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[Intervention Review]

Computer-assisted surgery for knee ligament reconstruction

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ABSTRACT

Background

Anterior cruciate ligament (ACL) reconstruction is one of the most frequently performed orthopaedic procedures. The most common technical cause of reconstruction failure is graft malpositioning. Computer-assisted surgery (CAS) aims to improve the accuracy of graft placement. Although posterior cruciate ligament (PCL) injury and reconstruction are far less common, PCL reconstruction has comparable difficulties relating to graft placement. This is an update of a Cochrane review first published in 2011.

Objectives

To assess the effects of computer-assisted reconstruction surgery versus conventional operating techniques for ACL or PCL injuries in adults.

Search methods

For this update, we searched the Cochrane Bone, Joint and Muscle Trauma Group Specialised Register (from 2010 to July 2013), the Cochrane Central Register of Controlled Trials (CENTRAL) (Issue 5, 2013), MEDLINE (from 2010 to July 2013), EMBASE (from 2010 to July 2013), CINAHL (from 2010 to July 2013), article references and prospective trial registers.

Selection criteria

We included randomized controlled trials (RCTs) and quasi-randomized controlled trials that compared CAS for ACL or PCL reconstruction versus conventional operating techniques not involving CAS.

Data collection and analysis

Two authors independently screened search results, assessed the risk of bias in the studies and extracted data. Where appropriate, we pooled data using risk ratios (RR) or mean differences (MD), both with 95% confidence intervals (CI).

Main results

The updated search resulted in the inclusion of one new study. This review now includes five RCTs with 366 participants. There were more female than male participants (70% were female); their ages ranged from 14 to 53 years. All trials involved ACL reconstructions performed by experienced surgeons.

Assessing the studies' risk of bias was hampered by poor reporting of trial methods, and consequently several studies were judged to be 'unclear' for several types of bias. One trial presenting primary outcome data was at high risk of detection bias from lack of clinician blinding and attrition bias from an unaccounted loss to follow-up at two years.

We found moderate quality evidence (three trials, 193 participants) of no clinically relevant difference between CAS and conventional surgery in International Knee Documentation Committee (IKDC) subjective scores (self-reported measure of knee function; scale of 0 to 100 where 100 was best function). Pooled data from two of these trials (120 participants) showed a small, but clinically irrelevant difference favouring CAS (MD 2.05, 95% CI -2.16 to 6.25). A third trial (73 participants) also found minimal difference in IKDC subjective scores (reported MD 0.2).

We found low quality evidence (two trials, 120 participants) showing no difference between the two groups in Lysholm scores, also measured on a scale 0 to 100 where 100 is best function (MD 0.25, 95% CI -3.75 to 4.25). We found very low quality evidence (one trial, 40 participants) showing no difference between the two groups in Tegner scores. We found low quality evidence (three trials, 173 participants) showing the majority of participants in both groups were assessed as having normal or nearly normal knee function (86/87 with CAS versus 84/86 with no CAS; RR 1.01, 95% CI 0.96 to 1.06).

Similarly, no differences were found for our secondary outcome measures of knee stability, loss in range of motion and tunnel placement. None of the trials reported on re-operation.

No adverse post-surgical events were reported in two trials (133 participants); this outcome was not reported by the other three trials.

CAS use was associated with longer operating times compared with conventional operating techniques: the mean difference in operating times reported in the studies ranged between 9 and 27 minutes.

Authors' conclusions

From the available evidence, we are unable to demonstrate or refute a favourable effect of CAS for cruciate ligament reconstructions of the knee compared with conventional reconstructions. However, the currently available evidence does not indicate that CAS in knee ligament reconstruction improves outcome. There is a need for improved reporting of future studies of this technology.

PLAIN LANGUAGE SUMMARY

Computer-assisted surgery for knee ligament reconstruction

Background

The anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) are centrally located ligaments in the knee. An ACL injury is common in sports such as football and basketball, while PCL injury is far less common. An operation to reconstruct the ACL, usually with a tendon, is one of the most frequently performed orthopaedic procedures. It is very important to perform this operation accurately to obtain a satisfactory outcome and a computer may be able to assist with this. This review set out to examine the evidence for using an additional computer during the operation to help with the positioning of the bone tunnels in which to place the replacement tendon.

Study characteristics

We conducted a comprehensive search of medical literature up to 5 July 2013 to find randomized controlled trials (clinical studies where people are randomly put into one of two or more treatment groups) and quasi-randomized controlled trials (e.g. allocation by hospital record number or date of birth) comparing computer-assisted surgery (CAS) of the ACL or PCL with conventional operating techniques not involving CAS in adults.

Key results and quality of evidence

We found five studies for inclusion in this review. These studies involved 366 participants, mainly female (70%), aged 14 to 53 years. All five trials involved ACL reconstruction.

We were uncertain about the reliability of study findings due to poor reporting of trial methods and, sometimes, results. Our assessment of the quality of the evidence available for individual outcomes ranged from 'moderate' quality (which means further research may change the estimate) to 'very low' quality (which means we are very uncertain about the estimate).

The trials provided some moderate quality evidence that there was no difference between computer-assisted surgery and conventional surgery for patient-reported knee function. There was low quality evidence of no difference between the two groups in self-reported function score and very low quality evidence of no difference in a score measuring activity levels. There was low quality evidence of no difference between the two treatment groups in the number of people assessed by clinicians as having a normal or nearly normal knee function at the final follow-up time. No adverse post-surgical events were reported in two trials; this outcome was not reported by the other three trials. CAS took longer to do than conventional surgery (from 9 to 27 minutes longer).

Overall, the currently available evidence does not indicate that CAS in knee ligament reconstruction improves outcome compared with conventional surgery.

SUMMARY OF FINDINGS

Summary of findings for the main comparison. Computer-assisted reconstruction surgery compared with conventional operating techniques for ACL or PCL injuries in adults

Participant or population: People, primarily adults, undergoing ACL reconstruction surgery

Settings: Inpatient

Intervention: Computer-assisted reconstruction surgery

Comparison: Conventional operating techniques

Outcomes	Illustrative comparative risks* (95% CI)		Relative effect (95% CI)	No of Participants (studies)	Quality of the evidence (GRADE)	Comments
	Assumed risk	Corresponding risk				
	Conventional operating techniques	Computer-assisted reconstruction surgery				
Functional status at 2 years or more: subjective IKDC score (score 0 to 100: best function)	The mean IKDC subjective score ranged across control groups from 73.1 to 83	The mean IKDC subjective score in the intervention groups was 2.05 points higher (-2.16 to 6.25) ¹	-	120 (2 studies)	⊕⊕⊕○ ² moderate	A third trial (73 participants) reported almost identical scores in the 2 groups at between 1 and 4.5 years' follow-up: 89.7 versus 89.5
Functional status at 2 years or more: Lysholm score (score 0 to 100: best function)	The mean Lysholm score ranged across control groups from 87.9 to 89	The mean Lysholm score in the intervention groups was 0.25 points higher (-3.75 to 4.25)	-	120 (2 studies)	⊕⊕○○ ³ low	-
Functional status at 2 years or more: Tegner activity score (score 0 to 10: highest activity)	The mean Tegner score was 5.58	The mean Tegner score was 0.35 points lower (-1.81 to 1.11)	-	40 (1 study)	⊕○○○ ⁴ very low	-
IKDC knee examination grade normal (grade A) or nearly normal (grade B) - Inter-	976 per 1000 ⁵	986 per 1000 (937 to 1036)	RR 1.01 (95% CI 0.96 to 1.06)	173 (3 studies)	⊕⊕○○ ⁶ low	Conversely only 3/173 knees were graded as abnormal

mediate/long-term follow-up (1 to 4.5 years)						
Adverse post-surgical events	See comment	See comment	Not estimable	140 (2 studies)	See comment	2 trials reported no events. The other 3 trials did not report this outcome. None reported on re-operation

*The basis for the **assumed risk** (e.g. the median control group risk across studies) is provided in footnotes. The **corresponding risk** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

ACL: anterior cruciate ligament; **CI:** confidence interval; **IKDC:** International Knee Documentation Committee; **PCL:** posterior cruciate ligament; **RR:** risk ratio

GRADE Working Group grades of evidence

High quality: Further research is very unlikely to change our confidence in the estimate of effect.

Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.

Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Very low quality: We are very uncertain about the estimate.

1. The 95% confidence intervals not include a clinically relevant difference. The minimum clinically important difference for the subjective IKDC score was estimated to be 6.3 at 6 months and 16.7 at 12 months for people with focal cartilage defects
2. The quality of evidence for the subjective IKDC was downgraded 1 level for serious study limitations
3. The quality of evidence for the Lysholm score was downgraded 1 level for serious study limitations and 1 level for imprecision
4. The quality of evidence for the Tegner score was downgraded 1 level for serious study limitations and 2 levels for imprecision
5. Basis for assumed risk was the mean incidence for the 3 contributing trials
6. The quality of evidence for the IKDC objective assessment (number with normal or nearly normal grades) was downgraded 1 level for serious study limitations and 1 level for imprecision

BACKGROUND

Description of the condition

The anterior and posterior cruciate ligaments (ACL and PCL) are located within the knee joint. These connect the femur (thigh bone) to the tibia (shin bone) and play a crucial stabilising role. The ACL restrains the anterior translation (forward movement) of the tibia relative to the femur. The PCL restrains posterior translation (backward movement) of the tibia relative to the femur. Both are also important for varus/valgus (sideward) and rotational stability of the knee joint during movement.

ACL injury is a common orthopaedic problem with an annual incidence of approximately 200,000 cases per year in the US (AAOS 2007). It often results from an abrupt change in direction or rapid deceleration during sports, typically football or skiing. As well as knee instability, an ACL rupture can give rise to recurrent episodes of the knee 'giving way' and pain (Noyes 1983), and can result in discontinuation or limitation of sporting activities (Barrack 1990a; Barrack 1990b). Although the natural history is not clearly defined, the ACL injury predisposes the knee to chronic instability and further damage, such as meniscal tears, with a consequent impairment to quality of life (Mohtadi 1998). An ACL injury may also predispose to early osteoarthritis (Daniel 1994; Meuffels 2009; Sherman 1988).

PCL injury is less common, comprising 1% to 20% of knee ligament injuries. It is most often sustained through a direct blow to the anterior part of the tibia in a traffic accident (e.g. a dashboard injury, in which the lower leg of the flexed knee hits the dashboard) or after athletic trauma (in which an athlete receives a blow to the anterior surface of the tibia) (Schulz 2003). Complaints after a PCL injury can include instability or knee pain, especially patellofemoral, and, in the long term, this injury can lead to progressive osteoarthritis and functional limitations (Margheritini 2002).

Description of the intervention

An ACL rupture with recurrent knee instability is most often treated with a tendon graft reconstruction, which involves reconstruction of the damaged ligament using a strip of tendon, often from the patient's knee (the patellar tendon or hamstring). In most cases, the surgery is done arthroscopically. As well as in the type of graft, there is much variation in surgical methods used in practice. Two commonly used types of reconstruction are the traditional single bundle reconstruction and the double bundle reconstruction, which represents the more anatomical approach. There is continuing uncertainty about which is the better of these two methods (Tiamklang 2012), and which are the best methods and devices for fixing the graft (Zeng 2013).

The primary goal of surgery is to restore a stable knee without incurring extra morbidity. Approximately 100,000 ACL reconstructions are performed annually in the US (AAOS 2007). PCL reconstruction is usually reserved for more complex knee injuries (Peccin 2005).

Navigation systems have been introduced to surgery, including orthopaedic surgery (Zaffagnini 2010). These systems are known as computer-assisted surgery (CAS) or computer-assisted orthopaedic surgery (CAOS). The most common types use images acquired pre-operatively by fluoroscopic computed tomography (CT) or

intra-operatively by fluoroscopy (dynamic X-rays) or an image-free system using pre-specified anatomical landmarks.

During surgery, the CAS system uses infrared feedback, enabling orientation of the surgical instruments relative to the anatomical structures of interest. In cruciate ligament reconstruction, CAS has the potential to optimize the preparation for grafting, which involves drilling into the femur and tibia to form a bone tunnel, and subsequent placement of the graft. The system also has the capacity to monitor femur and tibia positions and movements. With this information, knee stability and range of motion can be optimized during surgery.

For a clinically successful outcome, an accurate graft placement is considered essential. This is accomplished by an exact and reproducible tunnel placement. Although the anatomic attachment sites of the ACL and PCL have been well described, these vary to a great degree between individuals. The optimal bone tunnel placement for ACL and PCL grafts also remains controversial. Current surgical practice focuses on placing the bone tunnels within the anatomic insertion sites of the native ACL and PCL (anatomic placement). Given the individual variation in anatomy, defining a universal optimal position is not possible, thus an individualized approach is necessary (Meuffels 2012). The surgeon visualizes and chooses the most appropriate tunnel position based on their experience combined with identification of the anatomical landmarks for the femoral and tibial side. For instance, for the femoral tunnel position, the ACL footprint is used if visible and, if possible, is combined with the bony contour of the medial side of the lateral femoral condyle and the height and depth of the medial side of the femoral condyle. The size and shape of the femoral condyle or intercondylar notch, or both, can then be used to determine the appropriate tunnel position by visualizing the angle and height or by measuring and marking the central position of the femoral tunnel aperture.

How the intervention might work

Malposition of the graft can lead to limited range of motion, impingement of and damage to the graft, instability and re-injury. The most common cause of technical failure of cruciate ligament reconstruction is the misplacement of the bone tunnel (Giffin 2001; Morgan 2012; Nakagawa 2007). CAS could potentially give a more anatomically reproducible ACL or PCL reconstruction with an exact bone tunnel placement, which could potentially improve outcome by increasing knee stability and lowering the risk of complications, especially those associated with limited range of motion and knee discomfort. However, CAS requires a longer operating time, an extra investment in the necessary equipment and the additional fixation of navigation probes to the patient's leg. As with every new development, using CAS involves a learning curve for the experienced surgeon. However, compared with traditional surgical techniques, using CAS may shorten the learning curve for the novice surgeon (Scheep 2005).

Why it is important to do this review

Cruciate ligament reconstruction is a very common orthopaedic procedure. The pressure to implement technological advances is unrelenting. Thus, it is important to review the current evidence systematically comparing the effects of computer-assisted knee ligament reconstruction versus conventional surgery for the reconstruction of the ACL or PCL deficient knee. The previous

version of this review, published in 2011, concluded there was insufficient evidence to advise for or against the use of CAS. This absence of evidence and the rapid development and use of computer techniques, made it important to do an update of this review in order to ensure that treatment decisions are made on the most up-to-date and reliable evidence.

OBJECTIVES

To assess the effects of computer-assisted reconstruction surgery compared with conventional operating techniques for ACL or PCL injuries in adults.

To investigate possible effect modification by:

1. the type of system used for CAS: for example, intraoperative use of X-rays, pre-operative use of radiology (CT, magnetic resonance imaging (MRI), X-rays), intraoperative landmarks or bone morphing (this is using data such as intraoperative acquisition of points on the bone surface, to compute the shape (geometrical features) of the bone to aid surgical planning);
2. the type of ligament reconstruction: ACL or PCL or both.

METHODS

Criteria for considering studies for this review

Types of studies

Randomized controlled trials (RCTs) and quasi-randomized controlled trials (for example, allocation by hospital record number or date of birth) that compared CAS with conventional operating techniques.

Types of participants

Skeletally mature people undergoing reconstruction of the ACL, PCL or both ligaments. We included trials including skeletally immature people, based on age, provided that these were few and balanced between groups.

We included studies involving a policy of surgical treatment of other concomitant soft-tissue knee injuries, such as meniscal tears, in the same operation as cruciate ligament reconstruction provided this applied to both groups.

Types of interventions

Reconstruction of the ACL or PCL, or both using either CAS or conventional techniques. There was no exclusion based on the type of graft or the method of graft fixation.

Types of outcome measures

Primary outcomes

Validated self-reported health and quality of life measures, including knee-specific measures

These could include, for example, 36-item Short Form (SF-36), Tegner scale (Tegner 1985), Lysholm scale (Lysholm 1982), International Knee Documentation Committee (IKDC) subjective part (Irrgang 2001), the Cincinnati knee scales (Noyes 1989), Knee injury and Osteoarthritis Outcome Score (KOOS) (Roos 1998), and the ACL Quality of Life outcome measure (Mohtadi 1998).

Note: in the next update, we plan to separate out joint-specific and generic measures of function and quality of life.

Measures of objective assessment of overall knee function

International Knee Documentation Committee (IKDC) objective part (Hefti 1993). The IKDC 2000 forms can be accessed at [IKDC forms](#).

Secondary outcomes

Objective measures of knee function

These measures of specific aspects of knee function could include, for example, range of motion, static stability (measured by arthrometric (for instance KT 1000 or 2000) or other stability assessment devices, strength (Cybex muscle testing or equivalent).

Technical and anatomical outcomes

- Tunnel positions and positioning of the graft
- Development of radiological osteoarthritis

Adverse post-surgical events

- Re-rupture of the ACL
- Infection
- Venous thromboembolism

Measures of resource use

- Duration of surgery
- Radiological screening time
- Re-operation
- Formal economic evaluation

Timing of outcome measurement

We assessed the effect of the interventions in the short term (within six months of ACL/PCL reconstruction), intermediate term (between six months and two years of ACL or PCL reconstruction) and long term (more than two years after ACL or PCL reconstruction).

Search methods for identification of studies

Electronic searches

For this update, we searched the Cochrane Bone, Joint and Muscle Trauma Group Specialised Register (from 2010 to July 2013), the Cochrane Central Register of Controlled Trials (CENTRAL) (Issue 5, 2013), MEDLINE (from 2010 to July 2013), EMBASE (from 2010 to July 2013) and CINAHL (from 2010 to July 2013). Details of the search strategies used for the previous version of the review are given in [Meuffels 2011](#).

In MEDLINE (PubMed), the first two levels of the optimal trial search strategy (Higgins 2006) were modified slightly and combined with the subject specific search. The complete search strategy is shown in [Appendix 1](#). The search strategies that were used in *The Cochrane Library* (Wiley Online Library), EMBASE (Embase.com) and CINAHL (EBSCO online) are also shown in [Appendix 1](#).

We also searched the [WHO International Clinical Trials Registry Platform](#) and the [Current Controlled Trials Meta Register](#) (both July 2013) for ongoing and recently completed trials.

Searching other resources

We checked the bibliographies of relevant papers identified. Where appropriate and possible, we contacted the corresponding authors of studies identified by the search strategies to obtain other relevant studies not previously included for review.

Data collection and analysis

Selection of studies

Two review authors (VE and DM) independently assessed potentially eligible trials identified by the search strategy.

Data extraction and management

One review author (VE) and an associate with expertise in systematic reviews (Belle van Meer: BM) used pre-piloted data extraction forms to independently extract the data of the newly included trial. They compared the data extracted for this study to achieve consensus. We resolved any differences by discussion. We contacted the trial authors for missing data.

Assessment of risk of bias in included studies

One review author (VE) and an associate with expertise in systematic reviews (BM) independently assessed the risk of bias of the newly included study using the same version of The Cochrane Collaboration's 'Risk of bias' tool as previously ([Higgins 2008](#)). For the item 'blinding', we assessed blinding of 1. participant-reported outcomes, 2. outcomes assessed by a physician and 3. radiological outcomes. In addition to the items from the five domains listed in the tool (sequence generation, allocation concealment, blinding, incomplete outcome data, selective outcome reporting), we also assessed bias relating to differences in the surgeon's experience with the techniques being compared (performance bias). We considered other sources of bias that were not addressed in the domains of the tool in the category 'other sources of bias'; for this category, the review authors judged whether the study was apparently free of other problems that could put it at a high risk of bias.

Measures of treatment effect

For each study, we calculated risk ratios (RR) with accompanying 95% confidence intervals (CI) for dichotomous outcomes, and mean differences (MD) with 95% CI for continuous outcomes.

Dealing with missing data

We contacted trial investigators for missing data. Where appropriate, we performed intention-to-treat analyses to include all participants randomized to the intervention groups. We investigated the effect of drop-outs and exclusions by conducting worst-scenario and best-scenario analyses. If missing standard deviations could not be derived from CI data or retrieved from the study authors, we did not impute standard deviations for the analyses.

Assessment of heterogeneity

We examined forest plots visually for heterogeneity and considered the Chi² test and I² statistic.

Assessment of reporting biases

Should there be sufficient studies (at least 10) available in a future update, we plan to assess publication bias by examining a funnel plot. However, we checked prospective clinical trial registers to help us assess publication bias. We compared the method descriptions of the included studies with the actual reported outcomes in the results section to assess selective outcome reporting bias.

Data synthesis

If the participants, interventions, outcomes and the timing of the outcome measurements were sufficiently similar, we pooled the results using a fixed-effect model. In the presence of clinical or methodological heterogeneity, we planned to use the random-effects model. If necessary in future, we will calculate standardized mean differences for pooling data when outcomes are measured in different units or scales.

Subgroup analysis and investigation of heterogeneity

Should there be sufficient data in future updates, we plan, where appropriate, to explore heterogeneity using subgroup analyses by the type of lesion (ACL, PCL or both) and by CAS system used (CAS systems with or without pre-operative use of fluoroscopy, or preoperative use of radiological data as X-rays, CT or MRI).

We will investigate whether the results of subgroups are significantly different by inspecting the overlap of CI values and by performing the test for subgroup differences available in Review Manager 5 software ([RevMan 2012](#)).

Sensitivity analysis

In future updates, we plan, where appropriate, to conduct sensitivity analyses to explore the effects of various aspects of trial and review methodology, including the effects of missing data, whether allocation was concealed and differences in surgeon's experience with CAS and standard methods of ACL reconstruction.

Quality assessment

We used the GRADE approach to assess the quality of evidence relating to our primary outcomes and adverse post-surgical events (Section 12.2, [Higgins 2011](#)); this informed our [Summary of findings for the main comparison](#).

RESULTS

Description of studies

Results of the search

In the first version of this review ([Meuffels 2011](#)), the search resulted in 517 records, of which five articles reporting four RCTs were included in the review. As two reports appeared to report the same study ([Endele 2009](#); [Mauch 2007a](#)), with the same methods being performed at the same hospital in the same time interval (recruitment: December 2003 to April 2004), we considered them as one study ([Mauch 2007](#)). There was one ongoing trial (former study ID: Meuffels). The new searches for this update, run in July 2013, identified 202 articles: Cochrane Bone, Joint and Muscle Trauma Group Specialised Register (4), CENTRAL (23), MEDLINE (22), EMBASE (137), CINAHL (16), international registries of prospective RCTs and handsearches (0). Of these, a published report of the RCT formerly listed as ongoing was found ([Meuffels 2012](#)). There

are no excluded or ongoing trials or studies waiting assessment. A flow diagram summarising the study selection process is shown in [Figure 1](#).

Figure 1. Study flow diagram

Included studies

We included five studies, conducted in single centres in France (Chouteau 2008), the Czech Republic (Hart 2008), Germany (Mauch 2007), The Netherlands (Meuffels 2012), and France (Plaweski 2006). Details of each study are shown in the [Characteristics of included studies](#) table. All included studies compared computer-assisted ACL reconstruction with conventional surgery. No study involved PCL reconstruction.

Participants

The included studies reported data from 366 participants (262 males and 104 females). The ages of the participants included in the review ranged from 14 to 53 years. Three studies included participants younger than 18 years of age (Chouteau 2008; Hart 2008; Plaweski 2006). Separate outcome data on these skeletally immature participants were not available, but, since the numbers of participants in this category were low and were balanced between groups, we included these studies in this review. All participants in the five studies underwent ACL reconstruction.

Interventions

All five included studies compared computer-assisted ACL reconstruction with conventional surgery. However, the studies differed in the type of CAS used and in the techniques used for the conventional reconstruction. Chouteau 2008 and Meuffels 2012 used a CAS system that made use of intra-operative radiographic images to template the preferred femur and tibial tunnel placement. Both Hart 2008 and Mauch 2007 used the image-free OrthoPilot (Braun-Aesculap) system to aid in selecting the femoral and tibial tunnel placement. The image-free system of Surgetics using the Julliard protocol (Praxim) was used in Plaweski 2006.

All studies used devices to aid in tunnel placement. The tibial aperture of the tunnel was chosen using a guided cannulated aiming device (Acufex) in three studies (Mauch 2007; Meuffels 2012; Plaweski 2006). Mauch 2007 and Meuffels 2012 placed the tunnel at 7 mm and Plaweski 2006 at 6 mm anterior to the PCL on the tibia. Neither Chouteau 2008 nor Hart 2008 described the tibial tunnel placement in sufficient detail.

For the conventional femoral tunnel placement, Hart 2008 and Mauch 2007 planned the tunnel position by positioning the femur at the 10.30 o'clock position on the right side and 1.30 o'clock position on the left side. Meuffels 2012 planned a slightly more horizontal position aimed at the 10 o'clock position for the right knee and 2 o'clock position for the left knee. Plaweski 2006 planned the femoral tunnel in a slightly more vertical position with the femur at 11 o'clock on the right side and 1 o'clock on the left side. Chouteau 2008 did not describe the type of femoral placement.

Plaweski 2006 used a four-stranded hamstring autograft to reconstruct the ACL. Meuffels 2012 used a single-bundle, transtibial technique using either bone-patellar-tendon-bone (BPTB) or looped semitendinosus-gracilis autograft. The three remaining studies used BPTB autografts. A miscellaneous array of fixation

techniques (press-fit, interference screw and extra-cortical fixation) were used.

Outcomes

In Chouteau 2008, outcomes were assessed at a mean of 2.2 years (range 1 to 4.5 years). Meuffels 2012 reported only on tunnel position one day after operation. In the other three studies, long-term outcomes at two or more years post-operatively were reported.

Functional assessment of the participant's ACL reconstructed knee was assessed by the IKDC subjective score and the Lysholm score in two studies (Hart 2008; Mauch 2007), and by the post-operative IKDC knee examination grade in three studies (Chouteau 2008; Mauch 2007; Plaweski 2006). No study addressed return to previous activity level or generic quality of life measures.

The IKDC objective score was assessed by Chouteau 2008, Mauch 2007, and Plaweski 2006.

Secondary outcomes were reported infrequently, and when reported, the authors used different measurement tools for the same type of outcome, for instance, femoral and tibial aperture tunnel position. Meuffels 2012 used three-dimensional (3D) positioning of the intra-articular femoral and tibial tunnel apertures as depicted with a CT scanner. All other included studies reported tibial tunnel position on the lateral X-ray. Mauch 2007 also added MRI measurement of the tunnel position and of the graft quality. The measurements that were used consisted of absolute or relative measurements from the anterior to the posterior tibial plateau or looked at the position in relation to the Blumensaat's line (roof of the intercondylar notch) in full extension.

Femoral position was assessed using the triangle method by Chouteau 2008, the quadrant method by Mauch 2007 on X-ray and by Meuffels 2012 on the 3D CT scanner, and the relative position towards the Blumensaat line and the lateral femoral condyle by Hart 2008 and Plaweski 2006.

Stability measurements were assessed separately by the pivot-shift and Lachman test by Plaweski 2006, and the pivot-shift by Hart 2008. Range of motion loss was reported for Chouteau 2008.

Two trials reported on adverse post-surgical events (Hart 2008; Plaweski 2006).

None of the included studies performed an economic evaluation, but the MD between the groups in length of operation was reported by all studies. None of the studies reported the need to abandon the CAS or to alter the CAS proposed tunnel placement.

Risk of bias in included studies

Overall, it was difficult to judge risk of bias or the methodological quality of the five included studies due to poor reporting. The results of the risk of bias assessment are shown in [Figure 2](#) and [Figure 3](#).

Figure 2. Risk of bias summary: review authors' judgements about each risk of bias item for each included study (Empty cells = not applicable)

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding (performance bias and detection bias): Participant-reported outcomes	Blinding (performance bias and detection bias): Outcome assessed by physician	Blinding (performance bias and detection bias): Radiological outcome	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Surgeon's experience with the operations	Other bias
Chouteau 2008	?	?	?	+	?	+	?	?	+
Hart 2008	?	?	+	+	?	+	?	?	+
Mauch 2007	+	?	?	-	+	-	?	?	?
Meuffels 2012	+	+			+	+	-	+	+
Plaweski 2006	?	+	?	+	?	+	?	-	+

Figure 3. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies

Allocation

We judged two trials at low risk of bias relating to random sequence generation: [Mauch 2007](#) drew lots and [Meuffels 2012](#) used a computer-generated procedure (block randomization using a variable block size). We judged the other three trials, which did not provide any details on their methods of sequence generation, at unclear risk of bias. We rated [Meuffels 2012](#), which confirmed independent administration of allocation, and [Plaweski 2006](#), where sealed envelopes were opened just before surgery, at low risk of bias relating to allocation concealment. No details were provided by the other three trials, which we judged at unclear risk of selection bias relating to allocation concealment.

Blinding

We assessed blinding for trial participants, surgeons and outcome assessors. In a surgical trial, the surgeon cannot be blinded.

Participant (patient) blinding was described in [Hart 2008](#), which we judged at low risk of bias. We rated the risk of detection bias related to participant-reported outcome assessment as unclear in three trials ([Chouteau 2008](#); [Mauch 2007](#); [Plaweski 2006](#)). (To 2014, [Meuffels 2012](#) has not reported these outcomes.)

The outcome assessor for physician-reported outcomes was blinded or independent in three trials ([Chouteau 2008](#); [Hart 2008](#); [Plaweski 2006](#)), but not in [Mauch 2007](#); we judged this at high risk of detection bias for these outcomes. (To 2014, [Meuffels 2012](#) has not reported these outcomes.)

Assessment of radiological outcomes was blinded in two trials ([Mauch 2007](#); [Meuffels 2012](#)), which we judged at low risk of detection bias. We judged the other three trials as being at unclear risk of this bias.

Incomplete outcome data

Four studies described loss to follow-up or had no loss to follow-up for the outcomes reported and so were assessed as being at low risk

of bias in this domain. [Mauch 2007](#) did not describe loss to follow-up; however, 13 participants were not mentioned in the later report of this trial ([Endele 2009](#)). We assessed this trial as being at high risk of attrition bias.

Selective reporting

We considered [Meuffels 2012](#) to be at high risk of selective reporting bias because only placement was reported despite the fact participant-reported outcomes and physical examination were recorded. However, the trial authors have assured the independent reviewers for this study that these results will be published in a separate publication. It was unclear whether there was selective reporting in any of the other included studies.

Other potential sources of bias

There was an unclear risk of performance bias relating to surgeon experience in [Chouteau 2008](#), [Mauch 2007](#), and [Hart 2008](#). We considered [Plaweski 2006](#) at high risk of performance bias because the study's start coincided with the introduction of CAS into the department. We judged [Meuffels 2012](#) at low risk of performance bias as the surgeons had prior experience with CAS.

We judged that all trials with the exception of [Mauch 2007](#) were at low risk of any other bias. There was a possible bias in [Mauch 2007](#) relating to the lack of acknowledgement of the earlier report of this trial in the later report and the omission of 13 participants from investigations in the later report.

Effects of interventions

See: [Summary of findings for the main comparison](#) Computer-assisted reconstruction surgery compared with conventional operating techniques for ACL or PCL injuries in adults

Primary outcomes

1. Self-reported health and quality of life measures (knee function and generic)

Pooled data from two studies showed no statistically significant difference between the groups in the subjective IKDC score at two or more years' follow-up (MD 2.05, 95% CI -2.16 to 6.25; 120 participants; [Analysis 1.1](#)) ([Hart 2008](#); [Mauch 2007](#)). This difference is not clinically relevant; as supported by findings from [Greco 2010](#). Although for cartilage defects rather than ACL reconstruction, [Greco 2010](#) estimated the minimum clinically important difference for the subjective IKDC score was 6.3 at six months and 16.7 at 12 months. [Chouteau 2008](#) (73 participants) also found no significant difference in the mean IKDC subjective score between 1 and 4.5 years' follow-up (89.7 versus 89.5); no standard deviations were reported for this outcome.

Two studies reported Lysholm scores ([Hart 2008](#); [Mauch 2007](#)). Pooled data showed no significant difference between the two groups (MD 0.25, 95% CI -3.75 to 4.25; 120 participants; [Analysis 1.2](#)).

One study found no significant difference in Tegner level of activity scores (0 to 10: highest level of activity) between the two groups (MD -0.35, 95% CI -1.81 to 1.11; 40 participants at 2-year follow-up; [Analysis 1.3](#)) ([Mauch 2007](#)).

2. International Knee Documentation Committee Knee Examination Grade (objective score)

Three studies reported the IKDC knee examination grades at final follow-up ([Chouteau 2008](#); [Mauch 2007](#); [Plaweski 2006](#)). There was no statistically significant difference between CAS and conventional reconstruction in those knees with normal or nearly normal grades (86/87 versus 84/86; RR 1.01, 95% CI 0.96 to 1.06; 173 participants; [Analysis 1.4](#)). The knees of the other three participants were graded as abnormal.

Secondary outcomes

Other objective measures of knee function

Rotational stability was measured using the pivot shift test, which was dichotomised as either negative (0) or positive (+, ++, +++). Three studies provided data; there was no statistically significant difference between the two groups in those knees with a normal (negative) pivot shift test at follow-up (RR 1.06, 95% CI 0.91 to 1.22; 180 participants; [Analysis 1.5](#)) ([Hart 2008](#); [Mauch 2007](#); [Plaweski 2006](#)).

Reported arthrometric testing was performed with a KT-1000 in two studies ([Chouteau 2008](#); [Hart 2008](#)), and with a Telos device at 200 Newtons in one study ([Plaweski 2006](#)). None of the trials found significant differences between the two groups ([Appendix 2](#)).

We found no reports of strength outcomes (Cybex muscle testing or equivalent).

[Chouteau 2008](#) reported two participants with some loss of range of motion in the CAS group and three in the control group.

Technical and anatomical outcomes

Tunnel placement is an important aspect of ACL reconstruction surgery. All five studies reported the tibial tunnel position visualised on post-operative imaging acquired by X-ray images.

[Meuffels 2012](#) assessed tibial tunnel placement with the use of 3D CT. [Mauch 2007](#) used X-ray images and visualised tibial tunnel position using MRI measurement methods. The three remaining studies used X-ray images. This made pooling of the tunnel placement position data impossible. No significant differences were reported for overall placement between the two groups in any of the five trials ([Appendix 3](#)).

[Chouteau 2008](#), [Hart 2008](#), and [Plaweski 2006](#) also reported the femoral tunnel position on post-operatively acquired X-ray images. [Meuffels 2012](#) assessed femoral tunnel placement with the use of 3D CT. [Mauch 2007](#) visualised the femoral tunnel on post-operatively acquired MRI. [Chouteau 2008](#) showed a significantly more accurate tunnel placement for the femur in favour of the CAS group. None of the other studies showed a statistically significant difference between CAS and the conventional ACL reconstruction groups ([Appendix 4](#)).

None of the trials reported on outcomes relating to the development of radiological osteoarthritis.

Adverse post-surgical events

[Hart 2008](#) reported that there was no re-rupture of the ACL, loss of motion, infection or venous thromboembolism in either group. [Plaweski 2006](#) did not observe any infection, clinical thromboembolic events or haematoma requiring intervention. There was no specific reporting of post-operative complications in the other three trials.

Measures of resource use

Reported additional operating time for the CAS groups was 9.3 minutes in [Chouteau 2008](#), 11 minutes in [Hart 2008](#), 15 minutes in [Mauch 2007](#), 26 minutes in [Plaweski 2006](#), and 27 minutes in [Meuffels 2012](#). This difference was statistically significant in [Meuffels 2012](#) (131.9 versus 105.2 minutes; MD 26.70 minutes, 95% CI 19.67 to 33.73 minutes; [Analysis 1.6](#)). The difference was also reported to be statistically significant in [Plaweski 2006](#) (mean operating times: 78 minutes (range 40 to 120 minutes) in the CAS group versus 52 minutes (range 30 to 65 minutes) for the conventionally treated participants; reported P value = 0.03). [Chouteau 2008](#) also reported radiological screening time in the CAS group of "15 ± 5" seconds.

We found no data on frequency of re-operation. No formal economic evaluations were identified.

DISCUSSION

ACL reconstruction is one of the most frequently performed orthopaedic interventions, especially in the young active population. An improved surgical outcome has the potential to reduce time lost from work or athletic activity and additional suffering. This systematic review examined the evidence from RCTs for computer-assisted ACL surgery.

Summary of main results

We included five RCTs (366 participants) who underwent ACL reconstruction. The trials were heterogeneous but all involved ACL lesions eligible for ACL reconstruction.

We found moderate quality evidence (three trials, 193 participants) showing no statistically significant or clinically relevant differences

between CAS versus conventional surgery in IKDC subjective scores (self-reported measure of knee function). We found low quality evidence (two trials, 120 participants) showing no difference between the two groups in Lysholm scores. We found very low quality evidence (one trial, 40 participants) showing no difference between the two groups in Tegner scores. We found low quality evidence (three trials, 173 participants) showing the majority of participants in both groups were assessed as having normal or nearly normal knee function. No adverse post-surgical events were reported in two trials; this outcome was not reported by the other three trials. Similar findings of an absence of differences applied to reports of other secondary outcome measures such as knee stability and tunnel placement.

Therefore, apart from a consistently and significantly increased operating time (between 9.3 and 27 minutes longer) for participants randomized to CAS, no difference in outcome of CAS versus conventional ACL reconstruction was detected.

Overall completeness and applicability of evidence

The applicability of the results from this review is strengthened by the studies having been performed by research groups from different countries, and by the diversity in the CAS ACL reconstruction systems used. However, incomplete reporting of results and heterogeneity hampered the drawing of firm conclusions regarding the effect of CAS. Since all five included trials were on ACL reconstruction, we can draw no conclusions about PCL reconstruction.

All included trials were single-bundle ACL reconstructions, performed with a transtibial approach for the femoral placement of the tunnel. A transtibial approach can hinder the ideal placement of the femoral tunnel because of restrictions imposed by the shape and orientation of the tibial tunnel. To circumvent this problem, current practice has seen greater use of an accessory anteromedial portal. However, both the CAS ACL reconstruction and the conventional ACL reconstruction were single-bundle ACL reconstructions aiming at an anteromedial bundle femoral position, which is possibly less hindered by a transtibial tunnel.

Another issue is the use of different methods to evaluate tunnel position. The studies of [Mauch 2007](#) and [Meuffels 2012](#) used 3D techniques (MRI and CT) to evaluate the tunnel position, whereas the other studies used conventional X-rays. Imaging techniques using 3D images are superior in depicting tunnel placement over two-dimensional imaging techniques and might be less accurate in detecting differences between the two treatment groups ([Meuffels 2011a](#)).

The study groups were quite similar to large cohorts presented in national registries ([Kvist 2014](#); [Rahr-Wagner 2013](#)). The mean age of the participants ranged in the included studies from 26 to 34 years of age and the majority of participants were male. These participant characteristics are in accordance with the national registries from Sweden and Denmark. The vast majority of grafts recorded in both national registries are hamstrings (more than 80% of the operations); three of our five studies used predominantly BPTB grafts and two studies used hamstring grafts.

All studies were performed by ACL surgeons or surgical groups with ample experience in reconstructive procedures. Only one study reported the experience level with CAS of the participating

surgeons. It is difficult to judge if the high experience level of the surgeons only left a very small margin for improvement by, for instance, the additional help of CAS. It is conceivable that less experienced orthopaedic surgeons may derive more benefit from the use of CAS technology, including in terms of a training intervention, with a potential for improved clinical outcomes for the person. However, this has not been researched.

All CAS systems used were systems using infrared (either active (transmitting) or passive (reflecting)). However, the systems were homogeneous in the technique used to determine the desired tunnel position.

A complete analysis of the effect of the CAS system for these knee ligament reconstructions can only be given when the intra-operative goal can be measured with a universal validated objective gold standard, such as for optimal graft placement. 3D CT is a validated measurement tool for the placement of the tunnel, but there is no consensus on the ideal placement ([Meuffels 2011a](#)). The present outcome measures (rotational stability measurements and radiological measurements for tunnel placement and osteoarthritis) are limited in their ability to measure small but possibly significant clinical differences for short-term and longer-term outcome. In other words, the responsiveness of these related ACL reconstructed knee scores may be insufficient to identify improvements or differences that could be clinically important.

Quality of the evidence

We included only randomized clinical trials as these are considered to have the lowest risk of bias compared with other study designs. However, assessment of the risk of bias was hampered by poor reporting. Therefore, we were mainly unclear about the risk of bias. In terms of our primary outcomes, [Mauch 2007](#) was at high risk of bias relating to attrition bias for all outcomes, and also at high risk of bias relating to outcome assessment by physician. The included studies were small and possibly underpowered to determine an absence of difference between the two treatments. Only the study of [Meuffels 2012](#) performed a power analysis in advance; the number of participants was sufficient to conclude that CAS is not superior to conventional surgery in terms of tunnel placement.

We assessed the evidence available for the primary outcomes and adverse post-surgical events using GRADE. We downgraded the level of evidence for the IKDC subjective score by one level for serious study limitations, mainly reflecting high risk of attrition bias in [Mauch 2007](#). Although the numbers of participants from two trials in the meta-analysis were small (120 participants), the results from a third trial were consistent. Thus, we judged the evidence to be of moderate quality, which means that further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate. We downgraded the level of evidence for the Lysholm score by one level for serious study limitations, mainly reflecting high risk of attrition bias in [Mauch 2007](#), and by one level for imprecision. We downgraded the level of evidence for the Tegner score by one level for serious study limitations, mainly reflecting high risk of attrition bias in [Mauch 2007](#), and by two levels for imprecision given that these data were from one trial only. We downgraded the level of evidence for IKDC objective assessment (number with normal or nearly normal grades) by one level for serious study limitations, mainly reflecting

high risks of bias in [Mauch 2007](#), and one level for imprecision, since the very few participants failed to attain normal or nearly normal grades. Thus, we judged the evidence to be of low quality for both the Lysholm score and IKDC objective assessment of knee function, which means that further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.

Potential biases in the review process

We conducted a comprehensive search strategy. In an effort to locate all relevant trials, we conducted sensitive searches across a comprehensive list of electronic databases. We performed citation tracking and searched for unpublished studies through clinical trials registers. However, it is still possible that we missed some trials. Despite our efforts to contact authors, this review is limited by the availability of data from the included studies. As explained, we concluded that [Endele 2009](#) reported the two-year follow-up results of [Mauch 2007](#) based on the considerable similarity in methods, including identical period of recruitment. Even if this turned out to be an incorrect assumption, the difference in the outcomes reported by the two reports meant that there was no loss of evidence available to this review.

In the first version of our review, we modified our types of outcome measures, which was thus a 'post hoc' modification and susceptible to 'selective reporting bias'. We have kept the revised list of outcomes but plan to revisit this list before our next update to make a better distinction between patient-reported measures relating to knee function and overall quality of life.

Agreements and disagreements with other studies or reviews

To our knowledge, this was the first published systematic review on this specific topic. Since the first version of this review, another systematic review has been published ([Cheng 2012](#)). The conclusion of [Cheng 2012](#) is that there were no differences between CAS and conventional treatment with regard to knee stability and functional assessment during short-term follow-up. Although [Cheng 2012](#) does not include [Meuffels 2012](#) and presents the two trial reports of [Mauch 2007](#) as separate trials, their findings are in keeping with our review, which found no evidence of any differences in knee function at long-term follow-up.

There has also been a review looking at CAS and total knee prosthesis implantation, which did not show any significant differences in clinical outcome but did show, in some instances, that there are fewer outliers when using CAS ([Bauwens 2007](#)). Our review was inconclusive on this point, possibly because all included studies in our review compared CAS with conventional ACL reconstructions performed by experienced ACL surgeons. This might have reduced the differences expected between the groups

because of an already accurate ACL reconstruction, with fewer outliers due to the surgeons' greater experience.

AUTHORS' CONCLUSIONS

Implications for practice

There is insufficient evidence from randomized controlled trials to draw conclusions about the effectiveness of computer-assisted surgery (CAS) for knee ligament reconstructions compared with conventional reconstruction surgery. The currently available evidence does not indicate that CAS in knee ligament reconstruction improves outcome.

Implications for research

The reporting of the existing studies assessing the effects of CAS anterior cruciate ligament (ACL) reconstruction is generally poor, which hampers proper assessment of their methodological quality and the interpretation of results. Before further uptake of this technology, more rigorous studies are needed to establish whether CAS should play an important role in ACL reconstruction. Future studies should follow the Consolidated Standards of Reporting Trials (CONSORT) guidelines for reporting of randomized trials ([Moher 2010](#)), use adequate methods of randomization with adequate concealment of allocation of the participants to treatment groups, use an adequate sample size, blind the participants and outcome assessors to treatment allocation, include reliable and validated outcome measures, and be of sufficient duration to assess medium- and long-term effects.

Although the emphasis should remain on clinically important outcomes, we also advise research into the ideal anatomic placement of the aperture of the femoral and tibial tunnel. A validated and reliable reference standard is needed for this and should be used in further research as well as to inform graft placement and future approaches for CAS.

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References to other published versions of this review

Meuffels 2011

Meuffels DE, Reijman M, Scholten RJ, Verhaar JA. Computer assisted surgery for knee ligament reconstruction. *Cochrane Database of Systematic Reviews* 2011, Issue 6. [DOI: [10.1002/14651858.CD007601.pub2](https://doi.org/10.1002/14651858.CD007601.pub2)]

* Indicates the major publication for the study

CHARACTERISTICS OF STUDIES

Characteristics of included studies [ordered by study ID]

Chouteau 2008

Methods	Randomized controlled trial
Participants	73 participants (37 CAS intervention and 36 control) 46 male and 27 females, age range 14-53 years No inclusion or exclusion criteria mentioned Setting: Department of Orthopaedic Surgery and Sport Medicine, Centre Hospitalier Lyon-Sud, Cedex, France
Interventions	Intervention: CAS of arthroscopic ACL reconstruction CAS type used was self developed software (reported in separate article: Benareau 2002) with the use of lateral full extension X-rays pre-operatively and intra-operative fluoroscopic control Control: arthroscopic ACL reconstruction The ACL reconstruction technique used was BPTB, with the exception of 3 participants who received hamstring grafts. There was no mention of fixation mode
Outcomes	IKDC objective score at follow-up (1.0-4.5 years)

Computer-assisted surgery for knee ligament reconstruction (Review)

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Chouteau 2008 (Continued)

Stability measurement using KT-1000 at baseline and at follow-up (1.0-4.5 years)

Range of motion loss

Radiographic tunnel placement of femur (triangle method) and tibia (Aglietti and Howell method)

Operating time (difference between groups only)

Notes

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding (performance bias and detection bias) Participant-reported outcomes	Unclear risk	Not described whether participants were blinded. Surgeons were not blinded
Blinding (performance bias and detection bias) Outcome assessed by physician	Low risk	"Every patient was reviewed at an average of 2.2 years (1-4.5) by an independent observer, using IKDC scoring system, KT-1000, and passive stress radiographs following the Lerat's protocol"
Blinding (performance bias and detection bias) Radiological outcome	Unclear risk	Not described
Incomplete outcome data (attrition bias) IKDC	Low risk	"One patient was lost in the standard technique series"
Selective reporting (reporting bias)	Unclear risk	No protocol or trial registration available but main reported outcomes listed in Methods
Surgeon's experience with the operations	Unclear risk	"Every procedure was performed by the same senior surgeon" Experience with the CAS technique not described
Other bias	Low risk	No bias likely, including no important baseline differences

Hart 2008

Methods	Randomized controlled trial
Participants	80 participants (40 CAS intervention and 40 control) 64 male and 16 females, age range 16-39 years Inclusion criteria: complete ACL rupture, chronic > 6 months after injury

Hart 2008 (Continued)

Exclusion criteria: other intra-articular procedures, cartilage degeneration or meniscal tears; participants had to have a normal contralateral knee

Setting: Department of Orthopaedics and Traumatology, General Hospital, Znojmo, Czech Republic

Interventions	<p>Intervention: CAS of arthroscopic ACL reconstruction using OrthoPilot (Braun-Aesculap), an image-free system</p> <p>Control intervention: arthroscopic ACL reconstruction</p> <p>Graft used BPTB with titanium Kurosaka interference screw fixation of femoral and tibial side</p> <p>Planned tunnel position: positioning femur at 10.30 o'clock on right side and 1.30 o'clock on left side. Tibia positioning not mentioned</p>
Outcomes	<p>IKDC subjective score, Lysholm score, KT-1000 and Pivot shift at follow-up (24-35 months)</p> <p>Radiographic tunnel placement femur (Bernard and Hertel method) and tibia (Harner method)</p> <p>Adverse post-surgical events</p> <p>Operating time (difference between groups only)</p>
Notes	Funding source: grant from ministry of Health Czech Republic no NR/8477-3

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Unclear risk	Not described
Blinding (performance bias and detection bias) Participant-reported outcomes	Low risk	"The patients were not aware of their group pertinence (navigated or standard)"
Blinding (performance bias and detection bias) Outcome assessed by physician	Low risk	"At the most recent follow-up, the examiner (an orthopaedic surgeon) was not informed about the operative technique (navigated or standard) used in each patient. All patients had a very thin stocking on the operative leg during testing to hide the scars left by markers and to make the double-blinding possible"
Blinding (performance bias and detection bias) Radiological outcome	Unclear risk	No description of blinding of X-rays. "The position of both tunnels was evaluated by an independent experienced physician"
Incomplete outcome data (attrition bias) IKDC	Low risk	No drop-outs or loss to follow-up
Selective reporting (reporting bias)	Unclear risk	No protocol or trial registration available but main reported outcomes listed in Methods
Surgeon's experience with the operations	Unclear risk	<p>"All reconstructions were performed by 1 experienced surgeon"</p> <p>Experience with the CAS technique not described</p>

Hart 2008 (Continued)

Other bias	Low risk	Exclusion criterion was cartilage degeneration or meniscal tears, but how many participants with meniscal or chondral lesions were excluded pre- or intra-operatively was not described
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Mauch 2007

Methods	Randomized controlled trial
Participants	<p>Mauch 2007: 53 participants (24 CAS intervention and 29 control)</p> <p>36 male and 17 female, age range 18-49 years</p> <p>Endele 2009: 40 participants (20 CAS intervention and 20 control)</p> <p>24 male and 16 female, age range 18-54 years</p> <p>Inclusion criteria: rupture of the ACL in an athlete aged 18-59 years</p> <p>Exclusion criteria: revision or complex knee injuries (PCL, LCL)</p> <p>Setting: clinic for Orthopedic Surgery and Sports Traumatology, Stuttgart, Germany</p>
Interventions	<p>Intervention: CAS of arthroscopic ACL reconstruction by the use of the OrthoPilot (Braun-Aesculap), an image-free system</p> <p>Control: arthroscopic ACL reconstruction</p> <p>The ACL reconstruction technique used was an arthroscopic press-fit BPTB: no fixation device was used for the femur, tibia was fixed over an abarticular post screw</p> <p>Planned tunnel position:</p> <ul style="list-style-type: none"> - Tibia tunnel positioning 7 mm anterior of PCL (between anterior lateral meniscus and medial tibial spine) - Femoral tunnel last quadrant for left knee at 1.30 o'clock and for right knee at 10.30 o'clock
Outcomes	<p>IKDC subjective and objective score, Lysholm and stability measurements Lachman, pivot shift and arthrometric testing with Rolimeter at follow-up (24 months)</p> <p>Tegner scores</p> <p>Radiographic tunnel position</p> <ul style="list-style-type: none"> - X-ray 4 days post-operatively of tibia ((Howell method) see results Mauch 2007a) - MRI tunnel position: tibia (Staubli method), femur (Bernard and Hertel quadrant method) - MRI remodelling (category intensity (high/low), tense versus extended, smooth versus rough) <p>Operating time (difference between groups only)</p>
Notes	<p>The earlier report (Mauch 2007a) described 53 participants (24 treated with CAS and 29 receiving conventional treatment) and reported on X-ray visualization of the tibial tunnel placement, whereas the second report (Endele 2009) involved 40 participants (20 in each group) and reported on MRI findings after a median of 24 months (range 22 to 26 months)</p> <p>Additional data received from Dr Endele included SDs for IKDC subjective scores and pivot shift results</p>

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Endele 2009 : "The patients were randomly assigned by drawing lots to 1 of 2 groups"

Mauch 2007 (Continued)

Mauch 2007: drawing lots (24 CAS versus 29 conventional)

Allocation concealment (selection bias)	Unclear risk	Not described
Blinding (performance bias and detection bias) Participant-reported outcomes	Unclear risk	Not described
Blinding (performance bias and detection bias) Outcome assessed by physician	High risk	"Because of the additional scars after transmitter fixation in the navigated group, the examiners could not be blinded"
Blinding (performance bias and detection bias) Radiological outcome	Low risk	"The MRI scans were evaluated by 2 radiologists blinded to the patients and the method used" Blinding of the radiologists measuring the radiographic position of the tibial tunnel was not reported
Incomplete outcome data (attrition bias) IKDC	High risk	No loss to follow-up was described. Tables showed both groups have full follow-up in MRI measurements, and participant outcome. The 2007 publication reported on 53 participants whereas the 2009 (Endele 2009) publication reported on 40 participants. Thus, 13 participants seem to be lost to follow-up
Selective reporting (reporting bias)	Unclear risk	The discrepancies between the 2 reports of this trial give rise to some concerns relating to selective reporting but the outcomes listed in the methods are reported
Surgeon's experience with the operations	Unclear risk	"Three surgeons highly experienced in cruciate ligament replacement performed the operations" Experience with the CAS technique not described
Other bias	Unclear risk	The 2 studies appeared to include the same participants because these studies were performed at the same hospital at the same time interval. However, the latter of the 2 studies did not refer to this circumstance, which creates great uncertainty in dealing with the reported data

Meuffels 2012

Methods	Randomized controlled trial
Participants	100 participants (49 CAS intervention and 51 conventional ACL reconstruction) 71 male and 29 female Inclusion: participants aged 18 years or older and eligible for primary ACL reconstruction without any additional PCL or LCL injury Exclusion: insufficient grasp of the Dutch or English language and inability or unwillingness to comply with regular post-operative follow-ups Setting: Department of Orthopaedic Surgery, Erasmus MC, University Medical Center Rotterdam, Rotterdam, The Netherlands

Meuffels 2012 (Continued)

Interventions	<p>Intervention: CAS of arthroscopic ACL reconstruction by the use of a stand-alone computer with infrared control (ACL reconstruction application version 1.0; Brainlab, München, Germany) and an intra-operative X-ray for templating</p> <p>Control: arthroscopic ACL reconstruction</p> <p>The ACL reconstruction was performed using an arthroscopic, single-incision, single-bundle, transtibial surgical technique and either BPTB or looped semi-tendinosus-gracilis autograft. The choice of graft was made by the surgeon pre-operatively on a case-by-case basis, depending on the athletic demands and specific wishes of the participant and on the surgeon's preference</p> <p>Planned position:</p> <p>Tibia positioning using Acufex aimer 7 mm anterior of PCL</p> <p>Femoral positioning at the 10 o'clock position for the right knee and 2 o'clock position for the left knee</p>
Outcomes	<p>Radiographic tunnel position</p> <p>CT imaging of the knee 1 day post-operatively</p> <p>Participant age, weight, height, Tegner score, time between trauma and surgery were recorded in Methods, but not in the Results</p> <p>IKDC subjective form, KOOS score, Lysholm score pre-operatively in the Methods section but not in the Results, intra-operative findings were recorded in Methods, but not in the Results</p> <p>Operating time</p>
Notes	Research grant from Nuts Ohra. The sponsor had no role in the study design, data collection, data analysis, data interpretation or writing of the report

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Participants were randomized according to a computer-generated procedure (block randomization using a variable block size)
Allocation concealment (selection bias)	Low risk	The randomization codes were held by an independent observer to ensure masked blocking
Blinding (performance bias and detection bias) Radiological outcome	Low risk	Measurements of the 3-dimensional images were performed by 2 experienced observers who were blinded to participant allocation
Incomplete outcome data (attrition bias) IKDC	Low risk	No loss to follow-up
Selective reporting (reporting bias)	High risk	In the Methods, several participant-reported outcome measures and physical examination measurements were mentioned, but they were not reported in the results
Surgeon's experience with the operations	Low risk	2 experienced orthopaedic surgeons with over 500 ACL reconstructions performed and experience in CAS (> 20 procedures)
Other bias	Low risk	No bias likely

Plaweski 2006

Methods	Randomized controlled trial
Participants	<p>60 participants (30 CAS intervention and 30 control)</p> <p>40 males and 20 females, age range 16-50 years</p> <p>Inclusion: fresh ACL rupture 1-6 months after injury</p> <p>Exclusion criteria: no revisions, no complex lesions including LCL or MCL ruptures or bilateral ACL lesions</p> <p>Setting: Orthopaedic Department, Grenoble University Hospital, Grenoble, France</p>
Interventions	<p>Intervention: CAS of arthroscopic ACL reconstruction by the use of the Surgetics system using Julliard protocol (Praxim), an image-free system</p> <p>Control: arthroscopic ACL reconstruction</p> <p>The ACL reconstruction technique used was a 4-strand hamstring femoral fixation with an Endoloop device and BioRCI interference screw and tibial fixation with an BioRCI interference screw</p> <p>Planned tunnel position:</p> <ul style="list-style-type: none"> - Positioning: for the femur at a 11 o'clock position for the right knee and at 1 o'clock for the left knee - Tibia positioning using Acufex aimer 6 mm anterior of PCL
Outcomes	<p>Stability testing with Lachman, pivot shift and arthrometric testing using radiographic Telos, IKDC objective at follow-up of 24 months</p> <p>Radiographic tunnel positioning of tibia (Howell) and femur (length of Blumensaat within lateral condylar margin)</p> <p>Adverse post-surgical events</p> <p>Operating time</p>
Notes	Research grant "Navperop" by the French Ministry of Health

Risk of bias

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Unclear risk	Not described
Allocation concealment (selection bias)	Low risk	"Randomization was performed on the morning of surgery by selection of sealed envelopes"
Blinding (performance bias and detection bias) Participant-reported outcomes	Unclear risk	Not mentioned if and how participants were blinded
Blinding (performance bias and detection bias) Outcome assessed by physician	Low risk	"The detailed measurements included in this study were performed at the final assessment, which was performed by an independent surgeon at 24 months. The final clinical assessment was made without the hospital records to ensure the assessing surgeon was unaware of whether the navigation system had been used"
Blinding (performance bias and detection bias)	Unclear risk	"All measurements were performed by a single experienced radiologist"

Plaweski 2006 (Continued)

Radiological outcome

Incomplete outcome data (attrition bias) IKDC	Low risk	"No patients were lost to follow-up"
Selective reporting (reporting bias)	Unclear risk	No protocol or trial registration available but main reported outcomes listed in Methods
Surgeon's experience with the operations	High risk	"Operations in both groups were performed arthroscopically by a single, experienced ACL surgeon, well trained with the conventional instrumentation (about 1500 ACL reconstructions performed by this surgeon)." There is no previous experience with the CAS system. Start of the study at the same date (1 November 2002) as the system was taken in for use in the department
Other bias	Low risk	No bias likely, including no important baseline differences

ACL: anterior cruciate ligament; BPTB: bone-patellar-tendon-bone; CAS: computer-assisted surgery; IKDC: International Knee Documentation Committee; KOOS: Knee injury and Osteoarthritis Outcome Score; LCL: lateral collateral ligament; MCL: medial collateral ligament; MRI: magnetic resonance imaging; PCL: posterior cruciate ligament; SD: standard deviation.

DATA AND ANALYSES

Comparison 1. Computer-assisted surgery versus conventional surgery

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Functional status at 2 years or more: IKDC subjective (score 0 to 100: best function)	2	120	Mean Difference (IV, Fixed, 95% CI)	2.05 [-2.16, 6.25]
2 Functional status at 2 years or more: Lysholm score (score 0 to 100: best function)	2	120	Mean Difference (IV, Fixed, 95% CI)	0.25 [-3.75, 4.25]
3 Functional status at 2 years or more: Tegner activity level (score 0 to 10: best result)	1	40	Mean Difference (IV, Fixed, 95% CI)	-0.35 [-1.81, 1.11]
4 IKDC knee examination grade normal (grade A) or nearly normal (grade B)	3	173	Risk Ratio (M-H, Fixed, 95% CI)	1.01 [0.96, 1.06]
4.1 Intermediate-/long-term follow-up (1-4.5 years)	1	73	Risk Ratio (M-H, Fixed, 95% CI)	1.00 [0.93, 1.08]
4.2 Long-term follow-up (2 years or more)	2	100	Risk Ratio (M-H, Fixed, 95% CI)	1.02 [0.95, 1.09]
5 Negative (normal) pivot shift test at 2 years or more	3	180	Risk Ratio (M-H, Fixed, 95% CI)	1.06 [0.91, 1.22]
6 Length of operation (minutes)	1	100	Mean Difference (IV, Fixed, 95% CI)	26.70 [19.67, 33.73]

Analysis 1.1. Comparison 1 Computer-assisted surgery versus conventional surgery, Outcome 1 Functional status at 2 years or more: IKDC subjective (score 0 to 100: best function).

Analysis 1.2. Comparison 1 Computer-assisted surgery versus conventional surgery, Outcome 2 Functional status at 2 years or more: Lysholm score (score 0 to 100: best function).

Analysis 1.3. Comparison 1 Computer-assisted surgery versus conventional surgery, Outcome 3 Functional status at 2 years or more: Tegner activity level (score 0 to 10: best result).

Analysis 1.4. Comparison 1 Computer-assisted surgery versus conventional surgery, Outcome 4 IKDC knee examination grade normal (grade A) or nearly normal (grade B).

Analysis 1.5. Comparison 1 Computer-assisted surgery versus conventional surgery, Outcome 5 Negative (normal) pivot shift test at 2 years or more.

Analysis 1.6. Comparison 1 Computer-assisted surgery versus conventional surgery, Outcome 6 Length of operation (minutes).

APPENDICES

Appendix 1. Search strategies

Cochrane CENTRAL Register of Controlled Trials (Wiley Online Library)

Issue 5, 2013

#1 MeSH descriptor: [Anterior Cruciate Ligament] this term only (638)
 #2 MeSH descriptor: [Posterior Cruciate Ligament] this term only (53)
 #3 ((anterior or posterior) near cruciate*):ti,ab,kw in Trials (1005)
 #4 #1 or #2 or #3 (1089)
 #5 MeSH descriptor: [Surgery, Computer-Assisted] this term only (418)
 #6 MeSH descriptor: [Therapy, Computer-Assisted] this term only (592)
 #7 (computer* near/3 (assist* or aid* or control* or navigat* or surg*)):ti,ab,kw in Trials (6870)
 #8 (CAS or CAOS):ti,ab,kw in Trials (1080)
 #9 #5 or #6 or #7 or #8 (8129)
 #10 #4 and #9 (23) [Trials]

MEDLINE (PubMed and PubMed in process)

2010 to July 2013

((anterior cruciate ligament[mesh] OR posterior cruciate ligament[mesh] OR "anterior cruciate"[tw] OR "posterior cruciate"[tw]) AND (computer-assisted therapy[mesh:noexp] OR computer-assisted surgery[mesh] OR (computer*[tw] AND (assist*[tw] OR aid*[tw] OR control*[tw] OR controlled*[tw] OR navigat*[tw] OR surgery*[tw] OR surgical*[tw] OR therapy*[tw]))) AND ((randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized controlled trials [mh] OR random allocation [mh] OR double-blind method [mh] OR single-blind method [mh] OR clinical trial [pt] OR clinical trials [mh] OR "clinical trial"[tw] OR ((singl*[tw] OR doubl*[tw] OR tripl*[tw]) AND (mask*[tw] OR blind*[tw])) OR placebos [mh] OR placebo*[tw] OR random*[tw] OR research design [mh:noexp]) NOT (animals [mh] NOT humans [mh]))) (22)

EMBASE (Embase.com)

2010 to July 2013

('knee ligament'/exp OR 'knee ligament surgery'/exp OR 'anterior *2 cruciate' OR 'posterior *2 cruciate') AND ('computer assisted therapy'/de OR 'computer assisted surgery'/de OR (computer*:ti,ab,de AND (assist*:ti,ab,de OR aid*:ti,ab,de OR control*:ti,ab,de OR controlled*:ti,ab,de OR navigat*:ti,ab,de OR surgery*:ti,ab,de OR surgical*:ti,ab,de OR therapy*:ti,ab,de))) AND ('randomized controlled trial'/exp OR 'double blind procedure'/exp OR 'single blind procedure'/exp OR 'crossover procedure'/exp OR 'controlled study'/de OR ((clinical*:ti,ab,de OR controlled*:ti,ab,de OR comparative*:ti,ab,de OR placebo*:ti,ab,de OR prospective*:ti,ab,de OR randomi?ed*:ti,ab,de) AND (trial*:ti,ab,de OR study*:ti,ab,de)) OR (random*:ti,ab,de AND (allocat*:ti,ab,de OR allot*:ti,ab,de OR assign*:ti,ab,de OR basis*:ti,ab,de OR divid*:ti,ab,de OR order*:ti,ab,de)) OR ((singl*:ti,ab,de OR doubl*:ti,ab,de OR trebl*:ti,ab,de OR tripl*:ti,ab,de) AND (blind*:ti,ab,de OR mask*:ti,ab,de)) OR (crossover*:ti,ab,de OR cross-over*:ti,ab,de) OR ((allocat*:ti,ab,de OR allot*:ti,ab,de OR assign*:ti,ab,de OR divid*:ti,ab,de) AND (condition*:ti,ab,de OR experiment*:ti,ab,de OR intervention*:ti,ab,de OR treatment*:ti,ab,de OR therap*:ti,ab,de OR control*:ti,ab,de OR group*:ti,ab,de))) NOT (animal*:ti,ab,de NOT human*:ti,ab,de) (137)

CINAHL (EBSCO)

2010 to July 2013

((MH anterior cruciate ligament OR MH posterior cruciate ligament OR TX "anterior cruciate" OR TX "posterior cruciate") AND (MW therapy, computer-assisted OR TX "computer-assisted surgery" OR (TX computer* AND (TX assist* OR TX aid* OR TX control OR TX controlled OR TX navigat* OR TX surgery OR TX surgical OR TX therapy))) AND ((randomized controlled trial OR controlled clinical trial OR MH clinical trials OR MH random assignment OR MH double-blind studies OR MH single-blind studies OR PT clinical trial OR TX "clinical trial" OR ((TX singl* OR TX doubl* OR TX tripl*) AND (TX mask* OR TX blind*)) OR TX "latin square" OR MH placebos OR TX placebo* OR TX random* OR MH study design OR comparative study OR evaluation studies OR MH prospective studies OR TX "cross-over studies" OR TX control OR TX controlled OR TX prospectiv* OR TX volunteer*)) (16)

Appendix 2. Arthrometric testing results

	CAS pre-operatively	CAS post-operatively	Conventional pre-operatively	Conventional post-operatively
Chouteau 2008	n = 37	n = 37	n = 36	n = 35
Maximal KT-1000	15.3 mm (range 12 to 19)	8.9 mm (range 6 to 12)	14.9 mm (range 10 to 22)	9.5 mm (range 7 to 17)
Hart 2008	-	n = 40	-	n = 40
Maximal KT-1000 equal to other knee	-	12 (30%)	-	18 (45%)
< 2 mm	-	14 (35%)	-	12 (30%)
3-5 mm	-	14 (35%)	-	10 (25%)
> 5 mm	-	0	-	0
Plaweski 2006	n = 30	n = 30	n = 30	n = 30
Laxity measurements with Telos device 200 N	11.0 mm (SD 3.5)	1.3 mm (SD 1.0)	9.6 mm (SD 2.0)	1.5 mm (SD 1.5)
SD: standard deviation				

Appendix 3. Tibial tunnel position results

	Computer-assisted surgery	Manually navigated
Chouteau 2008	n = 37	n = 35
Agliette's method	28.5% (SD 5.4)	34% (SD 6.8)
Howell's method	38.4% (SD 4.8)	43% (SD 6.6)
Hart 2008	n = 40	n = 40
Correctly placed in zone 2 (no impingement)	39 (97.5%)	38 (95%)

(Continued)

Mauch 2007	n = 20	n = 20
X-ray		
- Anterior	21 mm (SD 2.5) (32%)	20 mm (SD 4.9) (30%)
- Central	27 mm (SD 2.2) (41%)	25 mm (SD 3.2) (39%)
- Posterior	32 mm (SD 2.9) (50%)	30 mm (SD 3.7) (47%)
Impingement	0	2
MRI		
Mean centre tibia position	46% (range 39% to 52%)	46% (range 31% to 58%)
Meuffels 2012	n = 49	n = 51
Anteroposterior tunnel position (Stäubli and Rausching)	38.2% (SD 5.8)	38.9% (SD 6.8)
Medial lateral tunnel position	42.7% (SD 3.6)	42.6% (SD 5.7)
Plaweski 2006	n = 30	n = 30
ATB (distance from projected Blumensaat line)	0.4 mm (range 0 to 3)	-1.2 mm (range -5 to 4)
W (tibial tunnel width)	10.6 mm (range 8 to 15)	11.5 mm (range 8 to 14)
CTT/ STD x 100	31.4% (range 18.2% to 40%)	34.4% (range 22.2% to 43.4%)

Footnotes

Hart 2008: Tibia anteroposteriorly divided in 4 equal zones (according to Harner), zone 2 is the tibial zone without impingement in extension.

Mauch 2007: X-ray results apply respectively to distances from the anterior edge of the tibial plateau, the centre and the posterior tibial border. The percentages data apply to the total anteroposterior tibial diameter.

Meuffels 2012: 3D-CT.

Plaweski 2006: "Definition of geometrical measurements performed on post-operative radiographs in extension and relative to standard anatomical landmarks. A, measurement of potential notch impingement. B, measurement of femoral tunnel position. CTT, distance between the centre of the tibial tunnel and the anterior edge of the internal tibial plateau; STD, anteroposterior width of the internal tibial plateau; W, width of the tibial tunnel; ATB, distance between the projection of the Blumensaat line on the tibial plateau and the anterior edge of the tibial tunnel; AB, distance between the anterior condyle edge and the anterior edge of the femoral tunnel; AC, length of the Blumensaat line, as referenced by the condyle cortical edges." (as described in [Plaweski 2006](#)).

Appendix 4. Femoral tunnel position results

	Computer-assisted surgery	Manually navigated
Chouteau 2008	n = 37	n = 35

(Continued)

Linear distance between actual and ideal position (Triangle method)	2.5 mm (SD 1.1)	7.0 mm (SD 1.5)
Hart 2008	n = 40	n = 40
a/t (posterior to anterior ideal 24.8%)	25.5% (SD 1.63%)	27.5% (SD 2.76%)
b/h (height of femoral condyle)	27.3% (SD 2.01%)	27.9% (SD 2.87%)
AP 10.30/1.30 position	40 (100%)	37 (92.5%)
Deviation ventrodorsal: < 7%	27 (67.5%)	14 (35%)
7 to 14%	13 (32.5%)	14 (35%)
> 14%	0	12 (30%)
Mauch 2007	n = 20	n = 20
MRI quadrant method	20 correct in 4/4 quadrant	19 correct in quadrant 4/4
	0 in other quadrants	1 in quadrant 3/4
MRI graft remodelling - Cat. A (low, tense, smooth)	13 (65%)	8 (40%)
- Cat. B (low/int, tense, rough)	7 (35%)	9 (45%)
- Cat C (high, elongated, rough)	0	3 (15%)
Meuffels 2012	n = 49	n = 51
3D CT quadrant method of Bernard et al.		
- distance of tunnel to Blumensaat	39.0% (SD 9.6%)	39.7% (SD 9.1%)
- AP height perpendicular to Blumensaat	39.1% (SD 8.4%)	37.9% (SD 9.7%)
Plaweski 2006	n = 30	n = 30
AB/AC x 100	60.1% (SD 4.68%)	61.3% (SD 6.4%)

Footnotes

Hart 2008 : a/t is the distance on the lateral radiograph of Blumensaat's line (t = sagittal diameter of the lateral condyle) divided by the length from posterior to the femoral tunnel (a);
b/h (h) is the maximum height of the notch and (b) the distance between the Blumensaat's line and the femoral tunnel aperture.

Plaweski 2006: see Footnotes in [Appendix 3](#).

3D: three-dimensional; AB: distance between the anterior condyle edge and the anterior edge of the femoral tunnel; AC: length of the Blumensaat line, as referenced by the condyle cortical edges; AP: antero-posterior; Cat: category; CT: computed tomography; SD: standard deviation

WHAT'S NEW

Date	Event	Description
18 August 2014	Amended	Author added
18 August 2014	New citation required but conclusions have not changed	Author added

HISTORY

Protocol first published: Issue 1, 2009

Review first published: Issue 6, 2011

Date	Event	Description
11 July 2014	New citation required but conclusions have not changed	Changes were made to the byline, with one new review author and removal of one previous review author.
5 July 2013	New search has been performed	The main changes were: <ul style="list-style-type: none"> • The search was updated to July 2013 • One new study was included • Quality of evidence was assessed using GRADE and a 'Summary of findings' table was added

CONTRIBUTIONS OF AUTHORS

DM drafted the protocol and the review. MR and DM searched the data and assessed the risk of bias. MR and JV edited the protocol and review for content and formatting. RS edited the review and performed the statistical analyses.

For the update of this review, VE, MR, JV, DM and RS adjusted the content and formatting. VE and DM searched the data. VE and BM assessed risk of bias of [Meuffels 2012](#) because they were not involved in this study. Final approval of the document to be published was done by JV, DM and MR.

DECLARATIONS OF INTEREST

One author (DM) performs ACL and PCL reconstructions with different types of grafts depending on each clinical case. One RCT ([Meuffels 2012](#)) comparing CAS versus conventional ACL reconstruction was conducted by this group (DM, MR and JV). The assessment of eligibility and quality, and data extraction of this trial was done independently by two others, one who was identified in the acknowledgements (BM), and one who was an author of the update (VE). Both also commented on the description of the trial in the review.

SOURCES OF SUPPORT

Internal sources

- No sources of support supplied

External sources

- Cochrane Bone, Joint and Muscle Trauma Group, University of Manchester, UK.

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

In the published protocol, we indicated our intention to include only skeletally mature patients in this review. For the review, we decided to include also trials that included some skeletally immature participants, based on age, provided that these were few and balanced between groups. Of the five included studies, three studies may have included a few skeletally immature participants.

A structural adjustment of the list of types of outcomes was made between the protocol and the first version of the review. We have retained this in this version but removed "loss of knee motion" as an example of adverse post-surgical event. We plan to revisit the types of outcomes in the next update, including restoring the distinction between subjective assessment of knee function and generic quality of life measures.

We assessed the quality of evidence using GRADE; and produced a 'Summary of findings' table.

INDEX TERMS

Medical Subject Headings (MeSH)

Anterior Cruciate Ligament [*surgery]; Anterior Cruciate Ligament Injuries; Anterior Cruciate Ligament Reconstruction [methods]; Orthopedic Procedures [*methods]; Posterior Cruciate Ligament [injuries] [*surgery]; Randomized Controlled Trials as Topic; Reconstructive Surgical Procedures [methods]; Surgery, Computer-Assisted [*methods]; Treatment Outcome

MeSH check words

Adolescent; Adult; Female; Humans; Male; Middle Aged; Young Adult