Implant survivorship, functional outcomes and complications with the use of rotating hinge knee implants: a systematic review

Joshua Xu1,2*, Lennart von Fritsch2, Shiraz A. Sabah2, Andrew J. Price1,2 and Abtin Alvand1,2

Abstract

Background: With more complex primary and revision total knee arthroplasty procedures there is often the need to use more constrained prostheses. This study aims to investigate patient-relevant outcomes following primary and revision rotating-hinged total knee arthroplasty.

Methods: Electronic searches were performed using four databases from their date of inception to January 2021. Relevant studies were identified, with data extracted and analysed using PRISMA guidelines.

Results: Nineteen studies were included, producing a cohort of 568 primary and 413 revision rotating hinge total knee arthroplasties (TKAs). Survival was assessed at 1-, 5-, and 10-year post-implantation. Sensitivity analyses based on person-time incidence ratios (PTIRs) were prespecified for studies not reporting survival at these timepoints. From the primary hinge TKA cohort, the median survival at 1 year was 93.4% and at 10 years it was 87%. The PTIR at long-term follow-up of this primary cohort was 1.07 (95% CI 0.4–1.7) per 100 person-years. From the revision hinge TKA cohort, the median survival at 1 year was 79.6%, and at 10 years it was 65.1%. The PTIR at long term-follow-up of this revision cohort was 1.55 (95% CI 0.9–2.3) per 100 person-years. Post-operative flexion range of motion (ROM) was 110° for primary hinge TKA and 103° for revision hinge TKA. Compared with baseline, the Knee Society Score (KSS) and Knee Society Function Score (KSFS) improved for both groups post-operatively (primary: KSS 17 to 86, KSFS 28 to 58; revision: KSS 37 to 82, KSFS 34 to 61).

Conclusion: The quality of the evidence for patient-relevant outcomes following hinged knee arthroplasty was limited. While there is the potential for high early revision rates, where successful, large functional benefits may be achieved.

Keywords: Rotating hinge knee, Total knee replacement, Reoperation, Revision, Patient-reported outcome measures

Introduction

Total knee arthroplasty (TKA) is a highly effective operation for the management of knee osteoarthritis [1]. The success of this surgery has resulted in a rise in demand from patients [2], including those who are younger and more active, and those with deformity who would not have previously been considered candidates for surgery. The requirement for complex primary, revision (and re-revision) TKA has risen accordingly [3]. For these patients, a more constrained knee replacement may be needed to provide optimal reconstruction.

When selecting an implant for reconstruction, one important principle is to select the least-constrained device that is considered appropriate [4]. The rationale is...
to minimise stresses at the bone–cement–implant interface and subsequent failure due to aseptic loosening [5]. Less constrained devices typically require a more conservative bone resection than hinged implants, and place lower demands on a stem for fixation, providing greater options for future reconstruction should it be necessary. However, in some cases, this must be balanced against the risk of instability, which may require subsequent revision surgery or provide a source of pain, poor function and patient dissatisfaction [6, 7].

For primary knee replacement, hinge-type devices are rarely needed, accounting for around 0.2% of procedures [3]. A recent study identified limited, specific indications for primary hinged knee replacement, and recommended that they are reserved mainly for elderly patients [8]. These indications included insufficiency of collateral ligaments, valgus or varus deformity, neuropathic arthropathy and significant bony defects [8]. For revision knee replacement, hinge-type devices are required in a greater proportion of cases due to the greater prevalence of ligamentous incompetence and bone loss [7].

Most studies reporting on the outcomes of hinge-type knee replacements have been small, retrospective observational studies focusing on implant survivorship. Few studies have provided information on other patient-relevant outcomes, such as pain, joint function and health-related quality of life [9]. In addition, much of the literature refers to early, highly constrained, fixed hinge designs which may not be relevant to current practice. More modern, rotating hinge implants combine flexion-extension with rotation of the femur on the tibial component. This allows more physiological movement on the prosthetic knee joint, reducing the stress placed on the implant, when compared with fixed hinge designs [6, 10, 11].

The aim of this study was to systematically review the evidence for patient-relevant outcomes following modern, rotating-hinge TKA. We investigate implant survivorship, joint function, health-related quality of life and complications following surgery. We report findings separately for primary and revision TKA, and summarise information reported by international and regional joint registries.

Methods
Search strategy
The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for this study. Electronic database searches were performed using PubMed, Ovid Medline, Cumulative Index of Nursing and Allied Health Literature (CINAHL) and Cochrane CENTRAL from their dates of inception to January 2021. The search strategy is provided in Appendix 1. The sensitivity of the search strategy to detect studies on hinged implants was maximised by including the names of common brands as search terms. The reference list of all retrieved articles was manually reviewed to further identify potentially relevant studies. National and regional joint registries listed in The International Society of Arthroplasty Registries (ISAR) were reviewed for data on rotating hinges.

Selection criteria
Eligible studies for this systematic review included patients undergoing primary or revision TKA using a rotating hinge implant. Included studies were required to report post-operative knee function. If multiple studies reported outcomes from the same cohort, data from the longest follow-up period was included for quantitative analysis. If studies reported survivorship at multiple follow-up periods, these were all included in our survivorship analysis. Neoplastic indications for rotating hinge TKA were excluded. All publications included were limited to those in the English language and involving human subjects. Conference presentations, case reports, reviews, editorials, and expert opinions were excluded. Studies with mixed primary and revision cohorts were excluded.

Data extraction
Two investigators (J.X and L.F) independently reviewed and extracted data from the retrieved articles. Discrepancies between the two reviewers were resolved by discussion with senior authors. Data were extracted on study year, country, number of patients undergoing primary and revision TKA, and indication for surgery.

The primary outcome measures were implant survivorship at 1-, 5- and 10-years following rotating hinge knee arthroplasty. Construct survival estimates and associated confidence intervals were extracted for these time points to allow pooling with meta-analysis if appropriate. Person-time incidence ratios (PTIR) were used to assess the incidence of implant failure in studies not reporting survival at these time points. Person-time (PT) was calculated by multiplying the number of cases and the mean follow-up. PTIRs per 100 person-years were then calculated based on the number of construct failures over the follow-up period. PTIRs were grouped by mean follow-up duration into short-term (<1 year), medium term (1–5 years) and longer term (>5 years).

Secondary outcome measures were knee range of motion, knee function and surgical complications. Knee range of motion was measured in degrees as the arc of movement between maximum knee flexion and extension. Knee function included both surgeon-completed [e.g. Knee Society Score (KSS), Knee Society Function
Score (KSFS)] and patient-completed scores [e.g. Oxford Knee Score (OKS)]. The KSS and KSFS were scored from 0 (worst) to 100 (best), and OKS from 0 (worst) to 48 (best). The number of surgical complications (including reoperations not classified as revisions or re-revisions) was recorded according to each of the time periods specified.

Data synthesis
Our statistical analysis plan prespecified a decision to be taken on whether or not to perform meta-analysis based on the body of evidence available after data extraction. Due to the clinical diversity of the included studies, incomplete reporting of effect estimates and uncertainty, and the methodological and statistical heterogeneity observed, we decided to perform systematic review without meta-analysis (SWiM) [12]. This approach is useful to report the range and distribution of effects when the average effect size cannot be calculated through meta-analysis. We selected to present medians and ranges for each of the available outcome measures. An important limitation of these estimates is that they do not account for study size.

Study quality
The quality of included studies was assessed using a non-summative four-point system developed by Wylde et al. [13] to rate studies on joint replacement. Studies were rated based on the inclusion of consecutive cases, representativeness (whether the study was multicentre), adequacy of follow-up (defined as < 20% loss to follow-up) and minimisation of confounding (defined as use of multivariate analysis).

Results
Search results
An initial search led to the identification of 1285 references (Fig. 1). After duplicate studies were removed, a total of 654 studies remained for screening. A further 566 studies were excluded following abstract screening, leaving 88 studies for full-text analysis. A total of 19 studies [14–32] were eligible following application of the inclusion criteria. Manual searching of references in each of the full-text articles did not yield further studies for inclusion.

Fig. 1 PRISMA flow chart of systematic review on clinical outcomes and complications of rotating hinge TKA
Characteristics of the included studies
No randomised controlled trials were identified. Nineteen observational studies (18 retrospective, 1 prospective) were included. A total of 915 patients with 981 total knee operations were extracted from the 19 studies. There were 568 hinge TKAs performed for primary TKA, and 413 performed for revision TKA. Seven studies reported on primary TKA and 12 studies on revision TKA. The study year ranged from 2000 to 2019, and patients had a median follow-up of 79.5 months (range 28–180 months). The median patient age was 69.7 years (range 65–79 years). The median proportion of females was 67.1% (range 39.3–100%). The study characteristics are summarised in Table 1.

Indications for surgery
For the seven studies reporting on primary TKA, osteoarthritis was the most common indication for surgery, accounting for a median of 68.7% of cases (range 25–90.1%). Rheumatoid arthritis was the only other surgical indication specified.
For the 12 studies reporting on revision TKA, the most common indication for surgery was aseptic loosening, with a median of 57.1% (range 40.0–100%). The median reported rates for other indications were infection 21.8% (range 12.9–45.1%), instability 21.4% (range 6.3–100%), implant wear/breakage 9.2% (range 3.2–26.0%), bone loss 37.8% (range 14.3–61.4%) and periprosthetic fracture 2.0% (range 1.3–90.1%).

Implant survival
There was heterogeneity in the reporting of survivorship for hinged TKAs. For the seven studies reporting on primary TKA, four studies (57.1%) reported on implant survivorship at the prespecified fixed timepoints, and five studies (71.4%) provided data from which PTIRs could be calculated. The median survival at 1 year was 93.4% (range 88.7–98%) (two studies [28, 29]), at 5 years was 85.9% (one study [29]) and at 10 years was 87% (range 79.8–100%) (three studies [25, 27, 29]). This is illustrated in the forest plot (Fig. 2). The longest follow-up was at 15 years, reported as 80.4% by Bistolfi et al [18]. Overall PTIR was 1.74 (95% CI 1.1–2.4) per 100 person-years. PTIR at medium follow-up was 2.12 (95% CI 0.7–3.5) per 100 person-years and at long-term it was 1.55 (95% CI 0.9–2.3) per 100 person-years.

Functional outcomes
For the seven studies reporting on primary TKA, the instruments used to measure knee function were flexion ROM in five studies, KSS in three studies, KSFS in two studies and OKS in one study (Table 2). For post-operative flexion range of motion, the median was 110° (range 102–120°). The median KSS pre-operatively was 7.4 (range 11.4–38.0) and improved post-operatively to 86.2 (range 73.0–93.4). The KSFS pre-operatively was 27.9 (range 19.7–36.0), and improved post-operatively to 58.4 (range 47.0–69.7). The OKS preoperatively was 11.6 and improved post-operatively to 31.5 [24].
For the 12 studies reporting on revision TKA, the instruments used to measure knee function were flexion ROM in 9 studies, KSS in 8 studies and KSFS in 8 studies. The OKS was not reported. For post-operative flexion range of motion, the median was 102.6° (range: 88–120°). The KSS pre-operatively was median 37.0 (range 25.0–56.9) and improved post-operatively to 82.0 (range 68.0–131.0). The KSFS preoperatively was 34.0 (range 27.0–40.0), and improved post-operatively to 61.1 (range 29.0–85.0).

Complications
Eighteen studies (94.7%) reported on post-operative complications, with only two studies reporting some complications with time-to-event data [23, 24]. The remainder of the studies presented simple counts of complications over the study period, thus meaningful narrative or quantitative summary of complication rates could not be made. Appendix 2 shows the summary of complications data for each study.

Quality of the included studies
From the included studies, 11 (57.9%) reported that they included consecutive patients, 0 (0.0%) studies were reported to be multi-centre, 15 (78.9%) studies reported adequate follow-up (>80% of original cohort) and 0 (0.0%) studies minimised confounding using multivariate analysis. These results are summarized in Table 3.

Registry studies
The International Society of Arthroplasty Registries (ISAR) includes 36 registries making up 24 national, 6 regional and 6 other registries. Only three registries [German registry (EPRD) [33], Finnish registry (FAR) [34] and National Joint Registry (NJR) [35]] publicly reported
Table 1  Characteristics and demographics of included studies

| Author          | Year | Study period | Country | Study type | Implant type | No. knees | No. patients | Females % | Mean age (range) | FU – mean years (range) |
|-----------------|------|--------------|---------|------------|--------------|-----------|--------------|-----------|------------------|-------------------------|
| **Revision cases** |      |              |         |            |              |           |              |           |                  |                         |
| Rodriguez       | 2015 | –            | Spain   | OS, R      | Endo-Model   | 96        | 96           | 75.0      | 790 (75–86)     | 7.3 (5–10)              |
| Neumann         | 2011 | 2005–2007    | Austria | OS, R      | NexGen       | 24        | 24           | 41.7      | 670 (40–87)     | 4.7 (3–5)               |
| Gudnason        | 2011 | 1991–2003    | Sweden  | OS, R      | Endo-Model   | 42        | 38           | 68.4      | 72.0 (55–88)    | 8.8 (8–18)              |
| Pradhan         | 2004 | 1996–2001    | UK      | OS, R      | Endo-Model   | 51        | 50           | 58.0      | 70.3 (39–85)    | 4.0 (2–6)               |
| Bistolfi        | 2013 | 1991–2004    | Italy   | OS, R      | Endo-Model   | 53        | 50           | 66.0      | 69.7 (45–85)    | 12.9 (7–20)             |
| Barrack         | 2000 | –            | USA     | OS, R      | S-ROM Noiles | 14        | 13           | 46.2      | 69.0 (34–80)    | 4.3 (2–6)               |
| Abdelaziz       | 2019 | 2007–2009    | Germany | OS, R      | Endo-Model   | 25        | 25           | 48.0      | 65.0 (40–70)    | 10.5 (10–12)            |
| Back            | 2008 | –            | UK      | OS, R      | SMILES       | 32        | 30           | 63.3      | 67.0 (46–86)    | 4.8 (5–11)              |
| Baer            | 2013 | 2003–2007    | Germany | OS, R      | TC3/S-ROM Noiles | 78   | 78           | 66.7      | 69.0 (53–84)    | 6.8 (5–9)               |
| Bistolfi        | 2012 | 2002–2008    | Italy   | OS, R      | NexGen RH    | 31        | 29           | 82.8      | 72.8 (43–81)    | 5.0 (3–8)               |
| Joshi           | 2008 | 1993–2002    | Spain   | OS, R      | Endo-Model   | 78        | 78           | 80.8      | 72.0 (53–88)    | 7.8 (5–11)              |
| Pour            | 2007 | 1997–2003    | USA     | OS, R      | Kinematic and Finn | 44  | 43           | 67.4      | 71.8 (55–88)    | 4.2 (2–8)               |
| **Primary cases** |      |              |         |            |              |           |              |           |                  |                         |
| Yang            | 2011 | 1992–2000    | Korea   | OS, R      | Endo-Model   | 50        | 40           | 100       | 72.0 (59–82)    | 15.0 (10–18)            |
| Rahman          | 2015 | 1996–2013    | UK      | OS, R      | SMILES       | 14        | 13           | 76.9      | 66.0 (51–84)    | 6.0 (1–13)              |
| Lozano          | 2012 | 2006–2009    | Spain   | OS, R      | Endo-Model   | 111       | 104          | 80.8      | 72.8            | 2.3                     |
| Kowalczewski    | 2014 | 2001–2003    | Poland  | OS, P      | Modular      | 12        | 12           | 58.3      | 67.5 (43–83)    | (10–12)                 |
| Petrou          | 2006 | 1987–1995    | Greece  | OS, P      | Endo-Model   | 100       | 80           | -         | 70.0 (56–85)    | 11.0 (7–15)             |
| Bistolfi 2      | 2013 | 1992–1995    | Italy and France | OS, R | Endo-Model | 98        | 94           | 83.3      | 69.1 (34–84)    | 14.5 (13–16)            |
| Leng            | 2018 | 2006–2012    | China   | OS, R      | Endo-Model   | 28        | 28           | 39.3      | 72.5 (60–81)    | 6.5 (4–10)              |

*n* number, % percentage, OS observational, R retrospective, P prospective, – not reported, FU follow-up
implant survivorship for modern, rotating hinge knee implants. Seventeen (47.2%) registries did not provide a publicly available report or not in the English language. Sixteen (44.4%) registries did not specify survivorship for modern rotating-hinge implants. This included seven registry reports which were excluded because they provided pooled outcomes for modern rotating-hinges and older fixed-hinge designs together. For specific brands of rotating hinge knee replacements, revision probabilities are provided in Appendix 3. The latest NJR report [3] stated that 2 out of 11 outlier implants for primary knee replacement reported to the Medicines and Healthcare Products Regulatory Agency (MHRA) were rotating hinge knee replacements.

Discussion
This study has critically summarised patient-relevant outcomes following modern rotating hinge primary and revision knee arthroplasty. The evidence base consisted of low quality, small, single-centre, case series, with 568 primary hinge TKA procedures and 413 revision hinge TKA procedures contributing to this review. The revision rate for primary hinge TKA from the included studies ranged from 2% to 11% at 1 year and 0% to 20% at 10 years. For revision hinge TKA, the rates of re-revision at 1 year was only reported in one study to be 20%, and ranged from 12% to 35% at 10 years. Three joint replacement registries (the German registry [33], Finnish registry [34] and National Joint Registry [35]) reported 1-year implant survivorship for modern rotating hinge implants after complex primary TKA. The reported revision rates at 1-year ranged from 1.4% to 4.8%. Only the FAR and NJR reported 10-year implant survivorship, with revision rates ranging from 8.3% to 14.0%. Re-revision data was not available for use of modern rotating hinge knee implants in revision TKA.

The evaluation of joint range of movement or function was required for inclusion in this review. Only one study [24] used a patient-completed score (the Oxford Knee Score) to assess joint function, with the remaining studies using clinician-completed instruments (the KSS and KSFS) or range of motion only. There was a large improvement in joint function from pre-operative baseline to post-operative follow-up for both primary and revision hinged knee replacements. Data on medical and surgical complications were poorly reported. The majority of studies simply reported counts of complications over their respective study...
periods. This is an inappropriate method for calculating complication rates which need to be paired with time data (e.g. a fixed time point, such as 90-days post-operation) [36].

The main strength of this study is its systematic evaluation of the current literature on hinged knee replacements for primary and revision surgery. Due to the clinical diversity of patients and poor reporting practices, the included studies were not suitable for meta-analysis. The quality of the evidence for patient-relevant outcomes following primary and revision hinged knee replacement was poor. We have identified several areas where study reporting could be improved in the future as described below. With respect to implant survivorship, few studies provided Kaplan–Meier survivorship estimates paired with uncertainty and numbers of patient at risk. For revision total knee replacement, there was inconsistency in the categorisation of indications for surgery, and future studies may benefit from consensus on this – for example, by using a hierarchical system for classification [37]. Only one study used a patient-completed instrument to report joint function, and future studies should look to capture this from the perspective of the patient. The Oxford Knee Score has recently been shown to be a validated instrument for the assessment of joint function after discretionary revision knee replacement [38].

It is important to identify the limitations of this study. As mentioned above, there was significant heterogeneity in the included studies, which was a contraindication to meta-analysis. The indications for rotating hinge knee replacement varied considerably, ranging from ligamentous incompetence to bony defects. The severity of disease and number of previous operations provided further sources of population diversity, and there was heterogeneity in the intervention, with a range of implants from different manufacturers utilised.

This systematic review can be used to provide some information for shared decision making with patients who are considering hinged knee arthroplasty. The revision rate following primary hinged knee arthroplasty was approximately 7% at 1 year from observational series. This is considerably higher than for primary unconstrained condylar knee arthroplasties [35]. The re-revision rate following revision hinged knee arthroplasty was higher than following primary arthroplasty. The only study that reported specifically on this outcome found a re-revision rate of 20.4% at 1 year [23]. A recent study based on data from the National Joint Registry found re-revision rates for all revision knee arthroplasties to be 19·9% at 13 years [39]. More granularity is needed on risk factors for re-revision (such as the indication for surgery) to improve communication with patients regarding

---

**Table 2** Functional and patient-reported outcomes measures

| Author       | Year | ROM – mean (range) | KSS – mean (range) | KSFS – mean (range) | OKS – mean (range) |
|--------------|------|--------------------|--------------------|---------------------|-------------------|
| **Revision cases** |      |                    |                    |                     |                   |
| Rodriguez    | 2015 | 120                | 37                 | 79                  | 34                |
| Neumann      | 2011 | 116 (90–125)      | 25                 | 91 (82–97)          | 35 (15–45)        |
| Gudnason     | 2011 | 108 (100–120)     | –                  | 85 (73–96)          | –                 |
| Pradham      | 2004 | –                  | –                  | –                   | –                 |
| Bistolfi     | 2013 | 103 (97–108)      | –                  | –                   | –                 |
| Barrack      | 2000 | 93 (70–125)       | 41 (6–81)          | 131 (104–160)       | –                 |
| Abdelaziz    | 2019 | 92 (30–120)       | –                  | –                   | –                 |
| Back         | 2008 | 88 (5–110)        | 26 (15–48)         | 68 (40–85)          | 72 (10–55)        |
| Baier        | 2013 | –                  | 57 (28–80)         | 71 (42–97)          | –                 |
| Bistolfi     | 2012 | 114 (108–121)     | –                  | –                   | –                 |
| Joshi        | 2008 | 102 (50–130)      | 38 (10–75)         | 86 (44–98)          | –                 |
| Pour         | 2007 | –                  | 29 (0–89)          | 74 (33–86)          | –                 |
| **Primary cases** |      |                    |                    |                     |                   |
| Yang         | 2011 | 102                | 38                 | 73                  | 36                |
| Rahman       | 2015 | –                  | –                  | –                   | –                 |
| Lozano       | 2012 | 120 (100–120)     | –                  | –                   | 12 (4–18)         |
| Kowalczewski | 2014 | 110 (80–120)      | 17                 | 86                  | –                 |
| Petrou       | 2006 | 120 (100–130)     | 11 (0–46)          | 93 (75–100)         | 20 (0–50)         |
| Bistolfi     | 2013 | 110                | –                  | –                   | –                 |
| Leng         | 2018 | –                  | –                  | –                   | –                 |

ROM: range of motion, KSS: Knee Society Score, KSFS: Knee Society Function Score, OKS: Oxford Knee Score, – not reported.
the risks and benefit of hinged revision knee arthroplasty. The available evidence suggests that patients do achieve a large improvement in functional outcome following hinged knee arthroplasty for both primary and revision procedures. This systematic review was not able to identify evidence on whether surgeons should select a constrained condylar implant versus a modern rotating hinge where the patient was suitable for either device. However, we note that this is the subject of an ongoing randomized controlled trial. [40].

**Conclusion**

In conclusion, the quality of the evidence for patient-relevant outcomes following hinged knee arthroplasty was poor. Prior to considering hinge TKA, patients should be counselled to expect relatively high early revision rates following both primary and revision procedures. However, when a rotating hinge TKA is indicated, our study provides evidence to support an improvement in functional outcomes after surgery.

**Appendix 1: Search strategy**

Each database was searched from inception to January 2021. Searches were translated for each database. The search strategy for MEDLINE is provided below:

1. Knee Prosthesis/ or Arthroplasty, Replacement, Knee/(28,369)
2. (total knee adj2 (arthroplast* or replacement*)).ti,ab. (22,565)
3. (TKA or TKR or RTKA or RTKR).ti,ab. (12,258)
4. 1 or 2 or 3 (34,340)
5. (hinge* adj2 rotat*).ti,ab. (285)
6. RHK.ti,ab. (33)
7. (Kinematic adj2 (hinge* or implant* or prosth*e*)).ti,ab. (69)
8. NexGen.ti,ab. (213)
9. S-ROM.ti,ab. (117)
10. Noiles.ti,ab. (5)
11. Endo-Model*.ti,ab. (37)
12. Finn.ti,ab. (620)
13. EnduRo.ti,ab. (23)
14. LPS.ti,ab. (82,998)
15. “Limb Preservation System”.ti,ab. (4)
16. Rotaflex.ti,ab. (5)
17. SMILES.ti,ab. (540)
18. 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 (84,818)
19. 4 and 18 (461)
## Appendix 2

See Table 4.

### Table 4  Summary of complication rates from each study

| Author       | Year | Total complications | Reoperation | Joint infection | Periprosthetic fracture | Dislocation | Patellar instability | Aseptic loosening | Prosthesis breakage | Extensor mechanism failure | Neurological injury | Superficial infection | Haematoma |
|--------------|------|---------------------|-------------|-----------------|-------------------------|-------------|---------------------|-------------------|----------------------|------------------------|---------------------|------------------------|-----------|
|              |      | n                  | %           | n               | %                       | n           | %                   | n                 | n                    | n                      | n                   | n                      | n         |
| Rodriguez    | 2015 | 1                  | 1%          | 1               | 1%                      |             |                     |                   |                      |                        |                    |                        |           |
| Neumann      | 2011 | 1                  | 4%          | 4               | –                       | –           | –                   | –                 | –                    | –                      | –                   | –                      |           |
| Gudnason     | 2011 | 12                 | 29%         | 12              | 29%                     | 2           | 5%                  | 1                 | 2%                   | 4                      | 10%                 | 2%                     | 5%        |
| Padham       | 2004 | –                  | –           | –               | –                       |             | –                   | –                 | –                    | –                      | –                   | –                      |           |
| Bistolfi     | 2013 | 19                 | 36%         | 14              | 26%                     | 3           | 6%                  | 1                 | 2%                   | 2                      | 4%                  | –                      |           |
| Barrack      | 2000 | 4                  | 29%         | 7               | 7%                      | –           | –                   | –                 | –                    | –                      | –                   | –                      |           |
| Abdelaziz    | 2019 | 13                 | 52%         | 13              | 12%                     | 1           | 4%                  | –                 | –                    | –                      | –                   | –                      |           |
| Back         | 2008 | 4                  | 14%         | 4               | 14%                     | –           | –                   | –                 | –                    | –                      | –                   | –                      |           |
| Baer         | 2013 | 19                 | 28%         | 18              | 26%                     | 3           | 4%                  | 1                 | 1%                   | –                      | 2                   | 3%                     | 4%        |
| Bistolfi     | 2012 | 10                 | 36%         | 7               | 25%                     | 2           | 7%                  | 1                 | 4%                   | –                      | 2                   | 7%                     | 1%        |
| Joshi        | 2008 | 18                 | 23%         | 8               | 10%                     | 2           | 3%                  | –                 | –                    | –                      | –                   | –                      |           |
| Pour         | 2007 | 22                 | 50%         | 19              | 43%                     | 5           | 11%                 | 1%                | 2%                   | –                      | 4                   | 9%                     | –         |
| Primary cases |      |                    |             |                 |                         |             |                     |                   |                      | –                      | –                   | –                      |           |
| Yang         | 2011 | 7                  | 14%         | 7               | 14%                     | –           | –                   | –                 | –                    | –                      | –                   | –                      |           |
| Rahman       | 2015 | 1                  | 7%          | 1               | 7%                      | –           | –                   | 1                 | 7%                   | –                      | –                   | –                      |           |
| Lozano       | 2012 | 25                 | 23%         | –               | –                       | 6           | 5%                  | 2                 | 2%                   | –                      | 11                  | 10%                    | –         |
| Kowalczyk    | 2014 | 6                  | 5%          | –               | –                       | –           | –                   | –                 | –                    | –                      | –                   | –                      |           |
| Petrou       | 2006 | 22                 | 22%         | 4               | 4%                      | 2           | 2%                  | 3                 | 3%                   | 1                      | 1%                  | –                      | –         |
| Bistolfi     | 2013 | 29                 | 30%         | 20              | 20%                     | 8           | 8%                  | 1                 | 1%                   | 5                      | 7%                  | –                      |           |
| Leng         | 2018 | 3                  | 11%         | 2               | 7%                      | 2           | 7%                  | 1                 | 4%                   | –                      | –                   | –                      | –         |

n = number, % = percentage of study cohort, – = not reported
Appendix 3
See Table 5.

Table 5  Revision rates in percent after 1 year (1 y), 5 years (5 y) and 10 years (10 y) by models reported by arthroplasty registries

| Model                                      | EPRD | NJR | FAR |
|--------------------------------------------|------|-----|-----|
| EPRD | NJR | FAR |
| n    | n    | n    | n    |
| 1 y  | 5 y  | 10 y | 1 y  | 5 y  | 10 y | 1 y  | 5 y  | 10 y |
| 591  | 3.8  | N/A  | N/A  | 676  | 4.4  | 7.9  | 8.3  |
| 119  | 3.4  | 7.9  | 14.0 |
| 1278 | 1.4  | 5.3  | 8.7  | 567  | 3.2  | 7.4  | 12.1 |
| 869  | 4.0  | N/A  | N/A  | 554  | 3.1  | 8.2  | 9.1  |
| 1101 | 4.3  | N/A  | N/A  |
| 327  | 4.8  | N/A  | N/A  |

EPRD: Endoprothesenregister Deutschland, NJR: National Joint Registry, FAR: Finnish Arthroplasty registry, n: numbers implanted

Acknowledgements
None.

Authors’ contributions
J.X.: conception, design, acquisition of data, analysis of data and drafting manuscript. L.F.: acquisition of data, analysis of data and drafting manuscript. S.S.: conception, design, analysis of data and drafting manuscript. A.P.: conception, analysis of data and drafting manuscript. A.A.: conception, design, analysis of data and drafting manuscript.

Funding
None.

Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
Not required.

Consent for publication
Yes.

Competing interests
The authors declare that they have no conflict of interest.

Author details
1 Nuffield Orthopaedic Centre, Windmill Rd, Oxford OX3 7LD, UK. 2 Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, Botnar Research Centre, University of Oxford, Old Road, Oxford OX3 7LD, UK.

Received: 9 November 2021  Accepted: 8 February 2022

Published online: 04 March 2022

References
1. Price AJ, Alvand A, Troelsen A et al (2018) Knee replacement. Lancet 392:1672–1682
2. Kurtz S, Ono K, Lau E, Mowat F, Halpern M (2007) Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 89:780–785
3. NJR: National Joint Registry for England Wales Northern Ireland and the Isle of Man; 2020.

4. Scuderi GR (2001) Revision total knee arthroplasty: how much constraint is enough? Clin Orthop Relat Res 392:300–305
5. Hampton CB, Berliner ZZ, Nguyen JT et al (2020) Aseptic loosening at the tibia in total knee arthroplasty: a function of cement mantle quality? J Arthroplasty 35:S190–S196
6. Pasquier G, Ehlinger M, Mainard D (2019) The role of rotating hinge implants in revision total knee arthroplasty. EFORT Open Rev 4:269–278
7. Rodriguez-Merchan EC (2019) Total knee arthroplasty using hinge joints: indications and results. EFORT Open Rev 4:121–132
8. Gehrke T, Kendorf D, Haasper C (2014) The role of hinges in primary total knee replacement. Bone Joint J 96:93–95
9. Wilson HA, Middleton R, Abram SGF et al (2019) Patient relevant outcomes of unicompartment versus total knee replacement: systematic review and meta-analysis. BMJ 368:k4352
10. Cuckler JM (1995) Revision total knee arthroplasty: how much constraint is necessary? Orthopedics 18:932–3
11. Makaram N, Clement ND, Hoo T, Nutten R, Burnett R (2018) Survival of the low contact stress rotating platform total knee joint replacement is influenced by age: 1058 implants with a minimum follow-up of 10 years. Knee 25:1283–1291
12. Neumann DR, Hofstaedter T, Dorn U, Neumann DRP, Hofstaedter T, Dorn U (2012) Follow-up of a modular rotating hinge knee system in salvage revision total knee arthroplasty. J Arthroplasty 27:814–819
13. Gudnason A, Milbrink J, Hailer NP (2011) Implant survival and outcome after rotating-hinge total knee revision arthroplasty: a minimum 6-year follow-up. Arch Orthop Trauma Surg 131:1–7
14. Pradhan NR, Bale L, Kay P, Porter ML (2004) Salvage revision total knee replacement using the endo-model rotating hinge prosthesis. Knee 11:469–473
15. Back D, David L, Hilton A, Blunn G, Briggs TW, Cannon SR (2008) The SMILES prosthesis in salvage revision knee surgery. Knee 15:40–44
21. Bistolfi A, Massazza G, Rosso F, Crova M (2012) Rotating-hinge total knee for revision total knee arthroplasty. Orthopedics 35:e325–e330
22. Joshi N, Navarro-Quilis A, Joshi N, Navarro-Quilis A (2008) Is there a place for rotating-hinge arthroplasty in knee revision surgery for aseptic loosening? J Arthroplasty 23:1204–1211
23. Pour AE, Parvizi J, Slentker N et al (2007) Rotating hinged total knee replacement: use with caution. J Bone Jt Surg Am 89:1735–1741
24. Rahman J, Hanna SA, Kayani B et al (2015) Custom rotating hinge total knee arthroplasty in patients with poliomyelitis affected limbs. Int Orthop 39:833–838
25. Lozano LM, Lopez Y, Rios J et al (2012) Better outcomes in severe and morbid obese patients (BMI > 35 kg/m²) in primary Endo-Model rotating-hinge total knee arthroplasty. Scientific World J 2012:249391
26. Kowalczywski J, Marczak D, Synder M, Sibinski M, Sibirski M (2014) Primary rotating-hinge total knee arthroplasty: good outcomes at mid-term follow-up. J Arthroplasty 29:1202–1206
27. Yang JH, Yoon JR, Oh CH, Kim TS (2012) Primary total knee arthroplasty using rotating-hinge prosthesis in severely affected knees. Knee Surg Sports Traumatol Arthrosc 20:517–523
28. Petrou G, Petrou H, Tilkeridis C et al (2004) Medium-term results with a primary cemented rotating-hinge total knee replacement. A 7- to 15-year follow-up. J Bone Jt Surg B 86:813–817
29. Bistolfi A, Lustig S, Rosso F, Dalmasso P, Crova M, Massazza G (2013) Results with 98 endo-modell rotating hinge prostheses for primary knee arthroplasty. Orthopedics 36:e746–e752
30. Leng Y, Zeng M, Hu Y, Zhu J, Su W, Xie J (2018) Primary total knee arthroplasty with rotating-hinge prosthesis in severely compromised knees. Int J Clin Exp Med 11:5867–5872
31. Baier C, Lüring C, Schaumburger J et al (2013) Assessing patient-oriented results after revision total knee arthroplasty. J Orthop Sci 18:955–961
32. Abdelaziz H, Jaramillo R, Gehrke T, Ohlmeier M, Citak M (2019) Clinical survivorship of aseptic revision total knee arthroplasty using hinged knees and tantalum cones at minimum 10-year follow-up. J Arthroplasty 34:3018–3022
33. German Arthroplasty Registry (EPRD). 2019 Annual Report; 2019.
34. Finnish Arthroplasty Registry. ENDOnet. Finnish Arthroplasty Registry; 2020.
35. National Joint Registry (NJR). 17th Annual Report, 2020.
36. Crowson CS, Larson DR, Devick KL et al (2021) Living with survival analysis in orthopedics. J Arthroplasty 36:3358–3361
37. AOA Australian Orthopaedic Association National Joint Replacement Registry. Annual Report 2020: Hip, Knee and Shoulder Arthroplasty.
38. Sabah SA, Alvand A, Beard DJ, Price AJ (2021) Evidence for the validity of a patient-based instrument for assessment of outcome after revision knee arthroplasty. Bone Jt J 103-B:627–634
39. Deere K, Whitehouse MR, Kunutsor SK et al (2021) How long do revised and multiply revised knee replacements last? A retrospective observational study of the National Joint Registry. Lancet Rheumatol 3:e438–e446
40. Hommel H, Wilke K, Kunze D, Hommel P, Fennema P (2017) Constraint choice in revision knee arthroplasty: study protocol of a randomised controlled trial assessing the effect of level of constraint on postoperative outcome. BMJ Open 7:e012964

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.