



State of the Art Review

Navigation in anterior cruciate ligament reconstruction: State of the art

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ABSTRACT

Computer navigation (CN) for anterior cruciate ligament (ACL) surgery has been used mainly for two purposes: to enhance the accuracy of tunnel position and to evaluate the kinematics of the ACL reconstruction (ACLR) and the stability achieved by different surgical techniques. Many studies have shown that navigation may improve the accuracy of anatomical tunnel orientation and position during ACL reconstructive surgery compared with normal arthroscopic tunnel placement, especially regarding the femoral side. At the same time, it has become the gold-standard method for intraoperative knee kinematic assessment, as it permits a quantitative multidirectional knee joint laxity evaluation.

CN in ACL surgery has been associated with diverse problems. First, in most optic systems additional skin incisions and drill holes in the femoral bone are required for fixation of a reference frame to the femur. Second, additional radiation exposure and extra medical cost to the patient for preoperative planning are usually needed. Third, CN, due to additional steps, has more opportunities for error during preoperative planning, intraoperative registration, and operation. Fourth, soft tissues, including the skin and subcutaneous tissues, are usually not considered during the preoperative planning, which can be a problem for kinematic and stability assessment.

Many studies have concluded that ACLR using a CN system is more expensive than conventional surgery, it adds extra time to the surgery and it is not mitigated by better clinical outcomes. This, combined with costs and invasiveness, has limited the use of CN to research-related cases. Future technology should prioritize less invasive intra-operative surgical navigation.

Introduction

Computer navigation (CN) in knee surgery represents the use of computer technology to determine a set of methods used for surgical planning, guiding or performing surgical interventions, and evaluating kinematics and stability after anterior cruciate ligament (ACL) reconstruction (ACLR). CN in ACLR was introduced by Dessenne et al. [1] in the mid-1990's as an intraoperative tool to assess knee kinematics after ACLR. Since then, many authors have used navigation systems predominantly for two purposes [2]: (1) to enhance the accuracy of tunnel position and (2) to evaluate the kinematic of the ACLR and the stability achieved by different surgical techniques.

Surgeon's opinion on the usefulness of CN for ACLR is divided [3].

While proponents of navigation systems argue that CN improves the positioning of the graft, leading to better clinical results by avoiding graft failure, those against highlight that these systems are associated with longer operating time and higher costs, without the justification of associated significant benefits when compared to conventional surgery, especially in high-volume surgeons [4,5]. These factors have limited the use of navigation systems to research-related cases (compared to total knee replacement, which started in 1998 [6], but expanded faster).

This narrative review will cover the history of CN in ACLR followed by the recent state-of-the-art advances in CN for ACLR; highlighting their current use and the potential future directions for routine application into surgical practice.

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Types of CN in ACL surgery

There are two methods for navigation in ACLR (Table 1) [7]: image-based and image-free. The image-based method uses pre-operative computed tomography (CT) or intra-operative x-ray fluoroscopy in real-time during ACLR procedures, both exposing the patient to the ionizing radiation. The image-free method usually uses a preoperatively generated 3D model from CT or magnetic resonance imaging (MRI) plus intraoperative 3D bone morphing with an optical tracking system. The optical tracking system captures reference markers that are rigidly attached to the patient and the mapping is made using surgical tools (Fig. 1). Different systems have been named in the literature, the most common being Orthopilot [Braun, Germany], PRAXIM-Medivision [France], KneeNav [Pittsburgh, PA], and Vectorvision [BrainLab, Germany] among others. In some scenarios, especially regarding kinematic analysis, non-invasive (skin-mounted) inertial sensors for clinical practice (e.g. KIRA [Orthokey, Italy]) have been developed [2].

Guiding tunnel placement

The initial application of intraoperative navigation in arthroscopy was largely focused on tunnel positioning in ACL reconstruction to optimize graft kinematics and isometry. As ligament position varies significantly across individuals and, despite the substantial effort to limit variance and provide anatomic references to be used during surgery, correct tunnel placement is still a matter of experience with success rates varying broadly between low- and high-volume surgeons [8]. Tunnel malposition has a significant influence on ACLR graft failure, supporting the application of navigation to facilitate an increase in the accuracy of tunnel placement [4].

Many studies have shown that CN can improve the accuracy of anatomical tunnel orientation and position during ACLR surgery compared with normal arthroscopic tunnel placement [9–24]. Probably, the most important impact of CN in tunnel placement has been specifically on the femoral side [25–27]. In addition, there are studies that underlined how the use of a navigation system in ACLR could be useful for inexperienced surgeons to avoid poor tunnel orientation and positioning [28,29].

An example of where tunnel positioning could be difficult is when preserving remnants in ACL surgery, as these may affect a good visualization of the footprints, making it necessary to clean the footprint to achieve a correct tunnel positioning. In such situations, navigation systems might be used to confirm the ACL footprint position on the intercondylar lateral wall and to create an adequate tunnel using the native ACL footprint as a landmark [30]. Healing at the femoral aperture is slower than at the tibial aperture [31], which may in part be due to the extensive soft tissue clearance required to visualize the femoral tunnel position.

Another example where tunnel positioning is challenging is revision ACL surgery because of several issues surgeons have to deal with, including bone defects, primary tunnel malposition and pre-existing fixation devices, making adequate new tunnel positions fundamental for surgery outcomes. In this scenario, CN has shown to increase the possibility of creating optimal tunnel positions whilst avoiding these pre-existing issues [32–34].

Recent studies regarding navigation use for tunnel positioning in ACL surgery have mainly originated from Asia. In 2016, Lee et al. [35] using an intraoperative image-free navigation system (preoperative CT plus intraoperative optical tracking system) concluded that navigational femoral tunneling could make predictable tunnel position and orientation with high accuracy and reproducibility, and it could be used to improve safety, decrease the risk of a short femoral tunnel, and prevent posterior wall breakage. The cadaveric experimental results had tunnel lengths with deviations less than 1 mm in both the arthroscopic and navigational experiment groups. For the posterior wall margin, a large deviation with more than 4 mm was reported in the arthroscopic group, while better

results were obtained in the experimental group with less than 1 mm error. However, it is important to note that the arthroscopic group consisted of only two cadavers, while the CN group consisted of 8 cadavers. The same group published another study the year later communicating similar results but with fewer (six) cadaveric specimens [7].

Cho et al. [36] in 2018 reported the development of an MRI-based surgical robot to create the femoral tunnel in ACLR with four sequential cadaveric experiments, each producing better accuracy compared to the previous one. The reported distances between the intra-articular points of the planned and the created tunnels were 7.78 mm in the first experiment and 1.47 mm in the last experiment. The difference in tunnel length was 4.62 mm in the first experiment and 0.99 mm in the last experiment. The investigators considered the latter results satisfactory.

Popkin et al. [37] in 2019 using 20 pediatric sawbone models (10 for CN [BrainLab, Germany] and 10 for fluoroscopic guidance) reported that the distance from the ideal tunnel placement using CN was $2.7 + 3.1$ mm versus $6.4 + 4.2$ mm for fluoroscopic guidance. The authors concluded that CN achieved a more accurate epiphyseal femoral ACL tunnel position but required more time to complete and had a higher effective radiation dose than fluoroscopic guidance.

The same year Raposo et al. [38] presented their proposition of a video-based navigation system for ACLR. Instead of using pin trackers far from the surgical site, this system used a marker being placed inside the joint (at an arbitrary point in the intercondylar surface). The results of their cadaveric study were defined as encouraging, obtaining a high accuracy and a relatively low increase in procedure time, avoiding the need for additional incisions or capital equipment.

Contrarily, regarding tibial tunnel location, Oshima et al. [39] in an in-vivo study of 35 patients, found that tibial tunnel location using fluoroscopy was more accurate than using an image-free navigation system, assessed by a postoperative 3D-CT. They considered that fluoroscopy provided consistent data on tunnel position intraoperatively and a good feedback system.

Kinematic evaluation

Navigation has become the gold-standard method for intraoperative knee kinematic assessment, as it permits a quantitative multidirectional knee joint laxity evaluation [2]. Since its appearance, it has provided a precise understanding of the different anatomical structures participating in knee stabilization in ACLR, and allowed the development of both in-vitro and in-vivo methodology to answer research questions in both native and reconstructed knee kinematics. Navigation has been employed to demonstrate the biomechanical difference between the two native ACL bundles [40–42] and the participation of secondary stabilizers such as the medial meniscus (for anteroposterior [AP] restraint and also rotational stabilization) [43–45] and the anterolateral capsule (or anterolateral ligament [ALL]) for rotational stability [46–48]. This improved knowledge of how knee structures influence knee kinematics has allowed investigators to study the implications after ACLR. Initially, there was interest in how navigation could compare a double-bundle (DB) and a single-bundle (SB) ACLR, followed by an increased interest in kinematic role of the anterolateral (AL) structures in an ACL deficient knee, and recently the kinematic properties of the ACL remnants.

It is common knowledge that the native ACL is a non-isometric structure: the anteromedial (AM) bundle is tense predominantly during knee flexion with a maximum at 45° – 60° , whereas the posterolateral (PL) bundle is maximally taut with the knee in full extension [49]. Therefore, surgical techniques were developed to reconstruct the AM and PL bundles separately, as anatomically as possible. Different biomechanical studies have shown superior results to support a double-bundle (DB) reconstruction over a single-bundle (SB) reconstruction [50–52]. However, biomechanical studies do not always align with clinical in-vivo assessments. In a review of studies using navigation for kinematic

Table 1
Strengths and weaknesses for type of CN.

	Strengths	Weaknesses
Imaged-based CN	Additional check during the procedure (fluoroscopy)	Exposure to ionizing radiation
Image-free CN	No radiation exposure during the procedure	Additional incisions and drill holes for optic trackers

assessment, Zaffagnini et al. [2] reported that the majority of clinical studies do not show significant differences in controlling AP displacement (anterior drawer and Lachman tests) when comparing the SB and DB techniques. However, they stated that two systematic reviews reported that the DB technique was shown to be more effective for controlling rotational displacement (internal-external rotation and pivot shift test) [49,53]. It must be highlighted that initially, most studies compared an anatomic DB reconstruction against a transtibial (non-anatomic) SB technique. The meta-analysis by Desai et al. [49] included only anatomic reconstructions and found that anatomic DB ACLR was superior to anatomic SB reconstruction in terms of primarily AP laxity (KT-1000 test), and in contradiction to what Zaffagnini et al. [2] reported in their review, found no differences in rotation stability (pivot shift and navigation). By means of navigation, recent in-vivo studies have aimed to solve this controversy. Ikuta et al. [54] randomized 34 patients for anatomic SB and DB ACLR and performed intraoperative image-free kinematic evaluations before and immediately after ACL reconstruction at different knee range of motion angles. They found no significant difference in AP translation or tibial rotation between the two surgical techniques.

Pursuing the longer-term effect of a DB ACLR, Komzák et al. [55] reported a randomized trial with a two-year follow-up of 40 patients, including only isolated complete ACL injuries, and compared knee kinematics according to the healthy contralateral leg using passive trackers fixed to the thigh and leg with stripes. The authors found that anatomic DB ACLR restored the rotational stability of the knee joint after at least two years without any significant difference in comparison to the contralateral healthy knee, while the anatomic SB ACLR was not

sufficient for restoring internal rotation. Despite this kinematic difference, a difference was not seen in patient-reported outcome measures, and AP translation was to the same extent for both techniques.

Considering that DB ACLR is more demanding and has shown to have a higher complication rate [56], a high interest has developed regarding the addition of an anterolateral (AL) tenodesis or reconstruction to augment a SB ACLR, increasing anterolateral rotational stability, restoring knee kinematics, and protecting the ACL graft whilst it heals and integrates. Navigation has demonstrated that AL supplementation provides an adequate rotatory restraint [2,57]. Moreover, clinical studies have shown superiority in controlling internal rotation of SB ACLR (non-anatomic) plus AL tenodesis technique versus an anatomic DB ACLR [47,58]. The question then arises whether an AL procedure is recommended for all SB ACLR, and if so which type of procedure. Based on biomechanical cadaveric studies using bone fixed markers for image-free navigation, it has been demonstrated that different AL procedures have different effects on kinematic control of anterolateral stability [59], with some subsequent concerns about an increase in lateral compartment pressures [60]. Select of appropriate patients for this additional procedure has interested many investigators, with recommendations for a patient-specific risk analysis [61,62]. The Anterolateral Ligament Expert Group consensus suggests that a patient who presents with a grade 2 or 3 pivot shift is a sufficient criterion for adding an AL supplementation [61]. However, the diverse reported sensitivity and specificity of the pivot shift examination [57,63] present a real challenge for this recommendation. As shown early on by Noyes et al. [64], the pivot shift is a subjective test, depending significantly on the examiner's hand. In this scenario, navigation could further aid in developing devices to create a reproducible and objective pivot shift assessment [2,57].

Navigation has provided the opportunity to evaluate the kinematic properties of different anatomical structures participating in knee stabilization, including ACL remnants. Nakamae et al. [65] using an intraoperative arthrometry with an image-free navigation system before and immediately after resection of the ACL remnant found that remnants up to one year from the initial injury that were bridged between the posterior cruciate ligament and the tibia or the intercondylar notch and the tibia, reduced AP translation at 30° of flexion, and had no rotational



Fig. 1. Example of the navigation system based on optical trackers mounted in the femur and tibia used in the study by Neri et al. [59].

implications. Contrarily, Nakase et al. [66] using the same intraoperative image-free navigation system and testing also before and immediately after remnant resection, found that ACL remnants may assist in both AP and rotational stability at 30° of knee flexion; however, the contribution to knee stability was only found in those complete remnants bridging from the anatomical origin on the medial wall of the lateral femoral condyle to the tibial insertion.

Limitations of CN

CN in ACL surgery has been associated with a wide variety of problems. First, in most optical tracking systems additional skin incisions and drill holes in the femoral bone are required for the fixation of an accurate reference frame. Second, additional radiation exposure and extra medical cost to the patient for preoperative planning are usually needed. Third, CN, due to additional steps, has a higher potential for error during preoperative planning, intraoperative registration, and technical operation. Fourth, soft tissues such as the skin and subcutaneous fat and muscle, are not usually considered during preoperative planning (e.g. when using skin-mounted sensors for kinematic assessment, subcutaneous tissue is fundamental as the distance between what we want to measure [knee laxity] from where we measure it, and can alter the results), and finally, most of the navigation systems require an anesthetized patient, meaning that a surgical setting is needed (which can be a limitation especially when wanting to measure joint laxity).

Alongside these four main limitations, a number of studies have also concluded that the increased expense of ACLR using a CN system, and the additional surgical time, are not mitigated by better clinical outcomes [7, 8,67,68]. These factors have limited the use of navigation systems to research-related cases.

Future perspectives

As stated by Musahl et al., in 2012 [69], we agree that navigation can be a helpful tool for evaluating knee laxity, and we consider that it might be the key to answering when should an ACLR be augmented with an AL procedure. Future AL consensus should incorporate objective navigational pivot shift assessment into their recommendations.

Considering that navigation in ACLR permits a personalized kinematic evaluation of each patient, when focusing on a comparison between their preoperative and postoperative status and their healthy contralateral knee, navigation data could guide their rehabilitation protocol and aid in the decision of timing to return to sports. Only a few studies have employed intraoperative navigation systems for comparison between affected and unaffected knees [70,71], probably due to an increase in costs, surgical time, and radiation. Interestingly, Imbert et al. found that ACLR, with respect to the contralateral knee, intra-articular plus additional anterolateral reinforcement procedures do not restore normal joint laxity [70]. More studies are needed to discuss whether contralateral healthy knee biomechanical records are needed to obtain better clinical results. No studies were found specifically for navigation and ACL rehabilitation programs; nevertheless, 2D and 3D motion analysis methods have been created for knee kinematic evaluations of failure risk factors such as dynamic valgus [72]. Di Paolo et al. [73] have recently validated wearable sensor systems in multidirectional high-speed complex movements to evaluate the specific joint parameters commonly used in rehabilitation and return to sport assessment after ACL injury. Future investigations could include navigational data during the rehabilitation process to improve functional outcomes and accelerate the rehabilitation process while diminishing the graft failure rates after ACLR.

We believe that as technology continues to improve, navigation will provide objective kinematic parameters to assess knee-joint stability, helping not only to guide and personalize the correct surgical technique for ACLR and rehabilitation, but also to prevent an ACL injury. Tabori

et al. [74] have recently published a machine-learning approach based on inertial sensors and optoelectronic bars to predict ACL injury risk in a female basketball player. Hopefully, future investigations using navigational data may reduce sport-related injuries.

Regarding tunnel positioning in ACLR, with the introduction of less invasive systems such as in Raposo et al. [38], navigational ACL surgery could be a possible choice in daily practice. There are cases that specifically would benefit from CN; a good example of this is multi-ligament knee surgery, where to our knowledge there are no studies published to this date. CN could help to guide faster, more accurate creation of the multiple tunnels required whilst avoiding tunnel collision, one of the biggest concerns in this type of surgery [75].

Compared to knee arthroplasty, where high dissatisfaction rates persist [76], ACLR has been a successful intervention over the last decades with high patient satisfaction rates. Thus, a remarkable improvement in clinical outcomes by navigation techniques might be hard to achieve and even harder to prove [77]. The use of surgical navigation for tunnel placement in ACL surgery remains inherently problematic because the optimal position for placement of ACL tunnels remains debatable [78,79]. Until today, the use of computer-assisted navigation systems has not correlated clinically with better results but led instead to increased concerns regarding the learning curve, higher costs, and time-consuming problems. Based on these factors, there are still major obstacles to the routine use of computer-assisted navigation systems in clinical practice.

Conclusions

CN is a developing technology in ACL surgery, which is currently mostly limited to research-related cases because current systems can require increased imaging radiation exposure, and are more invasive, more time consuming, and costly. In the contrary, regarding kinematic evaluation, it is considered the gold standard, thanks to the potential for in-vivo non-invasive skin-mounted monitoring, and the accuracy of results seen using in-vitro cadaveric biomechanical experiments. Future technology should prioritize less invasive intra-operative surgical navigation.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

1. Key articles

Dessenne et al. [1] reported the first use of CN in ACL surgery in 1995.

Zaffagnini [2] et al. published an historical review of CN in ACL surgery in 2016.

Raposo C [38] presented their proposition of a video-based navigation system for ACLR in 2019.

Ikuta et al. [54] and Komzák M et al. [55] reported biomechanical differences between SB and DB ACLR using navigation.

Neri et al. [59] and Neri et al. [60] analysed different AL procedures using image-free navigation.

Nakamae A et al. [65] and Nakase J et al. [66] did biomechanical evaluations of ACL remnants.

Di Paolo et al. [73] have validated navigational evaluation to specific joint parameters used in rehabilitation and return to sport after ACL injury.

2. Essential features of navigation in ACL surgery

There are two methods for navigation in ACLR: image-based and image-free

The image-based method uses pre-operative CT or intra-operative x-ray fluoroscopy in real-time during ACLR procedures, both exposing the patient to the ionizing radiation.

The image-free method usually uses a preoperatively generated 3D model from CT or MRI plus intraoperative 3D bone morphing with an optical tracking system.

In some scenarios, especially regarding kinematic analysis, non-invasive (skin-mounted) inertial sensors for clinical practice have been developed.

3. Major pitfalls

Most optic systems require additional skin incisions and drill holes for fixation of an accurate reference frame.

Additional radiation exposure and extra medical cost to the patient for preoperative planning are usually needed.

CN, due to additional steps, has a higher potential for error during preoperative planning, intraoperative registration, and technical operation.

The increased expense of ACLR using a CN system, and the additional surgical time, is not mitigated by better clinical outcomes

4. Future perspectives

Navigational data in ACLR could guide rehabilitation and aid in the decision of timing to return to sports.

Navigation could provide objective kinematic parameters to assess knee-joint stability, helping prevent an ACL injury in healthy individuals.

Regarding tunnel positioning in ACLR, with the introduction of less invasive systems, navigational ACL surgery could be a possible choice in daily practice.

References

- Dessenne V, Lavallée S, Julliard R, Orti R, Martelli S, Cinquin P. Computer-assisted knee anterior cruciate ligament reconstruction: first clinical tests. *J Image Guid Surg* 1995;1(1):59–64. [https://doi.org/10.1002/\(SICI\)1522-712X\(1995\)1:1<59::AID-IGS9>3.0.CO;2-L](https://doi.org/10.1002/(SICI)1522-712X(1995)1:1<59::AID-IGS9>3.0.CO;2-L). PMID: 9079428.
- Zaffagnini S, Urrizola F, Signorelli C, Grassi A, Di Sarsina TR, Lucidi GA, et al. Current use of navigation system in ACL surgery: a historical review. *Knee Surg Sports Traumatol Arthrosc* 2016;24(11):3396–409. <https://doi.org/10.1007/s00167-016-4356-y>. Epub 2016 Oct 15. PMID: 27744575.
- Hernandez D, Garimella R, Eltorai AEM, Daniels AH. Computer-assisted orthopaedic surgery. *Orthop Surg* 2017;9(2):152–8. <https://doi.org/10.1111/os.12323>. Epub 2017 Jun 7. PMID: 28589561; PMCID: PMC6584434.
- Karkenny AJ, Mendelis JR, Geller DS, Gomez JA. The role of intraoperative navigation in orthopaedic surgery. *J Am Acad Orthop Surg* 2019;27(19):e849–58. <https://doi.org/10.5435/JAAOS-D-18-00478>. PMID: 30720570.
- Anthony CA, Duchman K, McCunniff P, McDermott S, Bollier M, Thedens DR, et al. Double-bundle ACL reconstruction: novice surgeons utilizing computer-assisted navigation versus experienced surgeons. *Comput Aided Surg* 2013;18(5-6):172–80. <https://doi.org/10.3109/10929088.2013.795244>. Epub 2013 May 10. PMID: 23662622.
- Delp SL, Stulberg SD, Davies B, Picard F, Leitner F. Computer assisted knee replacement. *Clin Orthop Relat Res* 1998;354:49–56. <https://doi.org/10.1097/00003086-199809000-00007>. PMID: 9755763.
- Kim Y, Lee BH, Mekuria K, Cho H, Park S, Wang JH, et al. Registration accuracy enhancement of a surgical navigation system for anterior cruciate ligament reconstruction: a phantom and cadaveric study. *Knee* 2017;24(2):329–39. <https://doi.org/10.1016/j.knee.2016.12.007>. Epub 2017 Feb 9. PMID: 28189409.
- Samitier G, Marciano AI, Alentorn-Geli E, Cugat R, Farmer KW, Moser MW. Failure of anterior cruciate ligament reconstruction. *Arch Bone Jt Surg* 2015;3(4):220–40. PMID: 26550585; PMCID: PMC4628627.
- Chouteau J, Benareau I, Testa R, Fessy MH, Lerat JL, Moyer B. Comparative study of knee anterior cruciate ligament reconstruction with or without fluoroscopic assistance: a prospective study of 73 cases. *Arch Orthop Trauma Surg* 2008;128(9):945–50. <https://doi.org/10.1007/s00402-007-0452-2>. Epub 2007 Sep 15. PMID: 17874244.
- Endele D, Jung C, Becker U, Bauer G, Mauch F. Anterior cruciate ligament reconstruction with and without computer navigation: a clinical and magnetic resonance imaging evaluation 2 years after surgery. *Arthroscopy* 2009;25(10):1067–74. <https://doi.org/10.1016/j.arthro.2009.05.016>. PMID: 19801284.
- Hiraoka H, Kuribayashi S, Fukuda A, Fukui N, Nakamura K. Endoscopic anterior cruciate ligament reconstruction using a computer-assisted fluoroscopic navigation system. *J Orthop Sci* 2006;11(2):159–66. <https://doi.org/10.1007/s00776-005-0988-3>. PMID: 16568388.
- Kawakami Y, Hiranaka T, Matsumoto T, Hida Y, Fukui T, Uemoto H, et al. The accuracy of bone tunnel position using fluoroscopic-based navigation system in anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2012;20(8):1503–10. <https://doi.org/10.1007/s00167-011-1726-3>. Epub 2011 Oct 22. PMID: 22020962.
- Koh J, Koo SS, Leonard J, Kodali P. Anterior cruciate ligament (ACL) tunnel placement: a radiographic comparison between navigated versus manual ACL reconstruction. *Orthopedics* 2006;29(10 Suppl):S122–4. Erratum in: *Orthopedics*. 2007 Apr;30(4):327. PMID: 17407936.
- Mauch F, Apic G, Becker U, Bauer G. Differences in the placement of the tibial tunnel during reconstruction of the anterior cruciate ligament with and without computer-assisted navigation. *Am J Sports Med* 2007;35(11):1824–32. <https://doi.org/10.1177/0363546507305678>. Epub 2007 Sep 18. PMID: 17878429.
- Musahl V, Burkart A, Debski RE, Van Scyoc A, Fu FH, Woo SL. Anterior cruciate ligament tunnel placement: comparison of insertion site anatomy with the guidelines of a computer-assisted surgical system. *Arthroscopy* 2003;19(2):154–60. <https://doi.org/10.1053/jars.2003.50001>. PMID: 12579148.
- Panisset JC, Boux De Casson F. Navigated anterior cruciate ligament reconstruction: correlation between computer data and radiographic measurements. *Orthopedics* 2006 Oct;29(10 Suppl):S133–6. Erratum in: *Orthopedics*. 2007;30(4):327. PMID: 17407939.
- Piasecki DP, Bach Jr BR, Espinoza Orias AA, Verma NN. Anterior cruciate ligament reconstruction: can anatomic femoral placement be achieved with a transtibial technique? *Am J Sports Med* 2011;39(6):1306–15. <https://doi.org/10.1177/0363546510397170>. Epub 2011 Feb 18. PMID: 21335345.
- Plaweski S, Cazal J, Rosell P, Merloz P. Anterior cruciate ligament reconstruction using navigation: a comparative study on 60 patients. *Am J Sports Med* 2006;34(4):542–52. <https://doi.org/10.1177/0363546505281799>. PMID: 16556753.
- Taketomi S, Inui H, Nakamura K, Hirota J, Sanada T, Masuda H, et al. Clinical outcome of anatomic double-bundle ACL reconstruction and 3D CT model-based validation of femoral socket aperture position. *Knee Surg Sports Traumatol Arthrosc* 2014;22(9):2194–201. <https://doi.org/10.1007/s00167-013-2663-0>. Epub 2013 Oct 2. PMID: 24085109.
- Tensho K, Kodaira H, Yasuda G, Yoshimura Y, Narita N, Morioka S, et al. Anatomic double-bundle anterior cruciate ligament reconstruction, using CT-based navigation and fiducial markers. *Knee Surg Sports Traumatol Arthrosc* 2011;19(3):378–83. <https://doi.org/10.1007/s00167-010-1217-y>. Epub 2010 Jul 17. PMID: 20640401.
- Tsuda E, Ishibashi Y, Fukuda A, Tsukada H, Toh S. Validation of computer-assisted double-bundle anterior cruciate ligament reconstruction. *Orthopedics* 2007;30(10 Suppl):S136–40. PMID: 17983116.
- Hart R, Krejzla J, Sváb P, Kocis J, Stipčák V. Outcomes after conventional versus computer-navigated anterior cruciate ligament reconstruction. *Arthroscopy* 2008;24(5):569–78. <https://doi.org/10.1016/j.arthro.2007.12.007>. Epub 2008 Feb 1. PMID: 18442690.
- Angelini FJ, Albuquerque RF, Sasaki SU, Camanho GL, Hernandez AJ. Comparative study on anterior cruciate ligament reconstruction: determination of isometric points with and without navigation. *Clinics (Sao Paulo)*. 2010;65(7):683–8. <https://doi.org/10.1590/S1807-59322010000700006>. PMID: 20668625; PMCID: PMC2910856.
- Picard F, DiGioia AM, Moody J, Martinek V, Fu FH, Rytel M, et al. Accuracy in tunnel placement for ACL reconstruction. Comparison of traditional arthroscopic and computer-assisted navigation techniques. *Comput Aided Surg* 2001;6(5):279–89. <https://doi.org/10.1002/igs.10014>. PMID: 11892004.
- Luites JW, Wymenga AB, Blankevoort L, Eygendaal D, Verdonschot N. Accuracy of a computer-assisted planning and placement system for anatomical femoral tunnel positioning in anterior cruciate ligament reconstruction. *Int J Med Robot* 2014;10(4):438–46. <https://doi.org/10.1002/rcs.1548>. Epub 2013 Oct 24. PMID: 24677574.

- [26] Luites JW, Wymenga AB, Blankevoort L, Kooloos JM, Verdonchot N. Development of a femoral template for computer-assisted tunnel placement in anatomical double-bundle ACL reconstruction. *Comput Aided Surg* 2011;16(1):11–21. <https://doi.org/10.3109/10929088.2010.541040>. PMID: 21198424.
- [27] Shafizadeh S, Balke M, Wegener S, Tjardes T, Bouillon B, Hoehner J, et al. Precision of tunnel positioning in navigated anterior cruciate ligament reconstruction. *Arthroscopy* 2011;27(9):1268–74. <https://doi.org/10.1016/j.arthro.2011.03.073>. Epub 2011 Jun 24. PMID: 21704470.
- [28] Anthony CA, Duchman K, McCunniff P, McDermott S, Bollier M, Thedens DR, et al. Double-bundle ACL reconstruction: novice surgeons utilizing computer-assisted navigation versus experienced surgeons. *Comput Aided Surg* 2013;18(5-6):172–80. <https://doi.org/10.3109/10929088.2013.795244>. Epub 2013 May 10. PMID: 23662622.
- [29] Zhu W, Lu W, Han Y, Hui S, Ou Y, Peng L, et al. Application of a computerised navigation technique to assist arthroscopic anterior cruciate ligament reconstruction. *Int Orthop* 2013;37(2):233–8. <https://doi.org/10.1007/s00264-012-1764-6>. Epub 2013 Jan 12. PMID: 23314335; PMCID: PMC3560909.
- [30] Taketomi S, Inui H, Sanada T, Nakamura K, Yamagami R, Masuda H, et al. Remnant-preserving anterior cruciate ligament reconstruction using a three-dimensional fluoroscopic navigation system. *Knee Surg Relat Res* 2014;26(3):168–76. <https://doi.org/10.5792/ksrr.2014.26.3.168>. Epub 2014 Aug 29. PMID: 25229047; PMCID: PMC4163575.
- [31] Putnis SE, Oshima T, Klasan A, Grasso S, Neri T, Fritsch BA, et al. Magnetic resonance imaging 1 Year after hamstring autograft anterior cruciate ligament reconstruction can identify those at higher risk of graft failure: an analysis of 250 cases. *Am J Sports Med* 2021;49(5):1270–8. <https://doi.org/10.1177/0363546521995512>. Epub 2021 Feb 25. PMID: 33630656.
- [32] Nakagawa T, Hiraoka H, Fukuda A, Kuribayashi S, Nakayama S, Matsubara T, et al. Fluoroscopic-based navigation-assisted placement of the tibial tunnel in revision anterior cruciate ligament reconstruction. *Arthroscopy* 2007;23(4):443.e1–4. <https://doi.org/10.1016/j.arthro.2006.07.036>. Epub 2007 Jan 5. PMID: 17418342.
- [33] Plaweski S, Schlatterer B, Saragaglia D. Computer Assisted Orthopedic Surgery - France (CAOS - France). The role of computer assisted navigation in revision surgery for failed anterior cruciate ligament reconstruction of the knee: a continuous series of 52 cases. *Orthop Traumatol Surg Res* 2015;101(6 Suppl):S227–31. <https://doi.org/10.1016/j.otsr.2015.07.003>. Epub 2015 Aug 20. PMID: 26300454.
- [34] Taketomi S, Inui H, Nakamura K, Hirota J, Takei S, Takeda H, et al. Three-dimensional fluoroscopic navigation guidance for femoral tunnel creation in revision anterior cruciate ligament reconstruction. *Arthrosc Tech* 2012;1(1):e95–9. <https://doi.org/10.1016/j.eats.2012.04.003>. PMID: 23766985; PMCID: PMC3678652.
- [35] Lee BH, Kum DH, Rhyu IJ, Kim Y, Cho H, Wang JH. Clinical advantages of image-free navigation system using surface-based registration in anatomical anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2016;24(11):3556–64. <https://doi.org/10.1007/s00167-016-4332-6>. Epub 2016 Oct 19. PMID: 27761623.
- [36] Cho WJ, Kim JM, Kim DE, Lee JG, Park JW, Han YH, et al. Accuracy of the femoral tunnel position in robot-assisted anterior cruciate ligament reconstruction using a magnetic resonance imaging-based navigation system: a preliminary report. *Int J Med Robot* 2018;14(5):e1933. <https://doi.org/10.1002/rcs.1933>. Epub 2018 Jun 28. PMID: 29952064.
- [37] Popkin CA, Chan CM, Nowell JA, Crowley SG, Wright M, Ahmad CS. Computer navigation for pediatric femoral ACL tunnel placement. *Iowa Orthop J* 2019;39(1):121–9. PMID: 31413685; PMCID: PMC6604552.
- [38] Raposo C, Barreto JP, Sousa C, Ribeiro L, Melo R, Oliveira JP, et al. Video-based computer navigation in knee arthroscopy for patient-specific ACL reconstruction. *Int J Comput Assist Radiol Surg* 2019;14(9):1529–39. <https://doi.org/10.1007/s11548-019-02021-0>. Epub 2019 Jun 29. PMID: 31256360.
- [39] Oshima T, Nakase J, Ohashi Y, Shimozaki K, Asai K, Tsuchiya H. Intraoperative fluoroscopy shows better agreement and interchangeability in tibial tunnel location during single bundle anterior cruciate ligament reconstruction with postoperative three-dimensional computed tomography compared with an intraoperative image-free navigation system. *Knee* 2020;27(3):809–16. <https://doi.org/10.1016/j.knee.2020.02.017>. Epub 2020 Mar 13. PMID: 32178971.
- [40] Song EK, Oh LS, Gill TJ, Li G, Gadikota HR, Seon JK. Prospective comparative study of anterior cruciate ligament reconstruction using the double-bundle and single-bundle techniques. *Am J Sports Med* 2009;37(9):1705–11. <https://doi.org/10.1177/0363546509333478>. Epub 2009 Jun 9. PMID: 19509412; PMCID: PMC3740368.
- [41] Ho JY, Gardiner A, Shah V, Steiner ME. Equal kinematics between central anatomic single-bundle and double-bundle anterior cruciate ligament reconstructions. *Arthroscopy* 2009;25(5):464–72. <https://doi.org/10.1016/j.arthro.2009.02.013>. PMID: 19409303.
- [42] Ferretti A, Monaco E, Labianca L, De Carli A, Maestri B, Contedua F. Double-bundle anterior cruciate ligament reconstruction: a comprehensive kinematic study using navigation. *Am J Sports Med* 2009;37(8):1548–53. <https://doi.org/10.1177/0363546509339021>. Epub 2009 Jun 29. PMID: 19564423.
- [43] Musahl V, Bedi A, Citak M, O'Loughlin P, Choi D, Pearle AD. Effect of single-bundle and double-bundle anterior cruciate ligament reconstructions on pivot-shift kinematics in anterior cruciate ligament- and meniscus-deficient knees. *Am J Sports Med* 2011;39(2):289–95. <https://doi.org/10.1177/0363546510385422>. Epub 2010 Dec 7. PMID: 21139156.
- [44] Petrigliano FA, Musahl V, Suero EM, Citak M, Pearle AD. Effect of meniscal loss on knee stability after single-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2011;19(Suppl 1):S86–93. <https://doi.org/10.1007/s00167-011-1537-6>. Epub 2011 May 12. PMID: 21562842.
- [45] Grassi A, Di Paolo S, Lucidi GA, Macchiarella L, Raggi F, Zaffagnini S. The contribution of partial meniscectomy to preoperative laxity and laxity after anatomic single-bundle anterior cruciate ligament reconstruction: in vivo kinematics with navigation. *Am J Sports Med* 2019;47(13):3203–11. <https://doi.org/10.1177/0363546519876648>. Epub 2019 Oct 15. PMID: 31613650.
- [46] Colombet PD. Navigated intra-articular ACL reconstruction with additional extra-articular tenodesis using the same hamstring graft. *Knee Surg Sports Traumatol Arthrosc* 2011;19(3):384–9. <https://doi.org/10.1007/s00167-010-1223-0>. Epub 2010 Sep 1. PMID: 20811736.
- [47] Monaco E, Labianca L, Contedua F, De Carli A, Ferretti A. Double bundle or single bundle plus extraarticular tenodesis in ACL reconstruction? A CAOS study. *Knee Surg Sports Traumatol Arthrosc* 2007;15(10):1168–74. <https://doi.org/10.1007/s00167-007-0368-y>. Epub 2007 Jun 23. PMID: 17589826.
- [48] Colombet P. Knee laxity control in revision anterior cruciate ligament reconstruction versus anterior cruciate ligament reconstruction and lateral tenodesis: clinical assessment using computer-assisted navigation. *Am J Sports Med* 2011;39(6):1248–54. <https://doi.org/10.1177/0363546510395462>. Epub 2011 Feb 18. PMID: 21335352.
- [49] Desai N, Björnsson H, Musahl V, Bhandari M, Petzold M, Fu FH, et al. Anatomic single- versus double-bundle ACL reconstruction: a meta-analysis. *Knee Surg Sports Traumatol Arthrosc* 2014;22(5):1009–23. <https://doi.org/10.1007/s00167-013-2811-6>. Epub 2013 Dec 17. PMID: 24432729.
- [50] Kondo E, Merican AM, Yasuda K, Amis AA. Biomechanical comparison of anatomic double-bundle, anatomic single-bundle, and nonanatomic single-bundle anterior cruciate ligament reconstructions. *Am J Sports Med* 2011;39(2):279–88. <https://doi.org/10.1177/0363546510392350>. PMID: 21239692.
- [51] Nohmi S, Ishibashi Y, Tsuda E, Yamamoto Y, Tsukada H, Toh S. Biomechanical comparison between single-bundle and double-bundle anterior cruciate ligament reconstruction with hamstring tendon under cyclic loading condition. *Sports Med Arthrosc Rehabil Ther Technol* 2012;4(1):23. <https://doi.org/10.1186/1758-2555-4-23>. PMID: 22747942; PMCID: PMC3531271.
- [52] Yagi M, Wong EK, Kanamori A, Debski RE, Fu FH, Woo SL. Biomechanical analysis of an anatomic anterior cruciate ligament reconstruction. *Am J Sports Med* 2002;30(5):660–6. <https://doi.org/10.1177/03635465020300050501>. PMID: 12238998.
- [53] Björnsson H, Desai N, Musahl V, Alentorn-Geli E, Bhandari M, Fu F, et al. Is double-bundle anterior cruciate ligament reconstruction superior to single-bundle? A comprehensive systematic review. *Knee Surg Sports Traumatol Arthrosc* 2015;23(3):696–739. <https://doi.org/10.1007/s00167-013-2666-x>. Epub 2013 Sep 15. PMID: 24037314.
- [54] Ikuta Y, Nakamae A, Shimizu R, Ishikawa M, Nakasa T, Ochi M, et al. A comparison of central anatomic single-bundle reconstruction and anatomic double-bundle reconstruction in anteroposterior and rotational knee stability: intraoperative biomechanical evaluation. *J Knee Surg* 2022;35(3):273–9. <https://doi.org/10.1055/s-0040-1713730>. Epub 2020 Jul 2. PMID: 32615614.
- [55] Komzák M, Hart R, Feranec M, Šmíd P, Kocová R. In vivo knee rotational stability 2 years after double-bundle and anatomic single-bundle ACL reconstruction. *Eur J Trauma Emerg Surg* 2018;44(1):105–11. <https://doi.org/10.1007/s00068-017-0769-7>. Epub 2017 Mar 2. PMID: 28255611.
- [56] Janko M, Verboket RD, Plawetzki E, Geiger EV, Lustenberger T, Marzi I, et al. Vergleichbare Ergebnisse nach arthroskopischem Ersatz des vorderen Kreuzbandes : klinische und funktionelle Ergebnisse nach Einzelbündel- und Doppelbündelrekonstruktion [Comparable results after arthroscopic replacement of the anterior cruciate ligament : clinical and functional results after single bundle and double bundle reconstruction]. *German Chirug* 2020;91(1):67–75. <https://doi.org/10.1007/s00104-019-01050-4>. PMID: 31642938.
- [57] Horvath A, Meredith SJ, Nishida K, Hoshino Y, Musahl V. Objectifying the pivot shift test. *Sports Med Arthrosc Rev* 2020;28(2):36–40. <https://doi.org/10.1097/JSA.0000000000000260>. PMID: 32345924.
- [58] Zaffagnini S, Signorelli C, Lopomo N, Bonanzinga T, Marcheggiani Muccioli GM, Bigozzi S, et al. Anatomic double-bundle and over-the-top single-bundle with additional extra-articular tenodesis: an in vivo quantitative assessment of knee laxity in two different ACL reconstructions. *Knee Surg Sports Traumatol Arthrosc* 2012;20(1):153–9. <https://doi.org/10.1007/s00167-011-1589-7>. Epub 2011 Jun 28. PMID: 21711011.
- [59] Neri T, Dabirrahmani D, Beach A, Grasso S, Putnis S, Oshima T, et al. Different anterolateral procedures have variable impact on knee kinematics and stability when performed in combination with anterior cruciate ligament reconstruction. *J ISAKOS* 2021;6(2):74–81. <https://doi.org/10.1136/jisakos-2019-000360>. Epub 2020 Nov 24. PMID: 33832980.
- [60] Neri T, Cadman J, Beach A, Grasso S, Dabirrahmani D, Putnis S, et al. Lateral tenodesis procedures increase lateral compartment pressures more than anterolateral ligament reconstruction, when performed in combination with ACL reconstruction: a pilot biomechanical study. *J ISAKOS* 2021;6(2):66–73. <https://doi.org/10.1136/jisakos-2019-000368>. Epub 2020 Nov 24. PMID: 33832979.
- [61] Sonnerly-Cottet B, Daggert M, Fayard JM, Ferretti A, Helito CP, Lind M, et al. Anterolateral Ligament Expert Group consensus paper on the management of internal rotation and instability of the anterior cruciate ligament - deficient knee. *J Orthop Traumatol* 2017;18(2):91–106. <https://doi.org/10.1007/s10195-017-0449-8>. PMID: 28220268; PMCID: PMC5429259.
- [62] Getgood A, Brown C, Lording T, Amis A, Claes S, Geeslin A, et al. The anterolateral complex of the knee: results from the International ALC Consensus Group Meeting. *Knee Surg Sports Traumatol Arthrosc* 2019;27(1):166–76. <https://doi.org/10.1007/s00167-018-5072-6>. Epub 2018 Jul 25. PMID: 30046994.

- [63] Lopomo N, Zaffagnini S, Amis AA. Quantifying the pivot shift test: a systematic review. *Knee Surg Sports Traumatol Arthrosc* 2013;21(4):767–83. <https://doi.org/10.1007/s00167-013-2435-x>. Epub 2013 Mar 2. PMID: 23455384.
- [64] Noyes FR, Grood ES, Cummings JF, Wroble RR. An analysis of the pivot shift phenomenon. The knee motions and subluxations induced by different examiners. *Am J Sports Med* 1991;19(2):148–55. <https://doi.org/10.1177/036354659101900210>. PMID: 2039066.
- [65] Nakamae A, Ochi M, Deie M, Adachi N, Kanaya A, Nishimori M, et al. Biomechanical function of anterior cruciate ligament remnants: how long do they contribute to knee stability after injury in patients with complete tears? *Arthroscopy* 2010;26(12):1577–85. <https://doi.org/10.1016/j.arthro.2010.04.076>. PMID: 20888171.
- [66] Nakase J, Toratani T, Kosaka M, Ohashi Y, Tsuchiya H. Roles of ACL remnants in knee stability. *Knee Surg Sports Traumatol Arthrosc* 2013;21(9):2101–6. <https://doi.org/10.1007/s00167-012-2260-7>. Epub 2012 Oct 30. PMID: 23108682.
- [67] Plaweski S, Tchouda SD, Dumas J, Rossi J, Moreau Gaudry A, Cinquin P, et al. STIC NAV Per Op group; Computer Assisted Orthopaedic Surgery-France. Evaluation of a computer-assisted navigation system for anterior cruciate ligament reconstruction: prospective non-randomized cohort study versus conventional surgery. *Orthop Traumatol Surg Res* 2012;98(6 Suppl):S91–7. <https://doi.org/10.1016/j.otsr.2012.07.001>. Epub 2012 Aug 24. PMID: 22922105.
- [68] Saltzman BM, Cvetanovich GL, Nwachukwu BU, Mall NA, Bush-Joseph CA, Bach Jr BR. Economic analyses in anterior cruciate ligament reconstruction: a qualitative and systematic review. *Am J Sports Med* 2016;44(5):1329–35. <https://doi.org/10.1177/0363546515581470>. Epub 2015 Apr 30. PMID: 25930672.
- [69] Musahl V, Kopf S, Rabuck S, Becker R, van der Merwe W, Zaffagnini S, et al. Rotatory knee laxity tests and the pivot shift as tools for ACL treatment algorithm. *Knee Surg Sports Traumatol Arthrosc* 2012;20(4):793–800. <https://doi.org/10.1007/s00167-011-1857-6>. Epub 2011 Dec 30. PMID: 22207028.
- [70] Imbert P, Belvedere C, Leardini A. Knee laxity modifications after ACL rupture and surgical intra- and extra-articular reconstructions: intra-operative measures in reconstructed and healthy knees. *Knee Surg Sports Traumatol Arthrosc* 2017;25(9):2725–35. <https://doi.org/10.1007/s00167-015-3653-1>. PMID: 26037545; PMCID: PMC5570784.
- [71] Imbert P, Belvedere C, Leardini A. Human knee laxity in ACL-deficient and physiological contralateral joints: intra-operative measurements using a navigation system. *Biomed Eng Online* 2014;13:86. <https://doi.org/10.1186/1475-925X-13-86>. PMID: 24961322; PMCID: PMC4099024.
- [72] Wilczyński B, Zorena K, Ślęzak D. Dynamic knee valgus in single-leg movement tasks. Potentially modifiable factors and exercise training options. A literature review. *Int J Environ Res Publ Health* 2020;17(21):8208. <https://doi.org/10.3390/ijerph17218208>. PMID: 33172101; PMCID: PMC7664395.
- [73] Di Paolo S, Lopomo NF, Della Villa F, Paolini G, Figari G, Bragonzoni L, et al. Rehabilitation and return to sport assessment after anterior cruciate ligament injury: quantifying joint kinematics during complex high-speed tasks through wearable sensors. *Sensors (Basel)*. 2021;21(7):2331. <https://doi.org/10.3390/s21072331>. PMID: 33810610; PMCID: PMC8037754.
- [74] Taborri J, Molinaro L, Santospagnuolo A, Vetrano M, Vulpiani MC, Rossi S. A machine-learning approach to measure the anterior cruciate ligament injury risk in female basketball players. *Sensors (Basel)*. 2021;21(9):3141. <https://doi.org/10.3390/s21093141>. PMID: 33946515; PMCID: PMC8125336.
- [75] Moatshe G, Brady AW, Slette EL, Chahla J, Turnbull TL, Engebretsen L, et al. Multiple ligament reconstruction femoral tunnels: intertunnel relationships and guidelines to avoid convergence. *Am J Sports Med* 2017;45(3):563–9. <https://doi.org/10.1177/0363546516673616>. Epub 2016 Nov 24. PMID: 27872126.
- [76] Figueroa F, Wakelin E, Twigg J, Fritsch B. Comparison between navigated reported position and postoperative computed tomography to evaluate accuracy in a robotic navigation system in total knee arthroplasty. *Knee* 2019;26(4):869–75. <https://doi.org/10.1016/j.knee.2019.05.004>. PMID: 31171424.
- [77] Cheng T, Zhang GY, Zhang XL. Does computer navigation system really improve early clinical outcomes after anterior cruciate ligament reconstruction? A meta-analysis and systematic review of randomized controlled trials. *Knee* 2012;19(2):73–7. <https://doi.org/10.1016/j.knee.2011.02.011>. PMID: 21458274.
- [78] Zaffagnini S, Klos TV, Bignozzi S. Computer-assisted anterior cruciate ligament reconstruction: an evidence-based approach of the first 15 years. *Arthroscopy* 2010;26(4):546–54. <https://doi.org/10.1016/j.arthro.2009.09.018>. PMID: 20362837.
- [79] Pearle AD, Kendoff D, Musahl V, Warren RF. The pivot-shift phenomenon during computer-assisted anterior cruciate ligament reconstruction. *J Bone Joint Surg Am* 2009;91(Suppl 1):115–8. <https://doi.org/10.2106/JBJS.H.01553>. PMID: 19182036.