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# Is varus-valgus constraint a reliable option in complex primary total knee arthroplasty? A systematic review

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A R T I C L E  I N F O

*Keywords:*
Varus-valgus constraint
Constrained total knee
Primary total knee arthroplasty
Joint laxity
Coronal deformity

A B S T R A C T

*Purpose:* Knee instability is considered one of the most frequent cause of failure after primary total knee arthroplasty (TKA). In order to address intraoperative instability, varus-valgus constrained knee implants (VVC) are increasingly utilized in primary TKA. Despite an increased risk of mechanical failure, short to mid-term results seem to be encouraging, but long-term results are still lacking.
*Methods:* A systematic review of prospective and retrospective studies that reported clinical outcomes of patients with VVC systems in primary TKAs between 1990 and 2020 was performed.
*Results:* In all, 28 articles met our inclusion criteria. A total of 2798 VVC implants were used in primary TKA. The all-cause revision-free survivorship was 95.2% at a mean follow-up of 7 years. Infection and aseptic loosening were the most common reasons for reoperation with an incidence of 1.8% and 1.7%, respectively. Overall complication rate was 9.6%, the most common complications were knee stiffness and infection with an incidence of 2.8% and 2.5%, respectively.
*Conclusions:* VVC implants in primary TKA are associated with improved functional outcomes and good mid-term survivorship, comparable to lower level of constraint implants. Non-modular stemless seem to be reliable implants at mid-term follow-up. However, given the lack data coming from long-term studies, VVC implants should be used cautiously in primary TKA.

## Introduction

Total knee arthroplasty (TKA) is considered the gold standard for patients with end-stage knee osteoarthritis, demonstrating excellent long-term outcomes and reported survivorship >95% after 10 years.[1,2] Currently, more than 400 thousand primary TKAs and 90 thousand revision TKAs are performed yearly in the United States,[3] and joint instability represents the third most common cause of failure that leads to a revision, reaching up to 29% of the cases.[4–7]

When a standard cruciate-retaining (CR), posterior-stabilized (PS), medial-pivot (MP) or midlevel constraint (MLC) articular bearing designs are not enough to obtain a well-balanced and stable knee, a higher level of constraint may be necessary.[8] In the setting of a deficient soft-tissue envelope, incompetent collateral ligaments, and/or inability to achieve intraoperative balance, increased constraint is currently used.[9–12]

Varus-valgus constraint knee implants (VVC) provide coronal stability through a tall tibial post that articulates with a deep femoral box.[13] First generation VVC implants (not modular) were associated with a high rate of patellar related pain and complications including fractures, maltracking and osteonecrosis.[11] The second generation VVC implants (modular), introduced in 1998, presented a redesigned patellofemoral articulation, right and left femoral components, modular stem extensions for both the tibial and femoral components, and a new locking

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mechanism for the constrained tibial polyethylene insert.[14] Stem extensions are required to help transfer loads away from the articular and metaphyseal bone to the remaining diaphyseal bone and to widely distribute the increased stresses of a constrained articulation.[15] Drawbacks of VVC implants include bone resection necessary to accommodate the deep femoral box, and higher risk of early loosening due to the increased stresses at the bone-implant interface.[15,16]

Several studies have evaluated the survivorship and clinical outcomes of VVC implants in primary TKA[11,14,17–42] at different follow-up.

We performed a systematic review of the literature in order to examine results and complication rates of VVC implants in primary TKA. Specifically, we aimed to examine (1) what complications are most common when VVC implants are used in primary TKA? and (2) do VVC implants provide an adequate survivorship in line with alternative treatment methods in complex primary TKA?

## Methods

### Search strategy

This search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA).[43] The US National Library of Medicine (Pubmed/MEDLINE), EMBASE, the Cochrane Database of Systemic Reviews and CINAHL were queried for publications from 1990 to December 2020 utilizing various combinations of the search terms "varus-valgus constrained", "semi-constrained", "condylar-constrained", "primary", "knee arthroplasty", "TKA", "TKR", and "knee surgery" in combination with the Boolean operators (AND, OR, *). No limit was set with regard the year of publication. Two reviewers (F.M., F.M.) independently conducted all the searches and screened the titles and abstracts to identify relevant studies. Differences were solved by consulting a third reviewer (I.D.M.). Only abstracts that evaluated the clinical outcomes of patients with VVC systems in primary TKA were reviewed. An additional search was conducted by screening the references list of each selected article, as well as the available grey literature at our institution.

### Inclusion and exclusion criteria

Inclusion criteria were any original study in which a VVC system was used in primary TKA, postoperative complications were reported, clinical outcomes were reported using validated patient reported scales, and implant survivorships for aseptic loosening and for any reason were reported. Exclusion criteria were case-reports, surgical technique reports, review articles, expert opinions, letters to editors, biomechanical reports, instructional course lectures, studies on animals, cadaver or in vitro investigations, book chapters, abstracts from scientific meetings, unpublished reports, studies with less than 15 knees, studies with a mean followup of less than 2 years, and studies written in non-English language.

### Data extraction and collection

Two independent reviewers (F.M. and F.M.) separately examined all the identified studies and extracted data. During initial review of the data, the following information was collected for each study: title, first author, year of publication, study design, prosthetic knee system, number of patients, patients died and lost at followup, age of patients, length of followup, complication type, reoperation for any reason, implant loosening requiring revision, deep infections, and patient-reported outcomes. Revision was defined when femoral component or tibial component or both were removed. Polyethylene insert exchange was not considered as implant revision, but included in the reoperations. The level of evidence of a given study was assigned according the 2011 Oxford Centre for Evidence-based Medicine Level of Evidence.[44]

### Study quality

Excel 2011 (Microsoft Corp., Redmond, WA, USA) was used to collect all study data. To assess the quality of the studies, we used the revised Methodological Index for Non-Randomized Studies (MINORS).[45] This validated instrument was developed to determine the quality of observational and non-randomized studies. Two reviewers (F. M., F.M.) independently assessed the quality of each article. This scale contains 12 items, with the first 8 being specifically for non-comparative studies: aim of the study, inclusion of consecutive patients, prospective collection of data, appropriateness of the endpoints, unbiased assessment of the endpoint, appropriateness of length of followup, percentage of loss to followup, prospective calculation of the sample size, comparable control group, contemporary control groups, baseline equivalence of groups and the adequateness of the statistical analysis. The studies were scored from 0 to 2 points for each of these items. Methodological quality was categorized a priori as follows: a score of 0–8 or 0–12 was considered poor quality, 9–12 or 13–18 was considered fair quality and 13–16 or 19–24 was considered excellent quality, for non-comparative and comparative studies, respectively.

## Results

### Study selection

The search resulted in 402 abstracts that were examined to determine the outcome of patients treated with a VVC implant in primary TKA (Fig. 1). Following elimination of duplicate articles, predetermined inclusion and exclusion criteria were applied. In total, 28 articles met the inclusion criteria and were included in the final analysis (Table 1). Consensus on which articles would be analyzed in the present study was achieved by discussion between the reviewers based on the predetermined inclusion and exclusion criteria described above.

### Quality assessment

The quality of the studies was variable, with the average MINORS score of the included studies of 13 points (range 9–20), showing that the quality of the studies was fair. There was no level I and II studies available for inclusion. The studies included 9 level III, retrospective comparative studies, and 19 level IV, retrospective studies, according to Oxford Centre for Evidence-based Medicine Level of Evidence.[44] A meta-analysis was not undertaken due to the general fair quality of the studies.

### Demographic data

A total of 2798 knees were initially included in this analysis. After excluding 226 knees (8.1%) due to missing data and lost to followup, 2660 knees with a mean age of 63 years (range, 19–94 years) at the time of surgery were included for the final analysis. The mean followup was 7 years (range, 2–14 years). The average number of knees per study was 99, however only 17 studies included a relevant number of knees (>40).[11,17,20,22,27–33,35,37,38,40–42] All studies reported on patients with VVC implants in primary TKA. The underlying diagnosis that led to the primary TKA was reported in 16 studies.[11,14,17–23,27,29,30,32–34,37,40–42] The most common indication for the primary TKA was idiopathic osteoarthritis in 67.8% of the cases (1218 of 1797 knees), post-traumatic arthritis in 9.6% (173 knees) and rheumatoid arthritis in 7.6% (137 knees). The type of implant used was reported in 24 studies.[11,14,17–20,22–28,30–37,39,41,42] The VVC implants were stemless in 51.7% of the knees and patellar resurfacing was performed in 94.4% of the cases among the studies that described it (789 of 836 knees). Additional information is further outlined in Table 1.

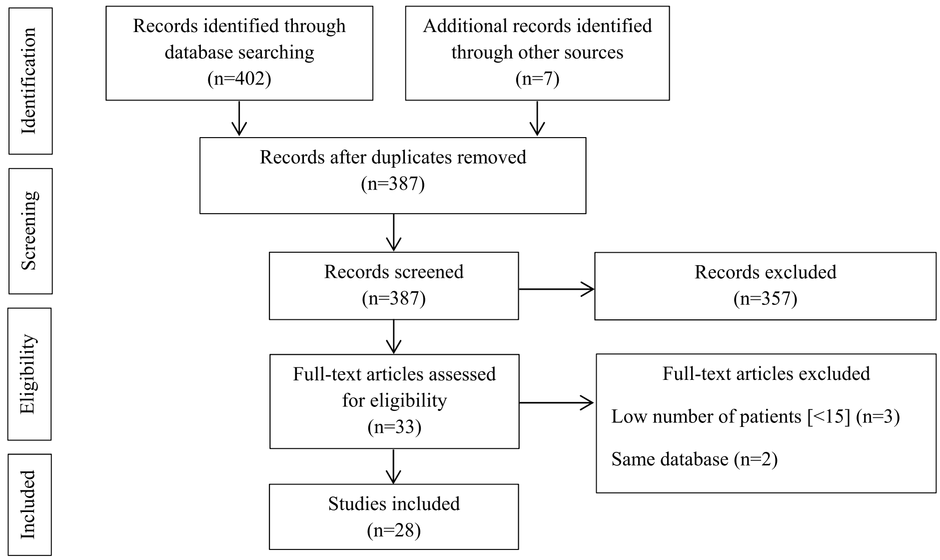


**Fig. 1.** PRISMA flow diagram outlining the systematic review process.

*Preoperative deformity*

Nineteen studies reported the preoperative coronal deformity[11,14,17,19,21,22,25–28,30–34,36,37,39,41] (Table 2). In three studies, coronal deformity was specified partially[26,28,32] while in four others was not provided as a mean angle value but as a threshold instead.[19,33,36] Valgus deformity was reported in 48.3% of the knees (655 of 1357 knees), while Varus deformity in 27.0% (367 knees) and neutral alignment in 8.8% (119 knees). Additional information is further outlined in Table 2.

*Reoperation and revision rates*

The overall reoperation rate was 11.1% (322 of 2902 knees) (Table 3). The overall revision rate was 4.8% (139 knees) at a mean followup of 7 years (range, 2–14 years). Periprosthetic joint infection (PJI) and aseptic loosening were the most common reasons of revision with an incidence of 1.8% (51 knees) and 1.7% (50 knees), respectively. Knee stiffness and/or arthrofibrosis was the cause of revision in 0.5% of the cases (14 knees). The all-cause reoperation-free survivorship was 91.1% at a mean followup of 7 years (range, 2–14 years) (Table 3).

*Revision rates in stemmed vs stemless implants*

Stemmed implants were used in 12 studies (534 knees).[14,19,21–23,25,30,33,34,36,39,41] The overall revision rate was 3.2% (17 knees) and the revision rate for aseptic loosening of the implant was 0.6% (3 knees). When considering only the studies with a followup equal or longer than 5 years (10 of 12 studies), the overall revision rate at mean 7.2 years was 3.4% (14 of 411 knees) and the revision rate for aseptic loosening of the implant was 0.5% (2 knees).

Of the 10 studies in which every implant was stemless (1398 knees),[17,20,24,26,27,31,32,35,40,42] the overall revision rate was 4.1% (57 knees) and the revision rate for aseptic loosening of the implant was 1.5% (21 knees). When considering only the studies with a followup equal or longer than 5 years (7 of 10 studies), the overall revision rate at mean 5.5 years was 5.6% (42 of 747 knees) and the revision rate for aseptic loosening of the implant was 2.3% (17 knees) (Tables 1 and 4).

*Complications*

Complication rates were reported in 27 of the included studies (Table 3).[11,14,17–22,24–42] The overall complication rate was 9.6% (279 of 2902 knees). The most common complication was knee stiffness (2.8%, 82 knees) and all the cases required manipulation under anesthesia (MUA), eventually, thirteen of them (16%), required further implant revision. Other frequent complications were superficial or deep infection (2.5%, 72 knees), deep venous thrombosis (DVT; 0.9%, 26 knees), periprosthetic fracture (0.7%, 19 knees), patellar clunk syndrome (0.3%, 9 knees) and nerve injury (0.2%, 6 knees) (Table 3).

The overall prevalence of infection was 2.5% (72 of 2902 knees). In total, the incidence of PJI was 1.8% (51 knees). Irrigation and debridement with implant retention and polyethylene insert exchange was performed in five knees, while a full implant revision was performed in 51 knees (Table 3).

*Aseptic loosening*

The incidence of VVC aseptic loosening was 1.7% (50 of 2902 knees). Among the studies that used modular VVC implants with extension stems[14,19,21–23,25,30,33,34,36,39] the incidence of aseptic loosening was 0.6% (3 of 537 knees); conversely, among the studies that used non-modular VVC implants[17,20,24,26,27,31,32,35] the incidence of aseptic loosening was 1.5% (21 of 1398 knees) (Table 3).

*Clinical scores*

Among all, 17 studies recorded preoperative Knee Society Score (KSS)[11,14,17,19,20,21,22,23,33,35,36,37,38,39,40-, 41] and 20 studies noted the postoperative KSS. The average postoperative KSS was 84 (excellent, range 40–100). In the 17 studies (1410 knees) that have both preoperative and postoperative KSS, improvements were seen on the KSS from mean 33 points (poor, range 0–93) preoperatively to mean 84 points (excellent, range 40–100) at the latest follow up. The preoperative Knee Society Function Score (KSS F) was recorded in 14 studies, and 15 studies noted the postoperative KSS F. The average postoperative KSS F was 64.8 (range 0–100). In the 12 studies (904 knees) that have both preoperative and postoperative KSS F, improvements were seen on the KSS F from mean 35 points (range 0–100) preoperatively to mean 64.8 points (range 0–100) at the latest follow up. The Hospital for Special Surgery Knee Score (HSS) was recorded in seven studies (241 knees)[11,14,19,21,33,34,39] improvements were seen on the HSS Knee Score from mean 48.2 points (poor, range 0–83) preoperatively to mean 82.7 points (good, range 12–95) at the latest follow up. The Oxford Knee Score (OKS) was recorded in three studies (215 knees),[24,30,33] improvements were seen on the OKS from mean 27.3 points preoperatively

**Table 1**
Study characteristics and patient demographics on varus-valgus constrained knee in primary TKA.

| Authors (year of publication) | Study design (level of evidence) | MINORS Score | No. of Knees Initial Cohort/ Final Cohort | No. of Knees Lost to Follow-Up and/or Died | Male/ Female | Mean age at index (y) (Range) | Mean Follow-Up (yr) (Range) | Tibial and Femoral Stem fixation | Patellar Resurfacing | Preoperative indication (aseptic/septic) |
|---|---|---|---|---|---|---|---|---|---|---|
| Lachiewicz et al. (1996) | Retrospective (IV) | 12 | 25 | N/A | N/A | 66 (44–81) | 5 (2–9) | stemless | N/A | N/A |
| Hartford et al. (1998) | Retrospective (IV) | 10 | 17 | N/A | N/A | 70 (32–84) | 5 (2–10) | Tibial: 17 Femoral: 17 | 16 (94%) | OA: 10, RA: 6, Post traumatic: 1 |
| Easley et al. (2000) | Retrospective (IV) | 10 | 44/28 | 16 | 4/33 | 72.7 (60–88) | 8 (5–11) | Tibial: 28 Femoral: 28 | N/A | OA: 20; RA: 2; Gout: 4 |
| Anderson et al. (2006) | Retrospective (IV) | 11 | 70/55 | 15 (21%) | 13/36 | 72 (53–84) | 4 (2–6) | stemless | N/A | OA: 45; RA: 3; Tuberculosis: 1 |
| Lachiewicz et al. (2006) | Retrospective (IV) | 10 | 54/42 | 12 (22%) | 2/32 | 67 (40–91) | 9 (5–16) | Modular Tibial: 7 Femoral: 6 | 42 (100%) | OA: 20; RA: 17; Post traumatic: 2; Neuropathic arthritis: 2; Villonodular synovitis: 1 |
| Lachiewicz et al. (2011) | Retrospective (IV) | 12 | 30/27 | 3 (10%) | 2/24 | 74 (28–94) | 5 (2–12) | Tibial: 27 Femoral: 27 | 27 (90%) | OA: 24; RA: 1; Charcot arthropathy: 2 |
| Nam et al. (2012) | Retrospective comparative (III) | 19 | 190 | N/A | 65/116 | 72.3 ± 10.2 | 7 ± 2 | stemless | 190 (100%) | OA: 180, RA: 3, Post traumatic: 6, Septic: 1 |
| Pang et al. (2013) | Retrospective comparative (III) | 19 | 50 | 0 (0%) | 5/45 | 70 (±9) | 2 | Tibial: 50 Femoral: 50 | N/A | OA: 30, RA: 20 |
| Maynard et al. (2014) | Retrospective (IV) | 11 | 132/127 | 3 (2%) | 29/95 | 68 (42–86) | 9 (7–13) | Tibial: 127 Femoral: 127 | 127 (100%) | OA: 107; RA: 2; Post traumatic: 4; Post septic: 1 |
| Tripathi et al. (2015) | Retrospective comparative (III) | 19 | 100 | N/A | 15/85 | 59 (45–70) | 7 | N/A | N/A | N/A |
| Camera et al. (2015) | Retrospective (IV) | 9 | 19/15 | 4 (21%) | 5/14 | 69 (43–82) | 11 (2–13) | Tibial: 19 (75 mm, 30–100) Femoral: 7 (75 mm, 30–75) | 0 (0%) | OA: 11; RA: 2; Post traumatic: 2; Post osteotomy: 3 |
| Ruel et al. (2015) | Retrospective (IV) | 9 | 184/142 | 42 (23%) | 45/95 | N/A | 5 (2–10) | Stemless | N/A | N/A |
| Cholewinski et al. (2015) | Retrospective (IV) | 10 | 43/25 | 18 (42%) | 14/27 | 66 (21–88) | 12 (10–14) | Tibial 43 Femoral: 43 | N/A | OA: 35; RA: 4; Post traumatic: 4 |
| Luque et al. (2015) | Retrospective (IV) | 16 | 109/99 | 10 (9%) | 13/57 | 71 | 7 (2–8) | Tibial: 109 (n = 21 120 mm) Femoral: 84 (n = 64 80 mm) | N/A | N/A |
| Martin et al. (2016) | Retrospective comparative (III) | 9 | 427 | 90 (21%) | 140/ 287 | 65 ± 13 | 5 (2–12) | N/A | N/A | OA: 161, post traumatic: 68, inflammatory arthritis (RA): 28, pediatric condition: 153, other: 17 |
| Siqueira et al. (2016) | Retrospective comparative (III) | 11 | 247 | N/A | 88/159 | 67 ± 14 | 8 (2–15) | 11 stemless Tibial: 236 Femoral: 236 | N/A | OA: 206, RA: 14, Post traumatic: 18, AVN: 4, Hemarthrosis: 3, Gout: 2 |
| Deshmukh et al. (2016) | Retrospective comparative (III) | 20 | 242 | N/A | 78/159 | 65 (53–77) | 3 (2–4) | 242 stemless | 242 (100%) | OA: 225, RA: 7, Post traumatic: 5 |
| Feng et al. (2016) | Retrospective (IV) | 8 | 52/48 | 4 (8%) | 27/19 | 61 (29–81) | 6 (3–8) | Tibial: 52 Femoral: 52 | N/A | OA: 15; RA: 10; Post traumatic: 14; Charcot arthropathy: 2; Gout: 3; Post tubercular: 1; Post septic: 1 |
| Ye et al. (2016) | Retrospective (IV) | 19 | 35/35 | 0 (0%) | 9/22 | 64 (52–76) | 6 (4–8) | Tibial: 35 (100 mm) Femoral: 35 (100 mm) | N/A | N/A |
| Moussa et al. (2017) | Retrospective (IV) | 18 | 439/439 | N/A | 134/ 305 | NSCCK 72 SCCK 67 | 2 | SCCK: 85 stemmed | N/A | N/A |

(*continued on next page*)

**Table 1** (*continued*)

| Authors (year of publication) | Study design (level of evidence) | MINORS Score | No. of Knees Initial Cohort/ Final Cohort | No. of Knees Lost to Follow-Up and/or Died | Male/ Female | Mean age at index (y) (Range) | Mean Follow-Up (yr) (Range) | Tibial and Femoral Stem fixation | Patellar Resurfacing | Preoperative indication (aseptic/septic) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | NSCCK: 354 stemless | | |
| Sabatini et al. (2017) | Retrospective (IV) | 10 | 28/28 | 0 (0%) | N/A | 82 (75–89) | 3 (1–4) | Tibial: 28 Femoral: 28 | 26 (93%) | N/A |
| Rai et al. (2018) | Retrospective (IV) | 12 | 38/36 | 2 (5%) | 22/14 | 58 (33–73) | 7 (3–10) | Stemmed | N/A | Post traumatic: 38 |
| Hossain et al. (2019) | Retrospective comparative (III) | 19 | 38 | N/A | 16/22 | 68 (36–84) | 5 (2–9) | Stemless | 38 (100%) | N/A |
| Li et al. (2019) | Retrospective (IV) | 10 | 43/43 | 0 (0%) | 4/39 | 65 (60–72) | 5 (2–10) | Stemless | 43 (100%) | OA: 33; RA: 7; Post traumatic: 1; Psoriasic arthropathy: 2 |
| Johnson Jr. et al. (2019) | Retrospective (IV) | 10 | 21/21 | 0 (0%) | 10/11 | 54 (39–59) | 6 (2–12) | Stemmed | 20 (95%) | N/A |
| Dayan et al. (2019) | Retrospective (III) | 21 | 241/241 | N/A | 79/162 | 65 ± 12 | 6 ± 1 | Stemless | 241 (100%) | OA: 228; RA:7; Post traumatic: 6 |
| Mancino et al. (2020) | Retrospective (IV) | 14 | 54/47 | 4/3 | 8/34 | 72 (43–86) | 9 (6–12) | Stemmed | 9 (19%) | OA: 36; Post traumatic: 7; RA: 4 |
| Stockwell et al. (2020) | Retrospective (III) | 19 | 68/68 | 0/0 | 17/51 | 65 (19–88) | 5 | Stemless | N/A | OA: 57; RA: 7; Post traumatic: 2; Other: 2 |
| Total | | | 2798/2304 | 219 | / | 63 (19–94) | 7 (2–14) | 987 Stemless of 1909 (51.7%) | 789 of 836 (94.4%) | OA: 1218 of 1797 (81.4%), Post traumatic: 173 (11.6%), RA: 137 (8.3%) |

N/A, not available; OA, osteoarthritis; RA, rheumatoid arthritis; SCCK, stemmed condylar constrained knee; NSCCK, non-stemmed condylar constrained knee.

to mean 33.3 points at the latest follow up. The postoperative Wester Ontario and McMaster Universities Arthritis Index (WOMAC) was recorded in three studies[18,30,31]. The average postoperative WOMAC Index was 85.7. In the two studies (566 knees) that have both preoperative and postoperative WOMAC Index, improvements were seen on the WOMAC Index from mean 51.5 preoperatively to mean 89.5 at the latest follow up. Camera et al.,[18] showed a postoperative Tegner Lysholm Knee Scoring Scale (TLKSS) of 87 (good, range 83–93) (Table 4).

*Range of motion*

The mean preoperative knee flexion was recorded in nine studies, and 12 studies noted the mean flexion at the latest follow up.[11,14,18,19,25,26,28,30,33,34,36,38,40,41] The average postoperative flexion was 105.6° (range 60°–130°). In the nine studies (614 knees) that have both preoperative and postoperative flexion, improvements were seen from mean 91.6° (range 30°–140°) preoperatively to mean 105.6° (range 60°–130°) at the latest follow up. The mean preoperative and postoperative flexion contracture was recorded in 8 studies (402 knees)[11,14,22,26,30,33,34,41], improvements were seen from mean 8.6° (range 0°–60°) preoperatively to mean 0.9° (range 0°–15°) at the latest follow up (Table 4).

*Radiographic outcomes*

Preoperative radiographic analysis showed that 367 knees (of 1357 knees, 27.0%) had varus deformity and 655 knees (48.3%) had valgus deformity. No preoperative alignment deformity was recorded in 119 knees (8.8%) (Table 2).

Radiolucent lines (RLL) were noted in 283 knees (of 1123, 25.2%) on the antero-posterior (AP) and lateral x-rays. Among those, 225 (79.5%) were underneath the tibial component, 23 were around the femoral component (2.0%) and three were noted around the patellar component. The RLL were all detected in the early postoperative x-rays, non-progressive and less than 2 mm in thickness. Camera et al. [18] recorded osteolytic areas in one or more zones in 5 knees (of 15 knees, 33.3%) (Table 4).

## Discussion

Instability after primary TKA is often related to inadequate intraoperative ligament balancing[13] and it represents one of the most frequent cause of revision TKA reaching up to 21% of indications at 2 years, and 27% at 5 years.[5,7] Knee collateral ligaments insufficiency may be due to severe coronal deformity or iatrogenic intraoperative injury.[8,46] A VVC implant can be necessary when intraoperatively is impossible to obtain a well-balanced and stable knee with a CR, PS, MP or MLC implant.[47] However, the intraoperative amount of instability that requires a higher degree of constraint has not been exactly clarified yet, leaving the final decision to the surgeon's personal preference. Nevertheless, the increased stability comes at a cost, it has been reported that an increased degree of constraint is associated with an increased mechanical stress at the bone-cement interface that can lead to higher risk of micromotions, aseptic loosening of the implant components, osteolysis, and implant failure.[15] Despite that, the overall survivorship from all-cause revision reported in this systematic review was 95.2% at mean of 7 years followup, suggesting that VVC implants are not associated with highly increased early failure rate but, in reverse, present a mid-term survivorship comparable with lower constraint implants.[48]

Moussa et al.,[49] compared revision rates at mean followup of 4.5 years of 817 VVC with 817 PS implants in primary TKA and found an all-cause revision rate of 1.35% in the PS group compared to a 3.43% revision rate in the VVC group. The authors reported a 6-fold greater revision rate for mechanical failure in the VVC implants compared to PS implants. However, these differences could be due to the fact that the VVC used were all stemless non-modular first-generation implants. Similarly, Pitta et al.,[4] in a prospective single institution total joint arthroplasty registry with 18,065 primary TKAs with a minimum of 5-year followup, found that in the 405 revised TKAs the failure rate was up to 2-fold greater in patients who had VVC implants compared to PS implants with a hazard ratio of 1.99, probably related to the

**Table 2**
Summary of VVC Systems in Primary TKA showing Coronal Deformity and Tibiofemoral Alignment.

| Authors (year of publication) | No. of Knees | Preoperative Alignment | | | HKA/Tibiofemoral Angle | |
|---|---|---|---|---|---|---|
| | | Varus Deformity Mean (range) | Valgus Deformity Mean (range) | Neutral Alignment | Pre-operative | Post-operative |
| Lachiewicz et al. (1996) | 25 | 3 knees (12%) | 12 knees (48%) | 10 knees (40%) | N/A | TF between 0° and 9° (1 outlier) |
| Hartford et al. (1998) | 17 | N/A | N/A | N/A | N/A | N/A |
| Easley et al. (2000) | 44 | 0 (0%) | 44 knees 17.6° (11°–25°) | 0 (0%) | TF 17.6° Valgus (11°–25°) | TF 5.3° Valgus (3°–7°) |
| Anderson et al. (2006) | 55 | 0 (0%) | 55 knees (100%) Mean 9.7° (15°–33°) | 0 (0%) | TF 19.7° Valgus (15°–33°) | TF 6.5° Valgus (0°–12°) |
| Lachiewicz et al. (2006) | 42 | 3 knees (7.1%) | 28 knees (66.7%) [>7°] Mean 20° | 11 (26.2%) | N/A | 41 knees TF 5° Valgus (3°–7°) 1 knee TF 5° Varus |
| Lachiewicz et al. (2011) | 27 | 4 knees (14.8%) Mean 4.8°(3°–10°) | 23 knees (85.2%) Mean 22.2°(12°–30°) | 0 (0%) | N/A | TF 6.4° Valgus (4°–11°) |
| Nam et al. (2012) | 190 | Mean 10.2° ± 5.4° | Mean 15.5° ± 5.1° | 0 (0%) | N/A | TF 4.2° ± 2.0° Valgus |
| Pang et al. (2013) | 50 | 0 (0%) | 50 knees (100%) [>10°] | 0 (0%) | TF 24.1° (±7.2) | TF 1.2 (±1.4) |
| Maynard et al. (2014) | 127 | 79 knees (62%) [<15°] | | 5 (3.9%) | N/A | |
| | | 15 knees (11.8%) [>15°] | 28 knees (22%) [>7°] | | | TF 5.7° ± 1.98° |
| | | Mean 10.7° ± 8.1° (2°–28°) | Mean 18.4° ± 5.44° (10°–30°) | | | Valgus (2°–9.4°) |
| Tripathi et al. (2015) | 100 | N/A | N/A | N/A | N/A | N/A |
| Camera et al. (2015) | 15 | N/A | N/A | N/A | N/A | N/A |
| Ruel et al. (2015) | 142 | N/A | N/A | N/A | N/A | N/A |
| Cholewinski et al. (2015) | 43 | 5 knee (20%) [<10°] 10 knees (40%) [>10°] | 7 knee (28%) [<10°] 10 knees (40%) [>10°] | 11 (25.6%) | HKA 182° ± 15.5° (150°–210°) | HKA 179° ± 2.5° (174°–184°) |
| Luque et al. (2015) | 99 | Mean 10.9° | Mean 25.9° | 0 (0%) | TF Varus 5.9° | TF Valgus 7.5° |
| Martin et al. (2016) | 427 | N/A | N/A | N/A | N/A | N/A |
| Siqueira et al. (2016) | 247 | 31 knees (11.3%) [>15°] | 31 knees (11.3%) [>15°] | N/A | N/A | N/A |
| Deshmukh et al. (2016) | 242 | N/A | N/A | N/A | TF −0.29 (±8.2) | TF 4.5 (±1.8) |
| Feng et al. (2016) | 48 | 3 knees (6.3%) Mean 11.74°(5°–25°) | 37 knees (77.1%) [>7°] Mean 10.48°(7°–15°) | 8 (16.7%) | N/A | TF 3.9°(2°–9°) |
| Ye et al. (2016) | 35 | 9 knees (25.7%) Mean 24.4°(19.8°–29°) | 10 knees (28.6%) Mean 25°(18.3°–31.7°) | 16 (45.7%) | N/A | N/A |
| Moussa et al. (2017) | 439 | 170 knees (38.7%) [9.7°] | 225 knees (51.3%) [11.5°] | 44 knees (10%) | N/A | N/A |
| | 85 SCCK 354 NSCCK | SCCK n = 33 [11.4°] NSCCK n = 137 [9.3°] | SCCK n = 40 [14.3°] NSCCK n = 185 [10.9°] | SCCK n = 12 NSCCK n = 32 | | |
| Sabatini et al. (2017) | 28 | 18 knees (64.3%) [>10°] | 10 knees (35.7%) [>15°] | 0 (0%) | N/A | N/A |
| Rai et al. (2018) | 36 | 10 knees (27.8%) 12°(0–30°) | 17 knees (47.2%) Mean 15°(7.5°–25°) | 9 (25%) | HKA 176.9° (135°–199°) | HKA 180.2° (175°–184°) |
| Hossain et al. (2019) | 38 | N/A | N/A | N/A | N/A | HKA 175°–178° |
| Li et al. (2019) | 43 | 0 (0%) | 43 knees (100%) Mean 14°(11°–17.5°) | 0 (0%) | N/A | TF 0° (0°–3.5°) |
| Johnson Jr.et al. (2019) | 21 | 16 knees (76.2%) 6.63° + 4.9°(1°–16°) | 5 knees (23.8%) Mean 14° + 2° (12°–16°) | 0 (0%) | N/A | TF 0.2° + 1° Valgus (3°Valgus-2°Varus) |
| Dayan et al. (2019) | 241 | N/A | N/A | N/A | TF -0.28° (±8.2) | TF 4.2° (±2.1) |
| Mancino et al. (2020) | 47 | 22 knees 13.3° (5°–30°) | 20 14.2° (5°–25°) | 5 | N/A | TF 3.7° Valgus (1° Varus −6° Valgus) |
| Stockwell et al. (2020) | 68 | N/A | N/A | N/A | N/A | N/A |
| Total | 2580 | 367/1357 (27.0%) | 655/1357 (48.3%) | 119/1357 (8.8%) | / | / |

characteristics of the patients, including poor bone stock, ligamentous deficiency, or more severe preoperative deformities. The authors identified the failure mechanisms of VVC implants in primary TKAs and reported a progressive change from polyethylene wear and osteolysis in the older cases to infection and instability in the more recent cases. However, a large proportion of the failed VVC were stemless non-modular first-generation implants.

Stemless VVC implants represent an attractive option in the setting of primary TKA reducing implant cost, additional iatrogenic bone loss in case of future revision, and operative time due to the stem preparation, potentially reducing the risk of superficial and deep infection.[50] Despite these potential advantages, stem extensions in VVC can improve load-sharing and avoid implant loosening secondary to stress forces at the bone-cement interface.[51,52] In a retrieval analysis of stemless non-modular VVC implants, Padgett et al.,[53] found extensive damage to both the post and the articular surfaces in implants revised for loosening and instability, suggesting that the loads placed on the polyethylene may be greater than the ability of the polymer to withstand. In addition, Moussa et al.,[31] in a retrospective analysis of 85 stemmed primary VVC implants compared with 354 stemless VVC, reported a higher revision rate in stemless VVC at 2-years follow-up (2.4% VS 1.1%), mostly for mechanical failure. Conversely, recent data[40,42] showed that stemless VVC implants are reliable at midterm follow-up and present comparable overall survivorship and survivorship from aseptic loosening with PS knees with no significant differences between the two. We reported a prevalence of revision for aseptic loosening of the implants at mid-term follow-up 3-fold greater in stemless VVC implants (1.5%) compared to stemmed VVC implants (0.6%). However, these data do not have statistical significance, and need to be taken cautiously. Despite the theoretical advantages of stemless implants, the long-term survivorship compared to stemmed ones need to be clearly assessed and further high-quality comparative studies are needed.

**Table 3**
Summary of VVC systems in primary TKA: Results showing reoperations and survivorship.

| Autho (year of publication) | No. of Knees | Overall Reoperations (Rate) | Overall Revisions (Rate) | Revisions for Aseptic Loosening (Rate) | Revisions for Infection (Rate) | Reoperations for Other Reasons (Rate) | Complications (rate) | All-Cause Survivorship (Rate) |
|---|---|---|---|---|---|---|---|---|
| Lachiewicz et al. (1996) | 25 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 5 (20%)[2 DVT, 3 stiffness {MUA}] | 25 (100%) |
| Hartford et al. (1998) | 17 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | N/A | N/A | 28 (100%) |
| Easley et al. (2000) | 28 | 1 (3.4%) | 1 (3.4%) | 0 (0%) | 0 (0%) | 1 (3.4%)[1 periprosthetic fracture {revision}] | 8 (28.6%) [4 DVT, 2 Patellar fracture {conservative}, 1 Siffness {MUA}, 1 periprosthetic fracture] | 27 (96.4%) |
| Anderson et al. (2006) | 55 | 1 (1.8%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (1.8%) [1 patellar clunk syndrome] | 1 (1.8%) [1 patellar clunk syndrome] | 54 (98.1%) |
| Lachiewicz et al. (2006) | 42 | 3 (7.1%) | 2 (4.8%) | 2 (4.8%) | 0 (0%) | 1 (2.4%) [1 I&D] | 8 (19%) [1 dislocation, 2 patellar osteonecrosis, 5 patellar tilt >5°, 1 acute infection] | 39 (92.9%) |
| Lachiewicz et al. (2011) | 27 | 2 (7.4%) | 0 (0%) | 0 (0%) | 0 (0%) | 2 (7.4%) [1 I&D, 1 wound complication] | 7 (25.9%) [1 acute infection, 1 hematoma, 5 DVT] | 25 (92.6%) |
| Nam et al. (2012) | 190 | 8 (4.2% | 8 (4.2%) | 5 (2.6%) | 1 (0.5%) | 2 (1.1%) ([1 stiffness {revision}, 1 instability {revision}] | 2 (1.1%) [1 stiffness, 1 instability] | 182 (95.8%) |
| Pang et al. (2013) | 50 | 2 (4%) | 2 (4%) | 1 (2%) | 0 (0%) | 1 (2%) [1 tibial post breakage] | 2 (4%) [2 superficial infection {iv atb}] | 48 (96%) |
| Maynard et al. (2014) | 127 | 13 (10.2%) | 3 (2.4%) | 0 (0%) | 2 (1.6%) | 10 (7.9%) [2 periprosthetic fracture, 1 wound complication, 6 patellar clunk syndrome, 1 patellar fracture] | 17 (13.4%) [4 periprosthetic fracture, 1 wound complication, 6 patellar clunk syndrome, 3 peroneal nerve palsy, 1 patellar fracture, 2 PJI] | 114 (89.8%) |
| Tripathi et al. (2015) | 100 | 3 (3%) | 2 (2%) | 1 (1%) | 1 (1%) | 2 (2%) [1 instability {revision}, 1 I&D] | 8 (8%) [1 instability, 1 acute infection, 6 N/A] | 97 (97%) |
| Camera et al. (2015) | 15 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 15 (100%) |
| Ruel et al. (2015) | 142 | 14 (9.9%) | 14 (9.9%) | 7 (4.9%) | 2 (1.4%) | 5 (3.5%) [4 stiffness, 1 polyethylene wear] | 31 (21.8%) [28 stiffness, 1 polyethylene wear, 2 PJI] | 128 (90.1%) |
| Cholewinski et al. (2015) | 25 | 5 (20%) | 3 (12%) | 0 (0%) | 2 (8%) | 3 (12%) [2 I&D, 1 instability] | 11 (44%) [2 PJI, 2 acute infection, 1 instability, 4 DVT, 1 wound complication, 1 periprosthetic fracture] | 20 (80%) |
| Luque et al. (2015) | 99 | 11 (11.1%) | 8 (8.1%) | 2 (2%) | 6 (6.1%) | 3 (3%) [2 non-union of tto, 1 periprosthetic fracture] | 9 (9.1%) [6 PJI, 2 non-union of tto, 1 periprosthetic fracture] | 88 (88.9%) |
| Martin et al. (2016) | 427 | 75 (17.6%) | 31 (7.3%) | 19 (4.4%) | 5 (1.2%) | 75 (17.6%) | 84 (19.7%) [25 wound complication, 36 stiffness, 2 periprosthetic fracture, 21 infection] | 352(82.4%) |
| Siqueira et al. (2016) | 247 | 22 (8.9%) | 22 (8.9%) | 2 (0.8%) | 13 (5.3%) | 7 (2.8%) [4 periprosthetic fracture {revision}, 1 arthrofibrosis {revision}, 1 dislocation {revision}, 1 instability {revision}] | 20 (8.1%) [4 periprosthetic fracture, 1 arthrofibrosis, 1 dislocation, 1 instability, 13 PJI] | 225 (91.1%) |
| Deshmukh et al. (2016) | 242 | 6 (2.5%) | 6 (2.5%) | 1 (0.4%) | 4 (1.7%) | 1 (0.4%) [1 arthrofibrosis {revision}] | 9 (3.7%) [4 PJI, 4 stiffness {MUA}, 1 arthrofibrosis {revision}] | 236 (97.5%) |
| Feng et al. (2016) | 48 | 1 (2.1%) | 1 (2.1%) | 1 (2.1%) | 0 (0%) | 0 (0%) | 9 (18.8%) [5 DVT, 1 periprosthetic fracture, 1 peroneal nerve palsy, 1 heterotopic ossification, 1 patella baja] | 47 (97.9%) |
| Ye et al. (2016) | 35 | 1 (2.9%) | 1 (2.9%) | 0 (0%) | 1 (2.9%) | 0 (0%) | 1 (2.9%) [1 PJI] | 34 (97.1%) |
| Moussa et al. (2017) | 439<br>85 SCCK<br>354 NSCCK | 10 (2.3%) | 10 (2.3%)<br>1 SCCK (1.2%)<br>9 NSCCK (2.5%) | 3 (0.7%)<br>3 NCCK (0.8%) | 2 (0.5%)<br>1 SCCK (1.2%)<br>1 NSCCK (0.3%) | 5 (1.1%)<br>5 NSCCK (1.4%) [2 periprosthetic fracture, 1 instability, 1 stiffness, 1 dislocation of patellar component] | 7 (1.6%) [2 PJI, 2 periprosthetic fracture, 1 instability, 1 stiffness, 1 dislocation of patellar component] | 429 (97.7%) |
| Sabatini et al. (2017) | 28 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 3 (10.7%) [thigh pain] | 28 (100%) |
| Rai et al. (2018) | 36 | 2 (5.6%) | 2 (5.6%) | 1 (2.8%) | 1 (2.8%) | 0 (0%) | 7 (19.4%) [1 PJI, 1 periprosthetic fracture, 3 DVT, 1 peroneal nerve palsy, 1 heterotopic ossification] | 34 (94.4%) |

(*continued on next page*)

Table 3 (*continued*)

| Autho (year of publication) | No. of Knees | Overall Reoperations (Rate) | Overall Revisions (Rate) | Revisions for Aseptic Loosening (Rate) | Revisions for Infection (Rate) | Reoperations for Other Reasons (Rate) | Complications (rate) | All-Cause Survivorship (Rate) |
|---|---|---|---|---|---|---|---|---|
| Hossain et al. (2019) | 38 | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 1 (2.6%) [1 DVT] | 38 (100%) |
| Li et al. (2019) | 43 | 2 (4.7%) | 2 (4.7%) | 0 (0%) | 0 (0%) | 2 (4.7%) [2 dislocation] | 9 (9.3%) [4 dislocation, 2 DVT, 1 MCL injury, 1 peroneal nerve palsy, 1 periprosthetic fracture] | 41 (95.3%) |
| Johnson Jr. et al. (2019) | 21 | 2 (9.5%) | 1 (4.8%) | 0 (0%) | 0 (0%) | 2 (9.5%) [1 arthrofibrosis. 1 patellar clunck syndrome] | 6 (28.6%) [5 arthrofibrosis. 1 patellar clunk syndrome] | 19 (90.5%) |
| Dayan et al. (2019) | 241 | 16 (6.6%) | 16 (6.6%) | 5 (2.1%) | 8 (3.3%) | 3 (1.2%) [1 arthrofibrosis, 1 patellar component loosening, 1 hardware failure] | 9 (3.7%) [8 PJI, 1 arthrofibrosis] | 225 (93.4%) |
| Mancino et al. (2020) | 47 | 3 (6.4%) | 2 (4.2%) | 0 (0%) | 2 (4.2) | 1 (1.1%) [1 patellar clunck syndrome] | 3 (6.4%) [2 PJI. 1 patellar clunk syndrome] | 44 (93.6%) |
| Stockwell et al. (2020) | 68 | 2 (2.9%) | 2 (2.9%) | 0 (0%) | 1 (1.5%) | 1 (1.5%) [instability] | 2 (2.9%) [1 instability, I PJI] | 66 (97.1%) |
| Total | 2902 | 322 (11.1%) | 139 (4.8%) | 50 (1.7%) | 51 (1.8%) | 128/2885 (4.4%) | 279 (9.6%) [82 stiffness/ arthrofibrosis (29.3%), 72 infection (25.8%), 28 wound complication (10.0%), 26 DVT (9.3%), 19 periprosthetic fracture (6.8%), 9 patellar clunk (3.2%), 6 peroneal nerve palsy (2.1%)] | 2643 (91.1%) |

N/A, not available; I&D, Irrigation and Debridement; TTO, Tibial Tuberosity Osteotomy; SCCK, Stemmed Condylar Constrained Knee; NSCCK, Non-Stemmed Condylar Constrained Knee; DVT, Deep Venous Thrombosis; MCL, Medial Collateral Ligament; PJI, Periprosthetic Joint Infection; MUA, Manipulation Under Anesthesia.

Recently, MLC articular bearings have been introduced as a promising alternative in case of mild coronal deformity. It is characterized by a wider post that limit rotation and varus-valgus lift-off to a few degrees but is less constrained that a VVC insert.[54] Crawford et al.,[6] reported in a cohort of 103 stemless MLC articular bearing implants, an overall survivorship of 97% and a survivorship from revision for aseptic loosening or instability of 100% at a mean follow up of 5 years. Those findings are supported by Dubin et al.[12] in their series of patients with mild coronal deformity treated with MLC (57 knees) and PS (96 knees) implants with a mean follow-up of 4 years. The authors reported a similar rate of revision when compared the two groups (3.5% MLC vs 2.1% PS, $p = 0.13$).

Despite VVC implants in primary TKA are associated with increased rate of revision compared to standard PS implants at long-term follow-up[49,55,56], the present systematic review shows considerable improvement in a variety of functional scores. All studies included in this review that reported clinical data demonstrated improved clinical scores from preoperative to final follow-up analysis. Specifically, VVC implants in primary TKA were associated with an average of 51 points increase of KSS between preoperative and postoperative periods. On average, patient improved from "poor" health (mean preoperative HHS of 33) to "excellent" health (mean postoperative HHS of 84) at latest followup. Similar improvements were reported on OKS, WOMAC Index and ROM. When VVC implants are used, internal and external rotation can be firmly limited to within 2–3° and coronal mobility can be limited to less than 2°, suggesting the risk of limited functional performance compared to lower constraint implants.[15] However, ROM, clinical and functional outcomes in patients who underwent primary TKA with VVC implants resulted to be comparable to non-constrained PS implants, while maintaining the benefit of added stability.[57,58]

There were a variety of limitations in this study. As with any review of the literature, limitations reflect the availability of current literature and the quality of the original studies, the variability in inclusion criteria as well as the methods for reporting the evaluated variables, and number of knees analyzed. Our methodology did not allow for identification of unpublished literature on VVC in primary TKA and is limited by potential publication bias. Additionally, implant survival endpoints were not clearly defined in all studies. The indications for constrained implants over PS or CR implant in primary TKA were variable across the included studies. The degree of preoperative coronal deformities was not always clearly defined, suggesting a potential use of VVC implants in knees with less severe deformities. In addition, since the characteristics of the VVC implant used were not always clarified, a more complete analysis of stem extension usage and its relationship with revision rate was not possible.

Larger multicenter studies with longer-term follow up would be helpful in order to better compare the clinical and radiographic outcomes of VVC systems with CR and PS systems in primary TKA.

## Conclusion

In this systematic review of studies reporting outcomes of VVC implants used in primary TKA, we found that patients had significant clinical improvements with a short-to mid-term survivorship comparable to implants with lower level of constraint suggesting that these implants are reliable option in case of complex primary TKA. However, we cannot recommend the routine use of the VVC implants in primary TKA since long term survivorship is still lacking requiring high quality long-term follow up studies in order to address the longevity of VVC implants and to compare them with PS implants.

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## Availability of data and material

Not applicable.

## Code availability

Not applicable.

**Table 4**
Summary of VVC Systems in Primary TKA showing Radiographic and Clinical Outcomes.

| Authors (year of publication) | No. of Knees | Preoperative Clinical Outcomes | Postoperative Clinical Outcomes | Knee Flexion | | Flexion Contracture | | Radiolucent Lines |
|---|---|---|---|---|---|---|---|---|
| | | | | Pre-operative | Post-operative | Pre-operative | Post-operative | |
| Lachiewicz et al. (1996) | 25 | N/A | HSS (20 good/excellent, 2 fair, 3 poor) | 87° (35°–135°) | 94° (45°–120°) | 23° (0°–45°) | 4° (0°–40°) | N/A |
| Hartford et al. (1998) | 17 | KSS 39 (0–93)<br>KSS F 29 (0–90) | KSS 88 (44–100)<br>KSS F 61 (0–100) | N/A | N/A | N/A | N/A | N/A |
| Easley et al. (2000) | 28 | KSS 27 (5–51)<br>KSS F 32 (5–60)<br>HSS 52 (37–63) | KSS 95 (90–100)<br>KSS F 67 (20–90)<br>HSS 90 (77–95) | Rom −6.3°-109.8° | Rom −1.3°-114.1° | N/A | N/A | Tibial: 2 (Zone 1) |
| Anderson et al. (2006) | 55 | KSS 34 (3–50)<br>KSS F 40 (0–70) | KSS 93 (40–100)<br>KSS F 74 (25–100) | Rom −4°-103° | Rom −0.5°-115° | N/A | N/A | Tibial: 5 (1 Zone), 1 (2 Zones)<br>Femoral: 2 (2 Zones) |
| Lachiewicz et al. (2006) | 42 | KSS 35 (0–91)<br>KSS F 26 (43–100)<br>HSS 48.5 | KSS 91 (43–100)<br>KSS F 32 (0–100)<br>HSS 78 | 93.2° (45°–135°) | 97.4° (60°–130°) | 16.6° (0–60°) | 1.7° (0–15°) | Tibial: 5 (1 Zone), 2 (2 Zones), 1 (3 Zones)<br>Femoral: 3 |
| Lachiewicz et al. (2011) | 27 | KSS 39 (11–62)<br>KSS F 22 (0–70)<br>HSS 56 (33–75) | KSS 95 (77–100)<br>KSS F 35 (0–80)<br>HSS 83 (65–94) | 106° (80–130) | 114° (100–130) | 7.2° (0°–25°) | 1.3° (0°–10°) | Tibial: 3 (1 Zone)<br>Femoral: 3 (1 Zone)<br>Patellar: 2 (1 Zone) |
| Nam et al. (2012) | 190 | N/A | KSS 88 (±15)<br>HSS 88 (±10) | N/A | N/A | N/A | N/A | N/A |
| Pang et al. (2013) | 50 | KSS 26 (±10)<br>KSS F 36 (±7)<br>OKS 39 (±8) | KSS 84 (±8)<br>KSS F 48 (±7)<br>OKS 21 (±3) | 75°(±9°) | 115°(±13°) | 9°(±4°) | 5 knees 5° (±6°) | N/A |
| Maynard et al. (2014) | 127 | WOMAC 36<br>OKS 20 | WOMAC 85<br>OKS 36 | 111° ± 14° (30°–135°) | 117° ± 6° (95°–130°) | 1.8° ± 3.3° (0°–20°) | 0.22° ± 1.2° (0°–10°) | Tibial: 14 |
| Tripathi et al. (2015) | 100 | KSS 39<br>KSS F 33 | KSS 96<br>KSS F 79 | 113° | 119.1° | N/A | N/A | N/A |
| Camera et al. (2015) | 15 | N/A | TLKSS:87 (83–93)<br>WOMAC 80 (74–81) | N/A | 100° (90°–100°) | N/A | N/A | 5 Knees: osteolytic areas in 1 or more Zones |
| Ruel et al. (2015) | 142 | KSS TOT. 67.4 | KSS TOT 149 | N/A | N/A | N/A | N/A | N/A |
| Cholewinski et al. (2015) | 25 | KSS 42 (16–77)<br>KSS F 31 (0–80)<br>HSS 53 (26–83) | KSS 90 (77–99)<br>KSS F 61 (10–90)<br>HSS 80 (55–93) | 109° (50°–140°) | 112° (90°–130°) | N/A | N/A | Tibial: 9<br>Femoral: 1<br>Patellar: 1 |
| Luque et al. (2015) | 99 | N/A | KSS 75.8<br>KSS F 73.1 | N/A | 100.6° | N/A | N/A | N/A |
| Martin et al. (2016) | 427 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Siqueira et al. (2016) | 247 | KSS 41<br>KSS F 35 | KSS 86<br>KSS F 58 | N/A | N/A | N/A | N/A | N/A |
| Deshmukh et al. (2016) | 242 | KSS 45 (±6)<br>KSS F 41 (±8) | KSS 83 (±8)<br>KSS F 79 (±14) | Rom 110° (±15°) | Rom 112° (±9°) | N/A | N/A | 20 (most in tibial Zone 1, stable, <2 mm) |
| Feng et al. (2016) | 48 | KSS 31 (8–65)<br>HSS 26 (0–68) | KSS 90 (66–99)<br>HSS 71 (12–92) | Rom 42.4° (0–100°) | Rom 95.3° (30–140°) | 5.3° (0°–45°) | 0.9° (0°–10°) | Tibial: 48 |
| Ye et al. (2016) | 35 | KSS 27 ± 14<br>KSS F 40 ± 16<br>HSS 51 (36–66) | KSS 79 ± 14<br>KSS F 85 ± 11<br>HSS 85 (77–94) | Rom 78.4° ± 15.2° | Rom 89.9° ± 15.8° | N/A | N/A | Tibial: 1<br>Femoral: 1 |
| Moussa et al. (2017) | 439<br>85 SCCK<br>354 NSCCK | NSCCK 2y: WOMAC P 57, WOMAC F 55<br>SCCK: WOMAC P 53, WOMAC F 51 | NSCCK: WOMAC P 87, WOMAC F 83<br>SCCK: WOMAC P 84, WOMAC F 79 | N/A | N/A | N/A | N/A | N/A |
| Sabatini et al. (2017) | 28 | KSS 30 | KSS 92 | N/A | 98.9° (90°–120°) | N/A | N/A | 0 |
| Rai et al. (2018) | 36 | KSS 45<br>KSS F 49<br>HSS 51 | KSS 92<br>KSS F 91<br>HSS 92 | 68.9° (35°–105°) | 113.7° (103°–124°) | 17° (5°–45°) | 0.1° (0°-5) | Tibial: 13<br>Femoral: 3 |
| Hossain et al. (2019) | 38 | OKS 23 (±9) | OKS 43 (±4) | Rom 87.8° (±24.0°) | Rom 114.1° (±12.3°) | N/A | N/A | 0 |
| Li et al. (2019) | 43 | N/A | N/A | N/A | N/A | 10° (0°–20°) | N/A | N/A |
| Johnson Jr.et al. (2019) | 21 | N/A | KSS 94.7 | 100.9° (65°–120°) | 116.2° (90°–130°) | N/A | N/A | 11 |
| Dayan et al. (2019) | 241 | KSS 44.8 ± 12.1<br>KSS F 45.2 ± 10.4 | KSS 83.4 ± 10.3<br>KSS F 81.5 ± 19.2 | 105.9° ± 12.9° | 113.8° ± 11.5 | N/A | N/A | 26 |
| Mancino et al. (2020) | 47 | KSS 43 (19–72)<br>KSS F 40 (17–69) | KSS 86 (54–100)<br>KSS F 59 (42–100) | 98° (75°–105°) | 108° (90°–120°) | 7° (0–15°) | 2° (0–5°) | Tibial: 5 |
| | 68 | OKS 18.9 (6–36) | OKS33.1 (6–48) | N/A | N/A | N/A | N/A | Tibial: 40 |

(*continued on next page*)

Table 4 (*continued*)

| Authors (year of publication) | No. of Knees | Preoperative Clinical Outcomes | Postoperative Clinical Outcomes | Knee Flexion | | Flexion Contracture | | Radiolucent Lines |
|---|---|---|---|---|---|---|---|---|
| | | | | Pre-operative | Post-operative | Pre-operative | Post-operative | |
| Stockwell et al. (2020) | | | | | | | | Femoral: 10 |
| Total | 1182 | KSS 36 (0–93)<br>KSS F 35 (0–100)<br>HSS 48.2 (0–83)<br>OKS 27.3 | KSS 84 (40–100)<br>KSS F 64.8 (0–100)<br>HSS 82.7 (12–95)<br>OKS 33.3 | 91.6° | 105.6° | 8.6° | 0.9° | 283/1123 (25.2%)<br>Tibial 225 (79.5%)<br>Femoral 23 (2.0%) |

N/A, not available; * means reduced cohort; KSSk, Knee Society Score knee; KSSf, Knee Society Score function; HSS, Hospital for Special Surgery Knee Score; OKS, Oxford Knee Score; WOMAC, Westen Ontario and McMaster Universities; TLKSS, Tegner Lysholm Knee Scoring Scale.

## Contributions

FM, IDM, FF, PKS: designing the work. FM, FM, IDM: acquisition and analysis of the data and drafting the work. GM, FF, IDM, PKS: revised it critically for important intellectual content. IDM: final approval of the version to be published.

## Statement of location

This work was performed at the Adult Reconstruction and Joint Replacement Service, Division of Orthopaedics and Traumatology, Department of Aging, Neurological, Orthopaedic and Head-Neck studies, Fondazione Policlinico Universitario Agostino Gemelli IRCCS, Roma, Italy.

## Declaration of competing interest

All authors declare that they have no conflict of interest. No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article. Dr. Sculco reports grants from Intellijoint, personal fees from Lima Corporate, grants from DePuy, personal fees from EOS Imaging, outside the submitted work.

## References


1 Australian Orthopeaedic Association National Joint Replacement Registry. *Annual Report 2018*. Adelaide, Australia: AOA; 2018.
2 American Joint Replacement Registry. *Annual Report. Rosemont, IL: American Academy of Orthopaedic Surgeons (AAOS), 2019*. 2019.
3 Lovald ST, Ong KL, Lau EC, Schmier JK, Bozic KJ, Kurtz SM. Mortality, cost, and health outcomes of total knee arthroplasty in Medicare patients. *J Arthroplasty*. 2013; 28(3):449–454.
4 Bozic KJ, Kurtz SM, Lau E, et al. The epidemiology of revision total knee arthroplasty in the United States. *Clin Orthop Relat Res*. 2010;468(1):45–51.
5 Sharkey PF, Hozack WJ, Rothman RH, Shastri S, Jacoby S. Insall Award paper. Why are total knee arthroplasties failing today? *Clin Orthop Relat Res*. 2002;404:7–13.
6 Mulhall KJ, Ghomrawi HM, Scully S, Callaghan JJ, Saleh KJ. Current etiologies and modes of failure in total knee arthroplasty revision. *Clin Orthop Relat Res*. 2006;446: 45–50.
7 Fehring TK, Valadie AL. Knee instability after total knee arthroplasty. *Clin Orthop Relat Res*. 1994;299:157–162.
8 Perkins MR, Arnholt CM, MacDonald DW, Kurtz SM, Mihalko WM. Retrieval analysis of cruciate-retaining and posterior-stabilized total knee arthroplasty and correlations to laxity and wear. *J Arthroplasty*. 2020;35(8):2249–2253. https://doi.org/10.1016/j.arth.2020.03.027. Epub 2020 Mar 21. PMID: 32279944 https://www.arthroplastyjournal.org/article/S0883-5403(20)30275-8/pdf.
9 Rossi R, Rosso F, Cottino U, Dettoni F, Bonasia DE, Bruzzone M. Total knee arthroplasty in the valgus knee. *Int Orthop*. 2014;38:273–283.
10 Vasso M, Beaufils P, Schiavone Panni A. Constraint choice in revision knee arthroplasty. *Int Orthop*. 2013;37:1279–1284.
11 Lachiewicz PF, Elizabeth S, Soileau BSN. Ten-year survival and clinical resuts of constrained components in primary total knee arthroplasty. *J Arthoplasty*. 2006;21 (6):803–808.
12 Rossi R, Cottino U, Bruzzone M, Dettoni F, Bonasia DE, Rosso F. Total knee arthroplasty in the varus knee: tips and tricks. *Int Orthop*. 2019;43:151–158.
13 Sculco TP. The role of constraint in total knee arthroplasty. *J Arthroplasty*. 2006;21 (4):54–56.
14 Lachiewicz PF, Soileau ES. Results of a second-generation constrained condylar prosthesis in primary total knee arthroplasty. *J Arthroplasty*. 2011;26(8):1228–1231.
15 Morgan H, Battista V, Leopold SS. Constraint in primary total knee arthroplasty. *J Am Acad Orthop Surg*. 2005;13(8):512–524.
16 Park CH, Bae JK, Song SJ. Factors affecting the choice of constrained prostheses when performing revision total knee arthroplasty. *Int Orthop*. 2019;43(8): 1831–1840.
17 Anderson JA, Baldini A, MacDonald JH, Pellicci PM, Sculco TP. Primary constrained condylar knee arthroplasty without stem extensions for the valgus knee. *Clin Orthop Relat Res*. 2006;442:199–203.
18 Camera A, Biggi S, Cattaneo G, Brusaferri G. Ten-year results of primary and revision condylar-constrained total knee arthroplasty in patients with severe coronal plane instability. *Open Orthop J*. 2015;31(9):379–389.
19 Cholewinski P, Putman S, Vasseur L, et al. Long-term outcomes of primary constrained condylar knee arthroplasty. *Orthop Traumatol Surg Res*. 2015;101(4): 449–454.
20 Deshmukh AJ, Rathod PA, Moses MJ, Snir N, Marwin SE, Dayan AJ. Does a non-stemmed constrained condylar prosthesis predispose to early failure of primary total knee arthroplasty? *Knee Surg Sports Traumatol Arthrosc*. 2016;24(10):3194–3199.
21 Easley ME, Insall JN, Scuderi GR, Bullek DD. Primary constrained condylar knee arthroplasty for the arthritic valgus knee. *Clin Orthop Relat Res*. 2000;380:58–64.
22 Feng XB, Yang C, Fu DH, et al. Mid-term outcomes of primary constrained condylar knee arthroplasty for severe knee deformity. *J Huazhong Univ Sci Technolog Med Sci*. 2016;36(2):231–236.
23 Hartford JM, Goodman SB, Schurman DJ, Knoblick G. Complex primary and revision total knee arthroplasty using the condylar constrained prosthesis: an average 5-year followup. *J Arthroplasty*. 1998;13(4):380–387.
24 Hossain F, Konan S, Kayani B, Kontoghiorghe C, Barrack T, Haddad FS. Early clinical and radiological outcomes of the metaphyseally fixed totally stabilized knee prosthesis in primary total knee arthroplasty. *J Knee Surg*. 2020 Jul;33(7):678–684. https://doi.org/10.1055/s-0039-1683976. Epub 2019 Apr 8. PMID: 30959540.
25 Johnson Jr DB, Triplet JJ, Gaines DR, Gupta A, Unverferth KL. Mid-term outcomes following primary semi-constrained total knee arthroplasty in patients less than 60 years old, a retrospective review. *Knee*. 2019;26(3):714–719.
26 Lachiewicz PF, Falatyn SP. Clinical and radiographic results of the Total Condylar III and Constrained Condylar total knee arthroplasty. *J Arthroplasty*. 1996;11(8): 916–922.
27 Li F, Liu N, Li Z, Wood KB, Tian H. Abnormally high dislocation rate following constrained condylar knee arthroplasty for valgus knee: a case-control study. *J Orthop Surg Res*. 2019;14(1):268.
28 Luque R, Rizo B, Urda A, Garcia-Crespo R, Moro E, López-Durán L. Primary modular total knee replacement in severe and unstable osteoarthritis. Predictive factors for failure. *Int Orthop*. 2015;39(11):2125–2133.
29 Martin JR, Beahrs TR, Stuhlman CR, Trousdale RT. Complex primary total knee arthroplasty: long-term outcomes. *J Bone Joint Surg Am*. 2016;98(17):1459–1470.
30 Maynard LM, Sauber TJ, Kostopoulos VK, Lavigne GS, Sewecke JJ, Sotereanos NG. Survival of primary condylar-constrained total knee arthroplasty at a minimum of 7 years. *J Arthroplasty*. 2014;29(6):1197–1201.
31 Moussa ME, Lee YY, Patel AR, Westrich GH. Clinical outcomes following the use of constrained condylar knees in primary total knee arthroplasty. *J Arthroplasty*. 2017; 32(6):1869–1873.
32 Nam D, Umunna BP, Cross MB, Reinhardt KR, Duggal S, Cornell CN. Clinical results and failure mechanisms of a nonmodular constrained knee without stem extensions. *HSS J*. 2012;8(2):96–102.
33 Pang HN, Yeo SJ, Chong HC, Chin OL, Chia SL, Lo NN. Joint line changes and outcomes in constrained versus unconstrained total knee arthroplasty for the type II valgus knee. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(10):2363–2369.
34 Rai S, Liu X, Feng X, et al. Primary total knee arthroplasty using constrained condylar knee design for severe deformity and stiffness of knee secondary to post-traumatic arthritis. *J Orthop Surg Res*. 2018;13:67.
35 Ruel A, Ortiz P, Westrich G. Five year survivorship of primary non-modular stemless constrained knee arthroplasty. *Knee*. 2016;23(4):716–718.
36 Sabatini L, Risitano S, Rissolio L, Bonani A, Atzori F, Massè A. Condylar constrained system in primary total knee replacement: our experience and literature review. *Ann Transl Med*. 2017;5(6):135.
37 Siqueira MBP, Jacob P, McLaughlin J, et al. The varus-valgus constrained knee implant: survivorship and outcomes. *J Knee Surg*. 2017;30(5):484–492.
38 Tripathi MS, Heinle CC, Manaqibwala MI, Tria Jr AJ. The utility of increased constraint in primary total knee arthroplasty for obese patients. *Orthop Clin N Am*. 2016;47(1):51–55.

39 Ye CY, Xue DT, Jiang S, He RX. Results of a second-generation constrained condylar prosthesis in complex primary and revision total knee arthroplasty: a mean 5.5-year followup. *Chin Med J*. 2016;129(11):1334–1339.

40 Dayan I, Moses MJ, Rathod P, Deshmukh A, Marwin S, Dayan AJ. No difference in failure rates or clinical outcomes between non-stemmed constrained condylar prostheses and posterior-stabilized prostheses for primary total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(9):2942–2947. https://doi.org/10.1007/s00167-019-05684-z, 9.

41 Mancino F, De Martino I, Burrofato A, et al. Satisfactory mid-term outcomes of condylar-constrained knee implants in primary total knee arthroplasty: clinical and radiological follow-up. *J Orthop Traumatol*. 2020 Dec 2;21(1):22. https://doi.org/10.1186/s10195-020-00561-9.

42 Stockwell KD, Gascoyne TC, Singh M, Turgeon TR. Survivorship of constrained polyethylene inserts in primary total knee replacements. *Knee*. 2020 Oct;27(5):1343–1348. https://doi.org/10.1016/j.knee.2020.06.010.

43 Moher D, Liberati A, Tetzlaff J, Altman DG, Prisma Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7), e1000097.

44 OCEBM Levels of Evidence Working Group*. The Oxford levels of evidence". Oxford Centre for evidence-based medicine. https://www.cebm.net/index.aspx?o¼5653, 1, 5, accessed.

45 Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological index for non-randomized studies (minors): development and validation of a new instrument. *ANZ J Surg*. 2003;73(9):712–716.

46 Mancino Fabio, Cacciola Giorgio, Malahias Michael-Alexander, et al. What are the benefits of robotic-assisted total knee arthroplasty over conventional manual total knee arthroplasty? A systematic review of comparative studies. *Orthopedic Reviews*. 2020;12(1):8657. https://doi.org/10.4081/or.2020.8657.

47 Mayle Jr RE, Graw BP, Huddleston HG, et al. A risk factor for early revision surgery. *J Knee Surg*. 2012;25(5):423–427.

48 Argenson JN, Boisgard S, Parratte S, et al. Survival analysis of total knee arthroplasty at a minimum 10 years' followup: a multicenter French nationwide study including 846 cases. *Orthop Traumatol Surg Res*. 2013;99(4):385–390.

49 Moussa ME, Lee YY, Westrich GH, Mehta N, Lyman S, Marx RG. Comparison of revision rates of non-modular constrained versus posterior stabilized total knee arthroplasty: a propensity score matched cohort study. *HSS J*. 2017;13(1):61–65.

50 Peersman G, Laskin R, Davis J, Peterson MGE, Richart T. Prolonged operative time correlates with increased infection rate after total knee arthroplasty. *HSS J*. 2006;2(1):70–72.

51 Stern SH, Wills RD, Gilbert JL. The effect of tibial stem design on component micromotion in knee arthroplasty. *Clin Orthop Relat Res*. 1997;345:44–52.

52 Yoshii I, Whiteside LA, Milliano MT, White SE. The effect of central stem and stem length on micromovement of the tibial tray. *J Arthroplasty*. 1992;7(1):433–438.

53 Padgett DE, Cottrell J, Kelly N, Gelber J, Farrell C, Wright TM. Retrieval analysis of nonmodular constrained tibial inserts after primary total knee replacement. *Orthop Clin N Am*. 2012;43(5):e39–43.

54 Cacciola Giorgio, Mancino Fabio, De Meo Federico, et al. Mid-term survivorship and clinical outcomes of the medial stabilized systems in primary total knee arthroplasty: A systematic review. *Journal of Orthopaedics*. 2021;24:157–164. https://doi.org/10.1016/j.jor.2021.02.022.

55 Pitta M, Esposito CI, Li Z, Lee YY, Wright TM, Padgett DE. Failure after modern total knee arthroplasty: a prospective study of 18,065 knees. *J Arthroplasty*. 2018;332(2):407–414.

56 Gu Alex, Wu Shitong, Mancino Fabio, et al. Impact of Chronic Obstructive Pulmonary Disease on Postoperative Complications Following Simultaneous Bilateral Total Knee Arthroplasty. *Journal of Knee Surgery*. 2021;34(3):322–327. https://doi.org/10.1055/s-0039-1695766.

57 Puah KL, Chong HC, Foo LSS, Lo NN, Yeo SJ. Clinical and functional outcomes: primary constrained condylar knee arthroplasty compared with posterior stabilized knee arthroplasty. *J Am Acad Orthop Surg Glob Res Rev*. 2018;2(2):e084.

58 King BR, Gladnick BP, Lee YY, Lyman S, Della Valle AG. Range of motion and function are not affected by increased post constraint in patients undergoing posterior stabilized total knee arthroplasty. *Knee*. 2013;21(1):194–198.