
Jae-Ang, S. *et al.* [62]	2015	53				31.00 ± 7.00	40.00 ± 9.00	3.10	3.09		
Young-Soo, S. *et al.* [63]	2013	38				33.00 ± 1.90	28.00 ± 1.20	0.93	0.70		
Seung-Suk, S. *et al.* [75]	2019	40				30.00 ± 6.10	29.40 ± 8.30	3.21	4.46		
Group V4 - AL Portal vs. AM Portal											
Mhaskar, V. A. *et al.* [76]	2020	30	Anterolateral Portal	Ruler	Anteromedial Portal	35.20 ± 6.70	35.80 ± 8.20	3.48	4.18	3.48	4.18
Mhaskar, V. A. *et al.* [76]	2020	30	Anteromedial Portal			35.80 ± 9.40	38.10 ± 8.60	4.79	4.12	4.79	4.12

Appendix VI.

Table VII Summary of the results regarding the precision of the **localization strategies** for femoral tunnel placement in ACLR employed in the studies included in the systematic review

Authors	Year of Publication	Population Size (n)	Viewing Strategy	Localization Strategy	Drilling Technique	Bernard-Hertel Quadrant Method		Adjusted CV (DS)	Adjusted CV (HL)	Mean aCV (DS)	Mean aCV (HL)
						Mean DS ± SD	Mean HL ± SD				
Group L1 - Estimation vs. Offset Guide vs. 3D-Printed Template vs. Ruler											
Takanori, I. *et al.* [70]	2017	24	Anterolateral Portal	Estimation based on anatomic landmarks	Anteromedial Portal	24.00 ± 3.90	33.50 ± 7.70	3.32	4.69	3.69	4.44
Eun-Kyoo, S. *et al.* [73]	2014	30				29.60 ± 7.50	34.40 ± 11.50	4.63	6.10		
Weijie, L. *et al.* [36]	2022	57				32.60 ± 7.70	28.40 ± 5.40	3.13	2.52		
Weijie, L. *et al.* [36]	2022	63		Offset Guide		38.80 ± 7.70	31.80 ± 5.30	2.50	2.10	2.56	1.79
Weiler, A. *et al.* [43]	2017	55				23.90 ± 5.10	31.30 ± 5.70	2.88	2.46		
Hrishikesh, P. *et al.* [29]	2017	43				31.30 ± 4.72	35.26 ± 1.84	2.30	0.80		
Dejian, L. *et al.* [65]	2020	22		3D-Printed Navigation Template		27.60 ± 4.20	36.00 ± 8.10	3.24	4.80	3.24	4.80
Mhaskar, V. A. *et al.* [76]	2020	30		Ruler		35.20 ± 6.70	35.80 ± 8.20	3.48	4.18	3.48	4.18
Group L2 - Estimation vs. Fluoroscopy											
Pansard, E. *et al.* [24]	2015	20	Anteromedial Portal	Estimation based on anatomic landmarks	Outside-In	31.00 ± 5.00	34.80 ± 9.00	3.61	5.78	2.71	3.51
Jae-Ang, S. *et al.* [62]	2015	53				31.00 ± 7.00	40.00 ± 9.00	3.10	3.09		
Young-Soo, S. *et al.* [63]	2013	38				33.00 ± 1.90	28.00 ± 1.20	0.93	0.70		
Seung-Suk, S. *et al.* [75]	2019	40				30.00 ± 6.10	29.40 ± 8.30	3.21	4.46		
Seung-Suk, S. *et al.* [75]	2019	40		Fluoroscopy		29.00 ± 3.20	30.80 ± 4.80	1.74	2.46	1.74	2.46
Group L3 - Estimation vs. Offset Guide											
Jae-Ang, S. *et al.* [62]	2015	50	Anterolateral Portal	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	31.00 ± 7.00	42.00 ± 8.00	3.19	2.69	2.49	2.20
Kwang, W. L. *et al.* [66]	2014	32				26.70 ± 2.70	30.00 ± 2.90	1.79	1.71		
Shafizadeh, S. *et al.* [74]	2014	112		Offset Guide		28.10 ± 2.70	28.10 ± 3.30	0.91	1.11	0.91	1.11
Group L4 - Ruler vs. Estimation											
Mhaskar, V. A. *et al.* [76]	2020	30	Anteromedial Portal	Ruler	Anteromedial Portal	35.80 ± 9.40	38.10 ± 8.60	4.79	4.12	4.79	4.12
Jin, A. H. *et al.* [60]	2016	36		Estimation based on anatomic landmarks		19.28 ± 8.06	24.84 ± 5.30	6.97	3.56	5.72	4.76
Pansard, E. *et al.* [24]	2015	20				30.00 ± 6.00	30.00 ± 8.00	4.47	5.96		

Appendix VII.

Table VIII Summary of the results regarding the precision of the **drilling techniques** for femoral tunnel placement in ACLR employed in the studies included in the systematic review

Authors	Year of Publication	Population Size (n)	Viewing Strategy	Localization Strategy	Drilling Technique	Bernard-Hertel Quadrant Method		Adjusted CV (DS)	Adjusted CV (HL)	Mean aCV (DS)	Mean aCV (HL)
						Mean DS ± SD	Mean HL ± SD				
Group D1 - AM Portal vs. OI vs. aAM Portal											
Takanori, I. *et al.* [70]	2017	24	Anterolateral Portal	Estimation based on anatomic landmarks	Anteromedial Portal	24.00 ± 3.90	33.50 ± 7.70	3.32	4.69	3.69	4.44
Eun-Kyoo, S. *et al.* [73]	2014	30				29.60 ± 7.50	34.40 ± 11.50	4.63	6.10		
Weijie, L. *et al.* [36]	2022	57				32.60 ± 7.70	28.40 ± 5.40	3.13	2.52		
Dhong, W. L. *et al.* [67]	2018	50			Outside-In	33.20 ± 2.50	40.90 ± 1.90	1.06	0.66	2.21	2.53
Jin, A. H. *et al.* [61]	2013	35				24.71 ± 4.90	27.08 ± 7.05	3.35	4.40		
Jae-Ang, S. *et al.* [62]	2015	50			Accessory Anteromedial Portal	31.00 ± 7.00	42.00 ± 8.00	3.19	2.69	2.49	2.20
Kwang, W. L. *et al.* [66]	2014	32				26.70 ± 2.70	30.00 ± 2.90	1.79	1.71		
Group D2 - OI vs. aAM Portal vs. AM Portal											
Jae-Ang, S. *et al.* [62]	2015	53	Anteromedial Portal	Estimation based on anatomic landmarks	Outside-In	31.00 ± 7.00	40.00 ± 9.00	3.10	3.09	2.71	3.51
Pansard, E. *et al.* [24]	2015	20				31.00 ± 5.00	34.80 ± 9.00	3.61	5.78		
Seung-Suk, S. *et al.* [75]	2019	40				30.00 ± 6.10	29.40 ± 8.30	3.21	4.46		
Young-Soo, S. *et al.* [63]	2013	38				33.00 ± 1.90	28.00 ± 1.20	0.93	0.70		
Young-Soo, S. *et al.* [63]	2013	73			Accessory Anteromedial Portal	37.00 ± 1.80	31.00 ± 1.10	0.57	0.42	2.43	2.09
Silva, A. *et al.* [53]	2011	20				26.00 ± 4.30	34.70 ± 3.80	3.70	2.45		
Yasutaka, T. *et al.* [72]	2017	30				29.70 ± 4.90	39.30 ± 7.30	3.01	3.39		
Jin, A. H. *et al.* [60]	2016	36			Anteromedial Portal	19.28 ± 8.06	24.84 ± 5.30	6.97	3.56	5.72	4.76
Pansard, E. *et al.* [24]	2015	20				30.00 ± 6.00	30.00 ± 8.00	4.47	5.96		
Group D3 - AM Portal vs. aAM Portal											
Weijie, L. *et al.* [36]	2022	63	Anterolateral Portal	Offset Guide	Anteromedial Portal	38.80 ± 7.70	31.80 ± 5.30	2.50	2.10	2.56	1.79
Weiler, A. *et al.* [43]	2017	55				23.90 ± 5.10	31.30 ± 5.70	2.88	2.46		
Hrishikesh, P. *et al.* [29]	2017	43				31.30 ± 4.72	35.26 ± 1.84	2.30	0.80		
Shafizadeh, S. *et al.* [74]	2014	112			Accessory Anteromedial Portal	28.10 ± 2.70	28.10 ± 3.30	0.91	1.11	0.91	1.11
Group D4 - AM Portal vs. OI											
Jin, A. H. *et al.* [60]	2016	35	Transseptal Portal	Estimation based on anatomic landmarks	Anteromedial Portal	28.44 ± 2.30	32.06 ± 1.80	1.37	0.95	1.37	0.95
Seung, H. L. *et al.* [37]	2019	109			Outside-In	24.10 ± 6.60	24.00 ± 5.00	2.62	2.00	2.62	2.00

Appendix VIII.

Table IX Summary of **other findings** regarding the precision of femoral tunnel placement in ACLR obtained in some of the studies included in the systematic review

Authors	Year of Publication	Population Size (n)	Viewing Strategy	Localization Strategy	Drilling Technique	Bernard-Hertel Quadrant Method		Adjusted CV (DS)	Adjusted CV (HL)
						Mean DS ± SD	Mean HL ± SD		
Inderhaug, E. *et al.* [35]	2015	48	-	Estimation based on anatomic landmarks	Accessory Anteromedial Portal	27.50 ± 2.60	28.50 ± 5.12	1.36	2.59
Inderhaug, E. *et al.* [35]	2015	33	-	Fluoroscopy	Accessory Anteromedial Portal	27.10 ± 2.79	38.30 ± 5.04	1.79	2.29
Osti, M. *et al.* [64]	2015	32	-	Fluoroscopy	Accessory Anteromedial Portal	27.37 ± 8.28	27.76 ± 10.46	5.35	6.66
Osti, M. *et al.* [64]	2015	32	-	Fluoroscopy	Outside-In	28.20 ± 14.10	27.29 ± 9.50	8.84	6.15
Man, K. S. *et al.* [69]	2019	25	-	Offset Guide	Accessory Anteromedial Portal	30.50 ± 4.60	32.60 ± 4.30	3.02	2.64
Dejian, L. *et al.* [65]	2020	19	Anterolateral Portal	-	Anteromedial Portal	30.40 ± 3.70	40.70 ± 6.40	2.79	3.61
Kosy, J. D. *et al.* [68]	2020	30	Anterolateral Portal	Estimation based on anatomic landmarks	-	33.30 ± 6.00	27.20 ± 5.20	3.29	3.49
Kosy, J. D. *et al.* [68]	2020	17	Anteromedial Portal	Estimation based on anatomic landmarks	-	31.70 ± 6.90	29.00 ± 6.20	5.28	5.19
Wayne, Y. X. F. *et al.* [71]	2022	26	-	Computer-Assisted Navigation	-	44.15 ± 6.74	38.90 ± 6.41	2.99	3.23
Wayne, Y. X. F. *et al.* [71]	2022	34	-	Estimation based on anatomic landmarks	-	43.20 ± 9.35	31.94 ± 5.00	3.71	2.68

Appendix IX.

Table X Summary of the **clinical scores** described in the studies included in the systematic review

<table>
<tr><th rowspan="2"></th><th rowspan="2">Pre-operation</th><th colspan="4">Post-operation</th></tr>
<tr><th>6 months</th><th>12 months</th><th>24 months</th><th>36 months</th></tr>
<tr><td colspan="6">Lysholm Score</td></tr>
<tr><td>Hrishikesh, P. et al. (2017) [29]</td><td>39.65 (± 7.24)</td><td>87.37 (± 2.64)</td><td>91.88 (± 2.57)</td><td>96.74 (± 1.14)</td><td>-</td></tr>
<tr><td>Yasutaka, T. et al. (2017) [72]</td><td>63.00 (± 14.00)</td><td colspan="4">95.00 (± 7.00)</td></tr>
<tr><td>Dhong, W. L. et al. (2018) [67]</td><td>71.20 (± 14.00)</td><td colspan="4">92.30 (± 12.90)</td></tr>
<tr><td>Seung, H. L. et al. (2019) [37]</td><td>51.20 (± 19.00)</td><td colspan="4">88.10 (± 10.60)</td></tr>
<tr><td>Dejian, L. et al. (2020) [65]</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Conventional Group</td><td>46.89 (± 4.08)</td><td>80.21 (± 5.37)</td><td>81.26 (± 5.31)</td><td>-</td><td>-</td></tr>
<tr><td>3D Group</td><td>46.68 (± 4.25)</td><td>81.16 (± 4.23)</td><td>82.00 (± 4.39)</td><td>-</td><td>-</td></tr>
<tr><td>Wayne, Y. X. F. et al. (2022) [71]</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Conventional Group</td><td>60.67 (± 18.14)</td><td>-</td><td>93.57 (± 6.79)</td><td>-</td><td>-</td></tr>
<tr><td>Navigated Group</td><td>65.67 (± 11.96)</td><td>-</td><td>94.70 (± 7.10)</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">IKDC Subjective Score</td></tr>
<tr><td>Hrishikesh, P. et al. (2017) (29)</td><td>41.65 (± 7.23)</td><td>80.37 (± 2.65)</td><td>90.88 (± 2.57)</td><td>91.67 (± 0.78)</td><td>-</td></tr>
<tr><td>Dhong, W. L. et al. (2018) (67)</td><td>66.70 (± 11.40)</td><td colspan="4">88.80 (± 12.10)</td></tr>
<tr><td>Seung, H. L. et al. (2019) (37)</td><td>49.10 (± 15.30)</td><td colspan="4">89.40 (± 10.10)</td></tr>
<tr><td>Dejian, L. et al. (2020) (65)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Conventional Group</td><td>45.58 (± 5.75)</td><td>82.94 (± 3.48)</td><td>85.68 (± 5.58)</td><td>-</td><td>-</td></tr>
<tr><td>3D Group</td><td>45.86 (± 5.15)</td><td>83.91 (± 3.15)</td><td>87.23 (± 5.60)</td><td>-</td><td>-</td></tr>
</table>

References

1. Spindler KP, Wright RW. Clinical practice. Anterior cruciate ligament tear. N Engl J Med. 2008;359(20):2135-42. doi: 10.1056/NEJMcp0804745. PubMed PMID: 19005197; PubMed Central PMCID: PMC3782299.

2. Bahr R, Holme I. Risk factors for sports injuries--a methodological approach. Br J Sports Med. 2003;37(5):384-92. doi: 10.1136/bjsm.37.5.384. PubMed PMID: 14514527; PubMed Central PMCID: PMC1751357.

3. Monk AP, Davies LJ, Hopewell S, Harris K, Beard DJ, Price AJ. Surgical versus conservative interventions for treating anterior cruciate ligament injuries. Cochrane Database of Systematic Reviews. 2016(4). doi: 10.1002/14651858.CD011166.pub2. PubMed PMID: CD011166.

4. Hernández LM, Micheo WF, Amy E. Rehabilitation update for the anterior cruciate ligament injured patient: current concepts. Bol Asoc Med P R. 2006;98(1):62-72. PubMed PMID: 19610551.

5. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. Am J Sports Med. 2006;34(2):299-311. doi: 10.1177/0363546505284183. PubMed PMID: 16423913.

6. Bowers AL, Spindler KP, McCarty EC, Arrigain S. Height, weight, and BMI predict intra-articular injuries observed during ACL reconstruction: evaluation of 456 cases from a prospective ACL database. Clin J Sport Med. 2005;15(1):9-13. doi: 10.1097/00042752-200501000-00003. PubMed PMID: 15654185.

7. Thorstensson CA, Lohmander LS, Frobell RB, Roos EM, Gooberman-Hill R. Choosing surgery: patients' preferences within a trial of treatments for anterior cruciate ligament injury. A qualitative study. BMC Musculoskelet Disord. 2009;10:100. Epub 20090810. doi: 10.1186/1471-2474-10-100. PubMed PMID: 19664258; PubMed Central PMCID: PMC2731720.

8. Øiestad BE, Engebretsen L, Storheim K, Risberg MA. Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. Am J Sports Med. 2009;37(7):1434-43. doi: 10.1177/0363546509338827. PubMed PMID: 19567666.

9. Rout R, McDonnell S, Hulley P, Jayadev C, Khan T, Carr A, et al. The pattern of cartilage damage in antero-medial osteoarthritis of the knee and its relationship to the anterior cruciate ligament. J Orthop Res. 2013;31(6):908-13. Epub 20130219. doi: 10.1002/jor.22253. PubMed PMID: 23423802.

10. Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long-term incidence of gonarthrosis. Sports Med. 1999;27(3):143-56. doi: 10.2165/00007256-199927030-00001. PubMed PMID: 10222538.

11. Roos H, Adalberth T, Dahlberg L, Lohmander LS. Osteoarthritis of the knee after injury to the anterior cruciate ligament or meniscus: the influence of time and age. Osteoarthritis Cartilage. 1995;3(4):261-7. doi: 10.1016/s1063-4584(05)80017-2. PubMed PMID: 8689461.

12. Crawford R, Walley G, Bridgman S, Maffulli N. Magnetic resonance imaging versus arthroscopy in the diagnosis of knee pathology, concentrating on meniscal lesions and ACL tears: a systematic review. Br Med Bull. 2007;84:5-23. Epub 20070903. doi: 10.1093/bmb/ldm022. PubMed PMID: 17785279.

13. Hefti F, Müller W, Jakob RP, Stäubli HU. Evaluation of knee ligament injuries with the IKDC form. Knee Surg Sports Traumatol Arthrosc. 1993;1(3-4):226-34. doi: 10.1007/bf01560215. PubMed PMID: 8536037.

14. Aglietti P, Giron F, Buzzi R, Biddau F, Sasso F. Anterior cruciate ligament reconstruction: bone-patellar tendon-bone compared with double semitendinosus and gracilis tendon grafts. A prospective, randomized clinical trial. J Bone Joint Surg Am. 2004;86(10):2143-55. PubMed PMID: 15466722.

15. Kannus P, Järvinen M. Conservatively treated tears of the anterior cruciate ligament. Long-term results. J Bone Joint Surg Am. 1987;69(7):1007-12. PubMed PMID: 3654691.

16. Mizuta H, Kubota K, Shiraishi M, Otsuka Y, Nagamoto N, Takagi K. The conservative treatment of complete tears of the anterior cruciate ligament in skeletally immature patients. J Bone Joint Surg Br. 1995;77(6):890-4. PubMed PMID: 7593101.

17. Casteleyn PP, Handelberg F. Non-operative management of anterior cruciate ligament injuries in the general population. J Bone Joint Surg Br. 1996;78(3):446-51. PubMed PMID: 8636184.

18. Kessler MA, Behrend H, Henz S, Stutz G, Rukavina A, Kuster MS. Function, osteoarthritis and activity after ACL-rupture: 11 years follow-up results of conservative versus reconstructive treatment. Knee Surg Sports Traumatol

Arthrosc. 2008;16(5):442-8. doi: 10.1007/s00167-008-0498-x. PubMed PMID: 18292988.

19. Collins JE, Katz JN, Donnell-Fink LA, Martin SD, Losina E. Cumulative incidence of ACL reconstruction after ACL injury in adults: role of age, sex, and race. Am J Sports Med. 2013;41(3):544-9. Epub 20130109. doi: 10.1177/0363546512472042. PubMed PMID: 23302260; PubMed Central PMCID: PMC3896975.

20. Mohtadi NG, Chan DS, Dainty KN, Whelan DB. Patellar tendon versus hamstring tendon autograft for anterior cruciate ligament rupture in adults. Cochrane Database Syst Rev. 2011;2011(9):Cd005960. Epub 20110907. doi: 10.1002/14651858.CD005960.pub2. PubMed PMID: 21901700; PubMed Central PMCID: PMC6465162.

21. Tiamklang T, Sumanont S, Foocharoen T, Laopaiboon M. Double-bundle versus single-bundle reconstruction for anterior cruciate ligament rupture in adults. Cochrane Database of Systematic Reviews. 2012(11). doi: 10.1002/14651858.CD008413.pub2. PubMed PMID: CD008413.

22. Yasuda K, van Eck CF, Hoshino Y, Fu FH, Tashman S. Anatomic single- and double-bundle anterior cruciate ligament reconstruction, part 1: Basic science. Am J Sports Med. 2011;39(8):1789-99. Epub 20110519. doi: 10.1177/0363546511402659. PubMed PMID: 21596902.

23. Gavriilidis I, Motsis EK, Pakos EE, Georgoulis AD, Mitsionis G, Xenakis TA. Transtibial versus anteromedial portal of the femoral tunnel in ACL reconstruction: a cadaveric study. Knee. 2008;15(5):364-7. Epub 20080625. doi: 10.1016/j.knee.2008.05.004. PubMed PMID: 18583137.

24. Pansard E, Klouche S, Vardi G, Greeff E, Hardy P, Ferguson M. How accurate are anatomic landmarks for femoral tunnel positioning in anterior cruciate ligament reconstruction? An in vivo imaging analysis comparing both anteromedial portal and outside-in techniques. Arthroscopy. 2015;31(5):882-9. Epub 20150127. doi: 10.1016/j.arthro.2014.11.038. PubMed PMID: 25636986.

25. Woo SL, Kanamori A, Zeminski J, Yagi M, Papageorgiou C, Fu FH. The effectiveness of reconstruction of the anterior cruciate ligament with hamstrings and patellar tendon . A cadaveric study comparing anterior tibial and rotational loads. J Bone Joint Surg Am. 2002;84(6):907-14. doi: 10.2106/00004623-200206000-00003. PubMed PMID: 12063323.

26. Mott HW. Semitendinosus anatomic reconstruction for cruciate ligament insufficiency. Clin Orthop Relat Res. 1983(172):90-2. PubMed PMID: 6822010.

27. Robin BN, Jani SS, Marvil SC, Reid JB, Schillhammer CK, Lubowitz JH. Advantages and Disadvantages of Transtibial, Anteromedial Portal, and Outside-In Femoral Tunnel Drilling in Single-Bundle Anterior Cruciate Ligament Reconstruction: A Systematic Review. Arthroscopy. 2015;31(7):1412-7. Epub 20150305. doi: 10.1016/j.arthro.2015.01.018. PubMed PMID: 25749530.

28. Duquin TR, Wind WM, Fineberg MS, Smolinski RJ, Buyea CM. Current trends in anterior cruciate ligament reconstruction. J Knee Surg. 2009;22(1):7-12. doi: 10.1055/s-0030-1247719. PubMed PMID: 19216345.

29. Pande H, Prabahkara A, Singh CM, Pande A, Mathew V, Bm N, et al. A 3DCT scan based assessment of femoral tunnel placement in arthroscopic ACL reconstruction by modified transtibial and anteromedial portal technique and its relation with the functional outcome: A retrospective comparative study. Journal of Arthroscopy and Joint Surgery. 2017;4(2):72-8. doi: https://doi.org/10.1016/j.jajs.2017.08.002.

30. Byrne KJ, Hughes JD, Gibbs C, Vaswani R, Meredith SJ, Popchak A, et al. Non-anatomic tunnel position increases the risk of revision anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2022;30(4):1388-95. Epub 20210513. doi: 10.1007/s00167-021-06607-7. PubMed PMID: 33983487.

31. Schützenberger S, Grabner S, Schallmayer D, Kontic D, Keller F, Fialka C. The risk of graft impingement still exists in modern ACL surgery and correlates with degenerative MRI signal changes. Knee Surg Sports Traumatol Arthrosc. 2021;29(9):2880-8. Epub 20201003. doi: 10.1007/s00167-020-06300-1. PubMed PMID: 33009942.

32. Ziegler CG, Pietrini SD, Westerhaus BD, Anderson CJ, Wijdicks CA, Johansen S, et al. Arthroscopically pertinent landmarks for tunnel positioning in single-bundle and double-bundle anterior cruciate ligament reconstructions. Am J Sports Med. 2011;39(4):743-52. Epub 20101220. doi: 10.1177/0363546510387511. PubMed PMID: 21173191.

33. Amis A, Bull A, Lie D. Biomechanics of Rotational Instability and Anatomic Anterior Cruciate Ligament Reconstruction. Operative Techniques in Orthopaedics. 2005;15:29-35. doi: 10.1053/j.oto.2004.10.009.

34. Morgan JA, Dahm D, Levy B, Stuart MJ. Femoral tunnel malposition in ACL revision reconstruction. J Knee Surg. 2012;25(5):361-8. Epub 20120503. doi: 10.1055/s-0031-1299662. PubMed PMID: 23150344; PubMed Central PMCID: PMC3652545.

35. 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(4):1211-8. Epub 20151118. doi: 10.1007/s00167-015-3858-3. PubMed PMID: 26581365.

36. Liu W, Wu Y, Wang X, Kuang S, Su C, Xiong Y, et al. ACL stump and ACL femoral landmarks are equally reliable in ACL reconstruction for assisting ACL femoral tunnel positioning. Knee Surg Sports Traumatol Arthrosc. 2023;31(1):219-28. Epub 20220810. doi: 10.1007/s00167-022-07084-2. PubMed PMID: 35947159.

37. Lee SH, Lee ES, Ko TW, Lee YS. Femoral tunnel placement in single-bundle, remnant-preserving anterior cruciate ligament reconstruction using a posterior trans-septal portal. Knee. 2019;26(3):628-35. Epub 20190320. doi: 10.1016/j.knee.2019.02.014. PubMed PMID: 30902512.

38. Bernard M, Hertel P, Hornung H, Cierpinski T. Femoral insertion of the ACL. Radiographic quadrant method. Am J Knee Surg. 1997;10(1):14-21; discussion -2. PubMed PMID: 9051173.

39. Colombet P, Robinson J, Christel P, Franceschi JP, Djian P, Bellier G, Sbihi A. Morphology of anterior cruciate ligament attachments for anatomic reconstruction: a cadaveric dissection and radiographic study. Arthroscopy. 2006;22(9):984-92. doi: 10.1016/j.arthro.2006.04.102. PubMed PMID: 16952729.

40. Luites JWH, Verdonschot N. Radiographic positions of femoral ACL, AM and PL centres: accuracy of guidelines based on the lateral quadrant method. Knee Surg Sports Traumatol Arthrosc. 2017;25(8):2321-9. Epub 20150704. doi: 10.1007/s00167-015-3681-x. PubMed PMID: 26142164.

41. Sullivan JP, Matava MJ, Flanigan DC, Gao Y, Britton CL, Amendola A, Wolf BR. Reliability of tunnel measurements and the quadrant method using fluoroscopic radiographs after anterior cruciate ligament reconstruction. Am J Sports Med. 2012;40(10):2236-41. Epub 20120907. doi: 10.1177/0363546512458086. PubMed PMID: 22962289.

42. Tsukada H, Ishibashi Y, Tsuda E, Fukuda A, Toh S. Anatomical analysis of the anterior cruciate ligament femoral and tibial footprints. J Orthop Sci. 2008;13(2):122-9. Epub 20080408. doi: 10.1007/s00776-007-1203-5. PubMed PMID: 18392916.

43. Weiler A, Wagner M, Kittl C. The posterior horn of the lateral meniscus is a reliable novel landmark for femoral tunnel placement in ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2018;26(5):1384-91. Epub 20171023. doi: 10.1007/s00167-017-4759-4. PubMed PMID: 29063153.

44. Robinson J, Inderhaug E, Harlem T, Spalding T, Brown CH, Jr. Anterior Cruciate Ligament Femoral Tunnel Placement: An Analysis of the Intended Versus Achieved Position for 221 International High-Volume ACL Surgeons. Am J Sports Med. 2020;48(5):1088-99. Epub 20200317. doi: 10.1177/0363546520906158. PubMed PMID: 32182091.

45. Donato H, Donato M. [Stages for Undertaking a Systematic Review]. Acta Med Port. 2019;32(3):227-35. Epub 20190329. doi: 10.20344/amp.11923. PubMed PMID: 30946795.

46. Cain EL, Jr., Clancy WG, Jr. Anatomic endoscopic anterior cruciate ligament reconstruction with patella tendon autograft. Orthop Clin North Am. 2002;33(4):717-25. doi: 10.1016/s0030-5898(02)00026-3. PubMed PMID: 12528913.

47. Defrate LE, Papannagari R, Gill TJ, Moses JM, Pathare NP, Li G. The 6 degrees of freedom kinematics of the knee after anterior cruciate ligament deficiency: an in vivo imaging analysis. Am J Sports Med. 2006;34(8):1240-6. Epub 20060424. doi: 10.1177/0363546506287299. PubMed PMID: 16636348.

48. Georgoulis AD, Papadonikolakis A, Papageorgiou CD, Mitsou A, Stergiou N. Three-dimensional tibiofemoral kinematics of the anterior cruciate ligament-deficient and reconstructed knee during walking. Am J Sports Med. 2003;31(1):75-9. doi: 10.1177/03635465030310012401. PubMed PMID: 12531761.

49. Scopp JM, Jasper LE, Belkoff SM, Moorman CT, 3rd. The effect of oblique femoral tunnel placement on rotational constraint of the knee reconstructed using patellar tendon autografts. Arthroscopy. 2004;20(3):294-9. doi: 10.1016/j.arthro.2004.01.001. PubMed PMID: 15007318.

50. Bach BR, Jr., Tradonsky S, Bojchuk J, Levy ME, Bush-Joseph CA, Khan NH. Arthroscopically assisted anterior cruciate ligament reconstruction using patellar tendon autograft. Five- to nine-year follow-up evaluation. Am J Sports Med. 1998;26(1):20-9. doi: 10.1177/03635465980260012101. PubMed PMID: 9474397.

51. Kocher MS, Steadman JR, Briggs K, Zurakowski D, Sterett WI, Hawkins RJ. Determinants of patient satisfaction with outcome after anterior cruciate ligament reconstruction. J Bone Joint Surg Am. 2002;84(9):1560-72. doi: 10.2106/00004623-200209000-00008. PubMed PMID: 12208912.

52. Marchant BG, Noyes FR, Barber-Westin SD, Fleckenstein C. Prevalence of nonanatomical graft placement in a series of failed anterior cruciate ligament reconstructions. Am J Sports Med. 2010;38(10):1987-96. Epub 20100811. doi: 10.1177/0363546510372797. PubMed PMID: 20702859.

53. Silva A, Sampaio R, Pinto E. ACL reconstruction: comparison between transtibial and anteromedial portal techniques. Knee Surg Sports Traumatol Arthrosc. 2012;20(5):896-903. Epub 20110818. doi: 10.1007/s00167-011-1645-3. PubMed PMID: 21850428.

54. Ouzzani M, Hammady, H., Fedorowicz, Z., Elmagarmid, A. . Rayyan - a web and mobile app for systematic reviews. . 2016. doi: 10.1186/s13643-016-0384-4.

55. Wells GA, Wells G, Shea B, Shea B, O'Connell D, Peterson J, et al., editors. The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Nonrandomised Studies in Meta-Analyses2014.

56. Munn Z, Barker TH, Moola S, Tufanaru C, Stern C, McArthur A, et al. Methodological quality of case series studies: an introduction to the JBI critical appraisal tool. JBI Evidence Synthesis. 2020;18(10):2127-33. doi: 10.11124/jbisrir-d-19-00099. PubMed PMID: 02174543-202010000-00005.

57. Augestad KM, Berntsen G, Lassen K, Bellika JG, Wootton R, Lindsetmo RO. Standards for reporting randomized controlled trials in medical informatics: a systematic review of CONSORT adherence in RCTs on clinical decision support. J Am Med Inform Assoc. 2012;19(1):13-21. Epub 20110729. doi: 10.1136/amiajnl-2011-000411. PubMed PMID: 21803926; PubMed Central PMCID: PMC3240766.

58. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (minors): development and validation of a new instrument. ANZ J Surg. 2003;73(9):712-6. doi: 10.1046/j.1445-2197.2003.02748.x. PubMed PMID: 12956787.

59. Wan X, Wang W, Liu J, Tong T. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Medical Research Methodology. 2014;14(1):135. doi: 10.1186/1471-2288-14-135.

60. Ahn JH, Lee YS, Ko TS, Shin JY. Accuracy and Reproducibility of the Femoral Tunnel With Different Viewing Techniques in the ACL Reconstruction. Orthopedics. 2016;39(6):e1085-e91. Epub 20160727. doi: 10.3928/01477447-20160719-08. PubMed PMID: 27459141.

61. Ahn JH, Jeong HJ, Ko CS, Ko TS, Kim JH. Three-dimensional reconstruction computed tomography evaluation of tunnel location during single-bundle anterior cruciate ligament reconstruction: a comparison of transtibial and 2-incision tibial tunnel-independent techniques. Clin Orthop Surg. 2013;5(1):26-35. Epub 20130220. doi: 10.4055/cios.2013.5.1.26. PubMed PMID: 23467279; PubMed Central PMCID: PMC3582868.

62. Sim JA, Kim JM, Lee S, Bae JY, Seon JK. Comparison of tunnel variability between trans-portal and outside-in techniques in ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2017;25(4):1227-33. Epub 20151228. doi: 10.1007/s00167-015-3950-8. PubMed PMID: 26713326.

63. Shin YS, Ro KH, Lee JH, Lee DH. Location of the femoral tunnel aperture in single-bundle anterior cruciate ligament reconstruction: comparison of the transtibial, anteromedial portal, and outside-in techniques. Am J Sports Med. 2013;41(11):2533-9. Epub 20130827. doi: 10.1177/0363546513500764. PubMed PMID: 23982399.

64. Osti M, Krawinkel A, Ostermann M, Hoffelner T, Benedetto KP. Femoral and tibial graft tunnel parameters after transtibial, anteromedial portal, and outside-in single-bundle anterior cruciate ligament reconstruction. Am J Sports Med. 2015;43(9):2250-8. Epub 20150702. doi: 10.1177/0363546515590221. PubMed PMID: 26138734.

65. Liu D, Li Y, Li T, Yu Y, Cai G, Yang G, Wang G. The use of a 3D-printed individualized navigation template to assist in the anatomical reconstruction surgery of the anterior cruciate ligament. Ann Transl Med. 2020;8(24):1656. doi: 10.21037/atm-20-7515. PubMed PMID: 33490168; PubMed Central PMCID: PMC7812217.

66. Lee KW, Hwang YS, Chi YJ, Yang DS, Kim HY, Choy WS. Anatomic Single Bundle Anterior Cruciate Ligament Reconstruction by Low Accessory Anteromedial Portal Technique: An In Vivo 3D CT Study. Knee Surg Relat Res. 2014;26(2):97-105. Epub 20140530. doi: 10.5792/ksrr.2014.26.2.97. PubMed PMID: 24944975; PubMed Central PMCID: PMC4061413.

67. Lee DW, Kim JG, Lee JH, Park JH, Kim DH. Comparison of Modified Transtibial and Outside-In Techniques in Anatomic Single-Bundle Anterior Cruciate Ligament Reconstruction. Arthroscopy. 2018;34(10):2857-70. Epub 20180906. doi: 10.1016/j.arthro.2018.05.041. PubMed PMID: 30197202.

68. Kosy JD, Walmsley K, Sharma AD, Gordon EA, Heddon SV, Anaspure R, et al. A comparison of femoral tunnel placement in ACL reconstruction using a 70° arthroscope through the anterolateral portal versus a 30° arthroscope through the anteromedial portal: a pilot 3D-CT study. Knee Surg Relat Res. 2020;32(1):17. Epub 20200403. doi: 10.1186/s43019-020-00037-4. PubMed PMID: 32660634; PubMed Central PMCID: PMC7219201.

69. Kim MS, Koh IJ, Sohn S, Kang BM, Jung H, In Y. Femoral offset guide facilitates accurate and precise femoral tunnel placement for single-bundle anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2019;27(11):3505-12. Epub 20190228. doi: 10.1007/s00167-019-05446-x. PubMed PMID: 30820602.

70. Iriuchishima T, Ryu K, Suruga M, Aizawa S, Fu FH. The correlation of femoral tunnel length with the height and area of the lateral wall of the femoral intercondylar notch in anatomical single-bundle ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2017;25(5):1632-7. Epub 20160204. doi: 10.1007/s00167-016-4025-1. PubMed PMID: 26846660.

71. Foo WYX, Chou ACC, Lie HM, Lie DTT. Computer-assisted navigation in ACL reconstruction improves anatomic tunnel placement with similar clinical outcomes. Knee. 2022;38:132-40. Epub 20220901. doi: 10.1016/j.knee.2022.08.006. PubMed PMID: 36058120.

72. Tashiro Y, Okazaki K, Murakami K, Matsubara H, Osaki K, Iwamoto Y, Nakashima Y. Anterolateral rotatory instability in vivo correlates tunnel position after anterior cruciate ligament reconstruction using bone-patellar tendon-bone graft. World J Orthop. 2017;8(12):913-21. Epub 20171218. doi:

10.5312/wjo.v8.i12.913. PubMed PMID: 29312850; PubMed Central PMCID: PMC5745434.

73. Song EK, Kim SK, Lim HA, Seon JK. Comparisons of tunnel-graft angle and tunnel length and position between transtibial and transportal techniques in anterior cruciate ligament reconstruction. Int Orthop. 2014;38(11):2357-62. Epub 20140814. doi: 10.1007/s00264-014-2457-0. PubMed PMID: 25120231.

74. Sven S, Maurice B, Hoeher J, Marc B. Variability of tunnel positioning in fluoroscopic-assisted ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2015;23(8):2269-77. Epub 20140511. doi: 10.1007/s00167-014-3029-y. PubMed PMID: 24817162.

75. Seo SS, Kim CW, Lee CR, Park DH, Kwon YU, Kim OG, Kim CK. Intraoperative fluoroscopy reduces the variability in femoral tunnel placement during single-bundle anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2020;28(2):629-36. Epub 20191115. doi: 10.1007/s00167-019-05791-x. PubMed PMID: 31732754.

76. Mhaskar VA, Singh AK, Soni P, Maheshwari J. Does Viewing the ACL Femoral Footprint End on Using a High Medial Portal Produce Better Tunnel Placement as Compared to Viewing it from a Lateral Portal while Drilling: A 3D CT-based Pilot Study. Indian J Orthop. 2021;55(2):368-74. Epub 20200713. doi: 10.1007/s43465-020-00179-3. PubMed PMID: 33927815; PubMed Central PMCID: PMC8046892.

77. Bird JH, Carmont MR, Dhillon M, Smith N, Brown C, Thompson P, Spalding T. 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(9):1259-67. Epub 20110708. doi: 10.1016/j.arthro.2011.03.077. PubMed PMID: 21741796.

78. Joreitz R, Lynch A, Rabuck S, Lynch B, Davin S, Irrgang J. PATIENT-SPECIFIC AND SURGERY-SPECIFIC FACTORS THAT AFFECT RETURN TO SPORT AFTER ACL RECONSTRUCTION. Int J Sports Phys Ther. 2016;11(2):264-78. PubMed PMID: 27104060; PubMed Central PMCID: PMC4827369.

79. Lee YS, Ko TS, Ahn JH, Kang SG, Choi UH, Elazab A, Lee HR. Comparison of Tibial Tunnel Techniques in Posterior Cruciate Ligament Reconstruction: C-Arm Versus Anatomic Fovea Landmark. Arthroscopy. 2016;32(3):487-92. Epub 20151117. doi: 10.1016/j.arthro.2015.08.036. PubMed PMID: 26597550.

80. Lee YS, Kim TW, Lee ES, Lee KH, Lee SH. Different Strategies in Making Transseptal Portal for the Different Purposes. J Knee Surg. 2020;33(8):825-31. Epub 20190508. doi: 10.1055/s-0039-1688557. PubMed PMID: 31067589.

81. Cohen SB, Fu FH. Three-portal technique for anterior cruciate ligament reconstruction: use of a central medial portal. Arthroscopy. 2007;23(3):325.e1-5. Epub 20070118. doi: 10.1016/j.arthro.2006.07.030. PubMed PMID: 17349482.

82. Hoshino Y, Rothrauff BB, Hensler D, Fu FH, Musahl V. Arthroscopic image distortion-part I: the effect of lens and viewing angles in a 2-dimensional in vitro model. Knee Surg Sports Traumatol Arthrosc. 2016;24(6):2065-71. Epub 20140924. doi: 10.1007/s00167-014-3336-3. PubMed PMID: 25246178.

83. Brown CH, Jr., Spalding T, Robb C. Medial portal technique for single-bundle anatomical anterior cruciate ligament (ACL) reconstruction. Int Orthop. 2013;37(2):253-69. Epub 20130120. doi: 10.1007/s00264-012-1772-6. PubMed PMID: 23334708; PubMed Central PMCID: PMC3560892.

84. Moloney G, Araujo P, Rabuck S, Carey R, Rincon G, Zhang X, Harner C. Use of a fluoroscopic overlay to assist arthroscopic anterior cruciate ligament reconstruction. Am J Sports Med. 2013;41(8):1794-800. Epub 20130606. doi: 10.1177/0363546513490657. PubMed PMID: 23744906.

85. Burnham JM, Malempati CS, Carpiaux A, Ireland ML, Johnson DL. Anatomic Femoral and Tibial Tunnel Placement During Anterior Cruciate Ligament Reconstruction: Anteromedial Portal All-Inside and Outside-In Techniques. Arthrosc Tech. 2017;6(2):e275-e82. Epub 20170306. doi: 10.1016/j.eats.2016.09.035. PubMed PMID: 28580242; PubMed Central PMCID: PMC5442353.

86. Schreiber VM, van Eck CF, Fu FH. Anatomic Double-bundle ACL Reconstruction. Sports Medicine and Arthroscopy Review. 2010;18(1):27-32. doi: 10.1097/JSA.0b013e3181bf6634. PubMed PMID: 00132585-201003000-00006.

Supplementary Files

Supplementary File I

Complementary Search Strategy

PubMed:

("anterior cruciate ligament" OR "ACL") AND ("tear" OR "injury" OR "lesion" OR "rupture" OR "reconstruction" OR "surgery" OR "management" OR "arthroscopy" OR "surgical technique" OR "surgical treatment" OR "surgical approach" OR "reconstructive techniques" OR "surgical procedures") AND ("tunnel placement" OR "femoral tunnel" OR "tunnel position" OR "tunnel length" OR "femoral insertion" OR "bone tunnel" OR "quadrant method" OR "grid" OR "radiographic quadrant") NOT ("rehabilitation")

Scopus:

TITLE-ABS-KEY ("anterior cruciate ligament" OR "ACL") AND TITLE-ABS-KEY ("tear" OR "injury" OR "lesion" OR "rupture" OR "reconstruction" OR "surgery" OR "management" OR "arthroscopy" OR "surgical technique" OR "surgical treatment" OR "surgical approach" OR "reconstructive techniques" OR "surgical procedures") AND TITLE-ABS-KEY ("tunnel placement" OR "femoral tunnel" OR "tunnel position" OR "tunnel length" OR "femoral insertion" OR "bone tunnel" OR "quadrant method" OR "grid" OR "radiographic quadrant") AND NOT TITLE-ABS-KEY ("rehabilitation")

Web of Science:

(((ALL=(("anterior cruciate ligament" OR "ACL"))) AND ALL=(("tear" OR "injury" OR "lesion" OR "rupture" OR "reconstruction" OR "surgery" OR "management" OR "arthroscopy" OR "surgical technique" OR "surgical treatment" OR "surgical approach" OR "reconstructive techniques" OR "surgical procedures"))) AND ALL=(("tunnel placement" OR "femoral tunnel" OR "tunnel position" OR "tunnel length" OR "femoral insertion" OR "bone tunnel" OR "quadrant method" OR "grid" OR "radiographic quadrant"))) NOT ALL=(("rehabilitation"))

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