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Similar outcome after retention or sacrifice of the posterior cruciate ligament in total knee arthroplasty

A systematic review and meta-analysis

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Background and purpose — To retain or to sacrifice the posterior cruciate ligament (PCL) in total knee arthroplasty (TKA) remains a matter of discussion. In this systematic review, we wanted to find differences in functional and clinical outcome between the 2 methods.

Methods — We conducted a systematic review and meta-analysis including all randomized controlled trials (RCTs) and quasi-RCTs that have compared PCL retention with PCL sacrifice in TKA with a minimum of 1-year follow-up. Primary outcome was range of motion. Secondary outcomes were knee pain and clinical scoring systems that were preferably validated. Quality of evidence was graded using the GRADE approach. All outcomes available for data pooling were used for meta-analysis.

Results — 20 studies involving 1,877 patients and 2,347 knees were included. In meta-analysis, the postoperative flexion angle had a mean difference of 2 degrees (95% CI: 0.23–4.0; $p = 0.03$) and the KSS functional score was 2.4 points higher in favor of PCL sacrifice (95% CI: 0.41–4.3; $p = 0.02$). There were no statistically significant differences regarding other measured clinical outcomes such as WOMAC, KSS pain, clinical and overall score, HSS score, SF-12, radiolucencies, femoro-tibial angle, and tibial slope. The quality of the studies varied considerably. Risk of bias in most studies was unclear; 5 were judged to have a low risk of bias and 5 to have a high risk of bias.

Interpretation — We found no clinically relevant differences between retention and sacrifice of the PCL in TKA, in terms of functional and clinical outcomes. The quality of the studies ranged from moderate to low. Based on the current evidence, no recommendation can be made as to whether to retain or to sacrifice the PCL.

There is an ongoing debate on whether to retain or to sacrifice the posterior cruciate ligament (PCL) during TKA surgery. Arguments for PCL retention are maintenance of natural knee motion and maintained stability (Mihalko and Krackow 1999, Lombardi et al. 2001). Furthermore, the PCL is believed to have different types of mechanoreceptors for proprioception and kinesthesia, so the PCL might give a better “sense” to the postoperative knee (Nelissen and Hogendoorn 2001, Swanik et al. 2004). Retention of the PCL leads to the need for adequate balancing of the ligament; inadequate balancing (i.e. too tight or too loose) may lead to knee pain, deteriorated range of motion, and instability (Pagnano et al. 1998, Most et al. 2003). On the other hand, sacrificing the PCL could be helpful in balancing knees with deformities or contractures. Another advantage of sacrificing the PCL is preventing paradoxal femoral rollback (Dennis et al. 2004). Femoro-tibial movement will then be dictated by the degree of congruency between the femur and the tibial insert (Wolterbeek et al. 2012). Sacrificing the PCL leads to an increase in the flexion gap and (to a lesser extent) an increase in the extension gap (Mihalko and Krackow 1999, Baldini et al. 2004).

A Cochrane systematic review from 2005 could not indicate what treatment option (retention or sacrifice of the PCL) is best regarding functional, clinical, and radiological outcome parameters (Jacobs et al. 2005). An update of this review was published by us in 2013 and still showed no relevant differences between the 2 groups (Verra et al. 2013).

Since that literature search, several new reports of randomized controlled trials (RCTs) comparing PCL retention with PCL sacrifice have been published, necessitating an update. We wanted to find differences in functional, clinical, and

radiological outcome between PCL-retaining and PCL-sacrificing TKA in the current literature.

Methods

Literature search and study selection

We used the same study protocol as developed for our Cochrane systematic review and meta-analysis (Jacobs et al. 2005, Verra et al. 2013). We conducted a sensitive search in order to retrieve all the literature available. In consultation with an experienced librarian of the medical library of Leiden University Medical Center (JS), we searched the following databases: Medline (via PubMed), the Cochrane Central Register of Controlled Trials, Embase, Web of Science, CINAHL, Academic Search Premier, Current Contents Connect, and Science Direct. All the databases were searched up to May 19, 2014 using a syntax adapted for each database (Supplementary Table 1). No restrictions or limits were formulated. A final check that no relevant articles were missed was carried out by screening the references from the articles and by performing citation tracking on the articles that were included.

Articles were selected in 2 steps. In the first step, only the title and abstract were screened. In the second step, articles that passed the first step were retrieved in full text and again evaluated against the inclusion and exclusion criteria. These criteria were as follows: (1) The intervention evaluated in the trials had to be primary TKA comparing PCL retention with sacrifice. (2) The indication for TKA had to be osteoarthritis. (3) Follow-up had to be at least 12 months. (4) Studies had to be RCTs or quasi-RCTs. Quasi-RCTs are studies using, for example, date of birth, patient identification numbers, or alternating sequences for randomization. 2 reviewers (WV and LB) independently selected the trials to be included in the review. Disagreements were resolved by consensus. When no consensus could be reached, a third reviewer (WJ) cast the decisive vote.

Data collection

An already developed and tested data extraction form was used to extract data from the studies included. Items collected were study design features, population data, statistical analysis techniques, intervention characteristics, and all the outcome parameters reported, including results. The primary outcome was range of motion (ROM), including flexion and extension angle separately. Secondary outcomes were knee pain (visual analog scale, Knee Society clinical pain sub-score), validated clinical scoring instruments (such as the Western Ontario and McMaster Universities osteoarthritis index (WOMAC), the knee osteoarthritis outcome scale (KOOS), and the Oxford knee score), other clinical questionnaire scores (such as the Knee Society score (KSS), the Hospital for Special Surgery score (HSS), etc.), radiological implant migration (preferably using radiostereometric analysis (RSA)), complication

rate, and other radiological outcomes (such as rollback and radiolucencies). All data were entered into Review Manager version 5.2 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2012).

The risk of bias (e.g. selection bias, performance bias, detection bias, attrition bias) was assessed for every study. The risk of selection bias was judged by assessing how the randomization sequence was generated and by assessing how the treatment allocation was concealed. Risk of performance and detection bias was judged by evaluating the methods for blinding of participants, personnel, and observers, as described in the studies. Risk of attrition bias was assessed by judging the completeness of the data, including the follow-up rate. The possible judgements that could be made were low risk of bias, high risk of bias, and unclear risk of bias.

The quality of the evidence was assessed using the GRADE approach (Atkins et al. 2004). In this method for grading of quality, RCTs are considered to be high-quality evidence; however, this can be downgraded to moderate, low, or very low quality for several reasons. These reasons are study limitations (e.g. high risk of bias), inconsistent results, indirectness of evidence, imprecision, or publication bias. The Cochrane Collaboration recommends using this approach to grade the quality of studies in systematic reviews (Higgins and Green 2011).

Analysis

Statistical analyses were conducted using Review Manager version 5.2. Continuous data were entered as mean and standard deviation (SD), and dichotomous outcomes as number of events. Standard deviations were used when available. When not provided, standard deviations were imputed from comparable studies or from original scores (i.e. confidence intervals). Estimates are given with 95% confidence intervals (CIs) where relevant.

In the meta-analysis, if the studies (patients, interventions, outcomes) were regarded to be clinically homogeneous, heterogeneity was first assessed by visual inspection of the forest plots. Furthermore, we investigated heterogeneity using the I² statistic and, if significant ($p < 0.05$ using the Q statistic), the source of heterogeneity was investigated by conducting a sensitivity analysis and considering additional clinical reasons for potential clinical heterogeneity. In the absence of significant heterogeneity, and given a sufficient number of trials included, results were combined using mean differences for continuous data and relative risk for dichotomous data. We used a random effects model for all analyses.

Results

We identified 2,609 unique references. 58 articles were selected for further evaluation, resulting in 21 full-text papers that were used for analysis (Figure 1, Table 2). The article by

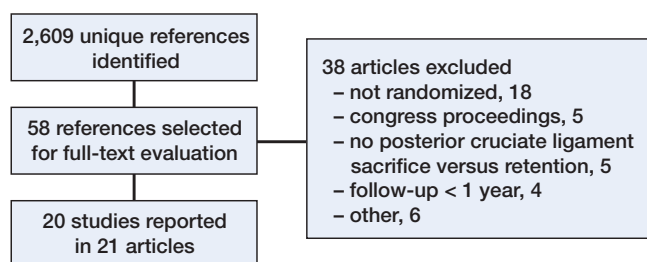


Figure 1. Flow chart of study selection showing the process of article selection and the reasons for articles being excluded.

Victor et al. (2005) described a population that was also part of the study population of Harato et al. (2008). Data from both articles were used only once. The article from de Andrade et al. (2009) was written in Portuguese and the article from Yansheng et al. (2013) was written in Chinese. The data were extracted by professional translators.

Study characteristics

The 20 studies involved 1,877 patients and 2,347 knees. In 17 studies, the comparison between the 2 arms was PCL retention with a cruciate-retaining design versus PCL sacrifice using a posterior-stabilized design. In 3 studies, the same (cruciate-retaining) TKA design was used for both groups. One study used all three treatments (i.e. cruciate-retaining design with ligament retention and with ligament sacrifice and posterior-stabilized design (Table 2).

All studies used a clinical rating scale, either validated (e.g. WOMAC) or unvalidated (e.g. Knee Society score) and reported ROM or flexion measurements. There was very little use of radiostereometric analysis (RSA).

Risk of bias and quality of evidence

5 of the 20 studies included were assessed as having a low risk of bias, 5 of them were assessed as having a high risk of bias, and 10 had an unclear risk of bias.

Table 1. Characteristics of the 20 studies

Authors	Sample size			TKA type		Mean [SD] age		% Females		Outcome	Follow-up (years)
	Patients	Knees	OA (%)	CR	CS	CR	CS	CR	CS		
Aglietti et al. 2005	197	210	100	103	107	71	70	86	81	ROM, VAS pain, KS score, radiographic evaluation, mechanical axis, radiolucencies	–4
Catani et al. 2004	40	40	100	20	20	70 [6]	71 [7]	65	75	ROM, RSA, KS score, HSS score	2
Chaudhary et al. 2008	100	100	ND	51	49	69 [9]	70 [8]	53	45	ROM, RAND-36, WOMAC	2
Clark et al. 2001	128	128	97	59	69	72 [12]	71 [14]	ND	ND	ROM, KS score, SF-12, WOMAC	–3
de Andrade et al. 2009	85	85	89	36	49	66 (41–78)		74		KS score (overall)	1.3
Harato et al. 2008	192	222	100	111	111	68	66	34	34	KS score, WOMAC, SF-12, radiolucencies, kinematics (Victor et al. 2005)	5.0–7.3
Kim et al. 2009	250	500	100	250	250	72 [6]		96		ROM, KS score, HSS score, WOMAC pain, radiological	2.3
Maruyama et al. 2004	20	40	100	20	20	74 (65–84)		60		ROM, KS score, joint line	–2.7
Matsumoto et al. 2012	41	41	100	19	22	74 [1]	74 [1]	100	100	ROM, KS score, laxity	5
Misra et al. 2012	103	105	92	51	54	67	67	67	59	ROM, HSS score, satisfaction score, radiological (rollback, loosening)	4.8
Roh et al. 2012	86	86	100	42	44	70 [5]	71 [5]	95	93	ROM, tibio-femoral angle	–3.1
Seon et al. 2011	95	95	100	48	47	68 [7]	69 [7]	91		KS score, HSS score, WOMAC	2
Shoji et al. 1994	28	56	54	28	28	60 (48–85)		71		ROM, HSS score	–4.5
Straw et al. 2003	167	167	ND	66	101	73	73/74 ^a	44	45	ROM, KS score, pain score, stability	–6.5
Tanzer et al. 2002	37	40	97	20	20	68	66	75	80	Flexion angle, KS score	2
Thomsen et al. 2013	36	72	97	36	36	67 (49–84)		58		ROM, knee pain, satisfaction, ability to perform ADL, SF-36	1
Wang et al. 2004	185	224	91	128	96	55	55	80	80	ROM, KS score, tibio-femoral angle, radiolucencies, SF-12	–5.5
Yagishita et al. 2012	29	58	100	29	29	74 [7]		86		functional score, ligament laxity	5
Yansheng et al. 2013	38	38	100	19	19	66	64	68	63	ROM, KS score, pain score, radiolucencies	–1.4
Yoshiya et al. 2005	20	40	100	20	20	74 (62–84)		66		ROM, WOMAC, proprioception	–4.4
										ROM, KS score, fluoroscopic motion analysis	

CR: (posterior) cruciate-retaining; CS: (posterior) cruciate sacrificing; ND: no data or unclear; ADL: activities of daily living; HSS: Hospital for Special Surgery; KS: Knee Society; ROM: range of motion; RSA: radiostereometric analysis; SF: short form; VAS: visual analog scale; WOMAC: Western Ontario and McMasters osteoarthritis index.

^a PS/resection

5 articles described how the randomization sequence for the study was generated (Misra et al. 2003, Chaudhary et al. 2008, Harato et al. 2008, Roh et al. 2013, Thomsen et al. 2013). The method of concealment of allocation was reported in 6 studies (Chaudhary et al. 2008, Harato et al. 2008, Kim et al. 2009, Seon et al. 2011, Matsumoto et al. 2012, Thomsen et al. 2013). 3 studies used quasi-randomization: Aglietti et al. (2005) based choice of treatment on odd/even patient identification numbers, Maruyama et al. (2004) used alternating sequences, and Wang et al. (2004) based the treatment on time of hospital admission. Blinding of the outcome assessor was reported in 10 studies (Tanzer et al. 2002, Misra et al. 2003, Straw et al. 2003, Aglietti et al. 2005, Chaudhary et al. 2008, de Andrade et al. 2009, Kim et al. 2009, Seon et al. 2011, Matsumoto et al. 2012, Thomsen et al. 2013). Seon et al. (2011) reported explicitly that no blinding was used.

Studies reporting on the primary outcome of knee flexion were graded according to the GRADE approach. These studies were generally assessed as being of low quality. Quality was downgraded due to the high proportion of studies with an unclear risk of bias and the presence of studies rated with a high risk of bias. Also, studies reporting on the secondary outcomes were graded as being of moderate to low quality.

Meta-analysis

There was low quality of evidence from 12 studies (1,056 knees) that sacrifice of the PCL results in a better flexion angle, with a mean difference of 2 degrees (95% CI: 0.23–4.0; $p = 0.03$). This is a homogeneous result ($I^2 = 29\%$, $p = 0.2$). Furthermore, there was low quality of evidence from 9 studies (1,530 knees) that sacrifice of the PCL results in a higher Knee Society functional score of 2.4 points (95% CI: 0.41–4.3; $p = 0.02$) (Figure 2). These were the only homogeneous and statistically significant differences between PCL retention and sacrifice. The WOMAC score was used in 5 studies; there was a 0.72-point difference between both groups (95% CI: –0.35 to 1.8; $p = 0.19$) in favor of PCL sacrifice. No other validated scoring systems were available for meta-analysis. Meta-analyses on the outcomes KSS pain, KSS clinical score, KSS overall score, HSS score, SF-12 mental, radiolucent lines, femoro-tibial angle, and tibial slope showed no statistically significant differences and they were comparable in terms of statistical homogeneity.

Sub-analysis of outcomes of low-quality studies comparing PCL retention with sacrifice using the same PCL-retaining TKA design in both groups showed no significant differences. Comparison of knee flexion in PCL retention with the PCL-sacrificing posterior-stabilizing design in 10 studies of moderate quality (746 knees) showed a mean difference of 2.8 degrees in favor of posterior stabilization (95% CI: 0.54–5.0; $p = 0.02$).

Complications were reported in 13 studies, and they ranged from anterior knee pain and femoral notching to deep infection (Table 3)

Table 3. Complications reported in the studies selected

Study	PCL retention	PCL sacrifice
Aglietti 2005 Catani 2004	None Anterior knee pain: 1 Limited ROM: 1	Septic loosening: 1 Anterior knee pain: 2
Chaudhary 2008 Harato 2008	Deep infection: 1 Stiff knee (< 90° flexion): 7 Knee pain: 5 Infection: 1	Limited ROM: 1 Stiff knee: 1 Knee pain: 2 Infection: 3
Kim 2009	Femoral notching: 2 Superficial infection: 1	Femoral notching: 3 Superficial infection: 1
Maruyama 2004 Matsumoto 2012 Misra 2003	None None Stiff knee (< 30° flexion): 2 Infection: 1 Aseptic loosening: 2 Instability: 3	None DVT: 1 Stiff knee: 2 Dystrophy: 1 Aseptic loosening: 3 Instability: 3
Roh 2012	PCL laxity: 2 PCL tightness: 1	None
Thomsen 2013 Yagishita 2012 Yansheng 2013	Infection: 1 None None	None DVT: 1 None

DVT: deep venous thrombosis; PCL: posterior cruciate ligament; ROM: range of motion.

Discussion

In this study of the current literature comparing PCL retention with PCL sacrifice in TKA, we did not find any clinically relevant differences between the groups. An extensive report on this topic, covering 17 studies, was published by our group in 2013 within the Cochrane Library of Systematic Reviews (Verra et al. 2013). The newly added studies have not given any new evidence on this topic.

The 20 studies selected are the best available evidence to date for evaluation of the difference between PCL retention and PCL sacrifice in TKA. The assessment of the quality of the evidence showed that it was low to moderate. Incompleteness of reporting issues such as failure to explain randomization methods and blinding raises the likelihood of bias in the studies, resulting in lower grades of quality of evidence. However, we see an improving trend in reporting, as the more recent publications were generally assessed as having a lower risk of bias.

Despite the fact that RCTs are known to provide the least biased evidence, they are not suited for all outcomes. Survival analysis of the TKA cannot easily be investigated in RCTs because of the relatively short follow-up period and relatively small number of patients. In addition, classical survival analysis can be biased by competing risks, which should be accounted for for valid interpretation of outcome (Keurentjes et al. 2012, Nouta et al. 2014). Observational, long-term follow-up cohort studies are valuable alternatives. Survivorship analyses of large cohorts showed a 10-year and 15-year survival of 91% and 90% in the PCL-retaining group and 76%

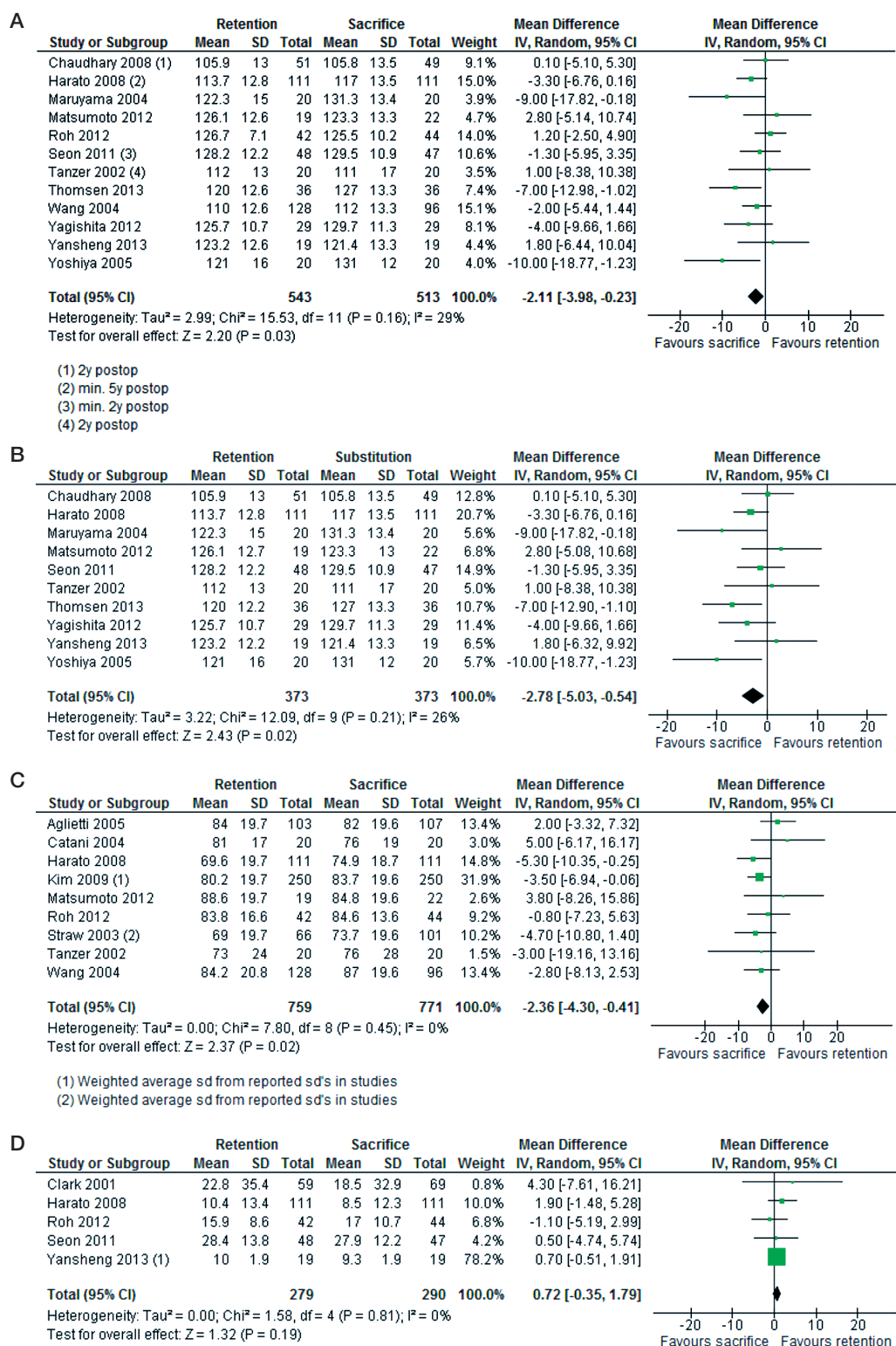


Figure 2. Forest plots from meta-analysis. A. Knee flexion from all PCL-sacrificing and PCL-retaining TKAs. Shows homogeneous results favoring PCL sacrifice with 2.1 degrees better flexion angle. B. Knee flexion from PCL-retaining TKA design versus posterior-stabilized TKA design. Shows homogeneous results favoring PCL sacrifice, with 2.8-degrees better flexion angle. C. Knee Society functional score from all PCL-sacrificing and PCL retaining TKAs. Shows homogeneous results favoring PCL sacrifice, with 2.4 more points in mean difference. D. WOMAC score from all PCL-sacrificing and PCL-retaining TKAs. Shows homogeneous results without any significant differences (0.78 points favoring PCL retention).

and 75% in the PCL-sacrificing, posterior-stabilized group (Rand et al. 2003, Abdel et al. 2011). However, other factors could influence these results, such as differences in TKA design or in materials in PCL-retaining and -stabilizing components (Engh 2011). A minimum dataset for cohort studies has been advocated by the AQUILA consortium (Pijls et al. 2011).

Our study had several strengths. We used a sensitive search in 8 relevant databases with no language limitations. We also checked references and used citation tracking. Recently published meta-analyses found and included only between 8 and 12 articles as compared to our 21 (Luo et al. 2012, Bercik et al. 2013, Li et al. 2014), while we excluded several RCTs because of the follow-up being less than 1 year (Swanik et al. 2004, Ishii et al. 2008, Nishizawa et al. 2013, Cankaya et al. 2014). Since our study was performed according to the Cochrane guidelines, an elaborate and systematic assessment of quality of evidence and risk of bias was performed. In the meta-analysis, we separately compared the subgroups PCL sacrifice using a PCL-retaining design and PCL sacrifice using a posterior-stabilized design against PCL retention.

One limitation was the lack of high-quality evidence in several articles. Furthermore, we could not present information on outcome measures such as patient experience and satisfaction, gait analysis, micromotion of the components (by RSA), and kinematic outcome measures such as antero-posterior stability and contact position. The importance of the predictive value of RSA and survival in TKA has been analyzed extensively (Nelissen et al. 2011, Pijls et al. 2012).

Future research on the question of PCL retention or sacrifice in TKA should consist of RCTs that have identical follow-up times, that include long(er)-term follow-up in their protocols, and that add outcome measures such as gait analysis, patient experience, and patient satisfaction. In addition to this, recently developed outcome measures such as the “forgotten joint score” can be used (Behrend et al. 2012). To study long-term TKA survival or complications, large observational studies are needed, focusing on retention or sacrifice of the PCL. Moreover, reporting in future studies must be more complete when describing study methods in order to reduce the likelihood of bias, and authors should also mention important confounders regarding outcome such as preoperative ROM measurements.

In conclusion, based on this systematic review and meta-analysis of all currently published RCTs, there are no clinically relevant differences between retention and sacrifice of the PCL in terms of clinical, functional, and radiological outcome.

Supplementary data

Table 1 is available at Acta's website (www.actaorthop.org), identification number 7534.

WCV: literature search, selection of articles, and writing of the manuscript. LGHvdB and WCHJ: selection of articles and revision of the manuscript. JWS: literature search. ABW and RGHHN: revision of the manuscript.

No competing interests declared.

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Abdel M P, Morrey M E, Jensen M R, Morrey B F. Increased long-term survival of posterior cruciate-retaining versus posterior cruciate-stabilizing total knee replacements. *J Bone Joint Surg Am* 2011; 93: 2072-8.

Aglietti P, Baldini A, Buzzi R, Lup D, de Lapo L. Comparison of mobile-bearing and fixed-bearing total knee arthroplasty: a prospective randomized study. *J Arthroplasty* 2005; 20: 145-53.

Atkins D, Best D, Briss P A, et al. Grading quality of evidence and strength of recommendations. *BMJ* 2004; 328: 1490

Baldini A, Scuderi GR, Aglietti P, Chalmick D, Insall JN. Flexion-extension gap changes during total knee arthroplasty: effect of posterior cruciate ligament and posterior osteophytes removal. *J Knee Surg* 2004; 17: 69-72.

Behrend H, Giesinger K, Giesinger J M, Kuster M S. The “forgotten joint” as the ultimate goal in joint arthroplasty: validation of a new patient-reported outcome measure. *J Arthroplasty* 2012; 27(3): 430-6.

Bercik M J, Joshi A, Parvizi J. Posterior cruciate-retaining versus posterior stabilized total knee arthroplasty: a meta-analysis. *J Arthroplasty* 2013; 28(3): 439-44.

Cankaya D, Ozkurt B, Aydin C, Tabak A Y. No difference in blood loss between posterior cruciate ligament retaining and posterior cruciate ligament stabilized total knee arthroplasties. *Knee Surg Sport Traumatol Arthrosc* 2014; 22(8): 1865-9.

Catani F, Leardini A, Ensini A, Cucca G, Bragonzoni L, Toksvig-Larsen S, Giannini S. The stability of the cemented tibial component of total knee arthroplasty: posterior cruciate-retaining versus posterior-stabilized design. *J Arthroplasty* 2004; 19: 775-82.

Chaudhary R, Beaupre L A, Johnston D W. Knee range of motion during the first two years after use of posterior cruciate-stabilizing or posterior cruciate-retaining total knee prostheses. A randomized clinical trial. *J Bone Joint Surg Am* 2008; 90: 2579-86.

Clark C R, Rorabeck C H, MacDonald S, MacDonald D, Swafford J, Cleland D. Posterior-stabilized and cruciate-retaining total knee replacement: a randomized study. *Clin Orthop Relat Res* 2001; (392): 208-12.

de Andrade M A P, Honório de Carvalho Jr L, Gonçalves M B J, de Castro C A C, and Frontes B P C. Clinical evaluation of total knee arthroplasties with posterior cruciate ligament retain and sacrifice. *Rev Brasil de Med* 2009; 66: 48-51.

Dennis D A, Komistek R D, Mahfouz M R, Walker S A, Tucker A. A multicenter analysis of axial femorotibial rotation after total knee arthroplasty. *Clin Orthop Relat Res* 2004; 428(11): 180-9.

Engh G A. Is long-term survivorship really significantly better with cruciate-retaining total knee implants?: Commentary on an article by Abdel et al.: “Increased long-term survival of posterior cruciate-retaining versus posterior cruciate-stabilizing total knee replacements”. *J Bone Joint Surg Am* 2011; 93: e136-2

Harato K, Bourne R B, Victor J, Snyder M, Hart J, Ries M D. Midterm comparison of posterior cruciate-retaining versus -substituting total knee arthroplasty using the Genesis II prosthesis. A multicenter prospective randomized clinical trial. *Knee* 2008; 15: 217-21.

Higgins J P T, Green S (editors). *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0. [updated March 2011]. The Cochrane Collaboration, 2011. Available from www.cochrane-handbook.org

- Ishii Y, Noguchi H, Matsuda Y, Takeda M, Kiga H, Toyabe S. Range of motion during the peri-operative period in total knee arthroplasty. *Arch Orthop Trauma Surg* 2008; 128: 795-9.
- Jacobs W C, Clement D J, Wymenga A B. Retention versus sacrifice of the posterior cruciate ligament in total knee replacement for treatment of osteoarthritis and rheumatoid arthritis. *Cochrane Database Syst Rev* 2005; 4: CD004803.
- Keurentjes J C, Fiocco M, Schreurs B W, Pijls B G, Nouta K A, Nelissen R G. Revision surgery is overestimated in hip replacement. *Bone Joint Res* 2012; 1(10): 258-62.
- Kim Y H, Choi Y, Kwon O R, Kim J S. Functional outcome and range of motion of high-flexion posterior cruciate-retaining and high-flexion posterior cruciate-substituting total knee prostheses. A prospective, randomized study. *J Bone Joint Surg Am* 2009; 91: 753-60.
- Li N, Tan Y, Deng Y, Chen L. Posterior cruciate-retaining versus posterior stabilized total knee arthroplasty: a meta-analysis of randomized controlled trials. *Knee Surg Sports Traumatol Arthrosc* 2014; 22(3): 556-64.
- Lombardi A V, Mallory T H, Fada R A, Hartman J F, Capps S G, Kefauver C A, Adams J B. An algorithm for the posterior cruciate ligament in total knee arthroplasty. *Clin Orthop Relat Res* 2001; (392): 75-87.
- Luo S X, Zhao J M, Su W, Li X F, Dong G F. Posterior cruciate substituting versus posterior cruciate retaining total knee arthroplasty prostheses: a meta-analysis. *Knee* 2012; 19(4): 246-52.
- Maruyama S, Yoshiya S, Matsui N, Kuroda R, Kurosaka M. Functional comparison of posterior cruciate-retaining versus posterior stabilized total knee arthroplasty. *J Arthroplasty* 2004; 19: 349-53.
- Matsumoto T, Muratsu H, Kubo S, Matsushita T, Kurosaka M, Kuroda R. Intraoperative soft tissue balance reflects minimum 5-year midterm outcomes in cruciate-retaining and posterior stabilized total knee arthroplasty. *J Arthroplasty* 2012; 27(9): 1723-30.
- Mihalko W M, Krackow K A. Posterior cruciate ligament effects on the flexion space in total knee arthroplasty. *Clin Orthop Relat Res* 1999; (360): 243-50.
- Misra A N, Hussain M R, Fiddian N J, Newton G. The role of the posterior cruciate ligament in total knee replacement. *J Bone Joint Surg Br* 2003; 85: 389-92.
- Most E, Zayontz S, Li G, Otterberg E, Sabbag K, Rubash H E. Femoral roll-back after cruciate-retaining and stabilizing total knee arthroplasty. *Clin Orthop Relat Res* 2003; (410): 101-13.
- Nelissen R G, Hogendoorn P C. Retain or sacrifice the posterior cruciate ligament in total knee arthroplasty? A histopathological study of the cruciate ligament in osteoarthritic and rheumatoid disease. *J Clin Pathol* 2001; 54: 381-4.
- Nelissen R G, Pijls B G, Kärrholm J, Malchau H, Nieuwenhuijse M J, Valstar E R. RSA and registries: the quest for phased introduction of new implants. *J Bone Joint Surg Am* 2011; 93 suppl 3: 62-5.
- Nouta K A, Pijls B G, Fiocco M, Keurentjes J C, Nelissen R G. How to deal with lost to follow-up in total knee arthroplasty: a new method based on competing risks approach. *Int Orthop* 2014; 38(5): 953-9.
- Nishizawa Y, Matsumoto T, Kubo S, et al. The influence of patella height on soft tissue balance in cruciate-retaining and posterior-stabilised total knee arthroplasty. *Int Orthop* 2013; 37: 421-5.
- Pagnano M W, Hanssen AD, Lewallen D G, Stuart M J. Flexion instability after primary posterior cruciate retaining total knee arthroplasty. *Clin Orthop Relat Res* 1998; (356): 39-46.
- Pijls B G, Dekkers O M, Middelorp S, Valstar E R, van der Heide H J, van der Linden H M, Nelissen R G. AQUILA: assessment of quality in lower limb arthroplasty. An expert Delphi consensus for total knee and hip arthroplasty. *BMC Musculoskelet Disord* 2011; 12: 173.
- Pijls B G, Valstar E R, Nouta K A, Plevier J W, Fiocco M, Middelorp S, Nelissen R G. Early migration of tibial components is associated with late revision: a systematic review and meta-analysis of 21,000 knee arthroplasties. *Acta Orthop* 2012; 83(6): 614-24.
- Rand J A, Trousdale R T, Ilstrup D M, Harmsen W S. Factors affecting the durability of primary total knee prostheses. *J Bone Joint Surg Am* 2003; 85-A: 259-65.
- Roh Y W, Jang J, Choi W C, et al. Preservation of the posterior cruciate ligament is not helpful in highly conforming mobile-bearing total knee arthroplasty: a randomized controlled study. *Knee Surg Traumatol Arthrosc* 2013; 21 (12): 2850-9.
- Seon J K, Park J K, Shin Y J, Seo H Y, Lee K B, Song E K. Comparisons of kinematics and range of motion in high-flexion total knee arthroplasty: cruciate retaining vs. substituting designs. *Knee Surg Sports Traumatol Arthrosc* 2011; 19: 2016-22.
- Shoji H, Wolf A, Packard S, Yoshino S. Cruciate retained and excised total knee arthroplasty. A comparative study in patients with bilateral total knee arthroplasty. *Clin Orthop Relat Res* 1994; (305): 218-22.
- Straw R, Kulkarni S, Attfield S, Wilton T J. Posterior cruciate ligament at total knee replacement. Essential, beneficial or a hindrance? *J Bone Joint Surg Br* 2003; 85: 671-4.
- Swanik C B, Lephart S M, Rubash H E. Proprioception, kinesthesia, and balance after total knee arthroplasty with cruciate-retaining and posterior stabilized prostheses. *J Bone Joint Surg Am* 2004; 86-A: 328-34.
- Tanzer M, Smith K, Burnett S. Posterior-stabilized versus cruciate-retaining total knee arthroplasty: balancing the gap. *J Arthroplasty* 2002; 17: 813-9.
- Thomsen M G, Husted H, Otte K S, Holm G, Troelsen A. Do patients care about higher flexion in total knee arthroplasty? A randomized controlled double-blinded trial. *BMC Musc Skeletal Dis* 2013; 14: 127.
- Verra W C, van den Boom L G, Jacobs W C, Clement D J, Wymenga A A, Nelissen R G. Retention versus sacrifice of the posterior cruciate ligament in total knee arthroplasty for treating osteoarthritis. *Cochrane Database Syst Rev* 2013; 10: CD004803.
- Victor J, Banks S, Bellemans J. Kinematics of posterior cruciate ligament-retaining and -substituting total knee arthroplasty: a prospective randomised outcome study. *J Bone Joint Surg Br* 2005; 87: 646-55.
- Wang C J, Wang J W, Chen H S. Comparing cruciate-retaining total knee arthroplasty and cruciate-substituting total knee arthroplasty: a prospective clinical study. *Chang Gung Med J* 2004; 27: 578-85.
- Wolterbeek N, Garling E H, Mertens B J, van der Linden H M, Nelissen R G, Valstar E R. Kinematics of a highly congruent mobile-bearing total knee prosthesis. *Knee Surg Sport Traumatol Arthrosc* 2012; 20(12): 2487-93.
- Yagishita K, Muneta T, Ju Y J, Morito T, Yamazaki J, Sekiya I. High-flex posterior cruciate-retaining vs posterior cruciate-substituting designs in simultaneous bilateral total knee arthroplasty: a prospective, randomized study. *J Arthroplasty* 2012; 27: 368-74.
- Yansheng W U, Yongsheng L I, Baicheng C H. Effect of posterior cruciate ligament retaining or not on knee joint proprioception. *Chinese J Reporative and Reconstructive Surg* 2013; V27: 7.
- Yoshiya S, Matsui N, Komistek RD, Dennis D A, Mahfouz M, Kurosaka M. In vivo kinematic comparison of posterior cruciate-retaining and posterior stabilized total knee arthroplasties under passive weight-bearing conditions. *J Arthroplasty* 2005; 20(6): 777-83.