



Total knee arthroplasty using hinge joints: Indications and results

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- Possible indications for a rotating hinge or pure hinge implant in primary total knee arthroplasty (TKA) include collateral ligament insufficiency, severe varus or valgus deformity ($> 20^\circ$) with relevant soft-tissue release, relevant bone loss, including insertions of collateral ligaments, gross flexion-extension gap imbalance, ankylosis and hyperlaxity.
- The use of hinged implants in primary TKA should be limited to the aforementioned selected indications, especially for elderly patients.
- Potential indications for a rotating hinge or pure hinge implant in revision TKA include infection, aseptic loosening, instability and bone loss.
- Rotating hinge knee implants have a 10-year survivorship in the range of 51% to 92.5%.
- Complication rates of rotating hinge knee implants are in the range of 9.2% to 63%, with infection and aseptic loosening as the most common complications.
- Although the results reported in the literature are inconsistent, clinical results generally depend on the implant design, appropriate technical use and adequate indications.
- Considering that the revision of implants with long cemented stems can be challenging, in the future it would be better to use shorter stems in modular versions of hinged knee implants.

Keywords: knee; prosthesis; hinged implants; rotating hinged implants; results

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Introduction

Since 1975, many articles have been published on various models of hinge knee prostheses. Table 1 summarizes these models and the bibliographic references of the authors who published them.¹⁻⁴⁷ In this article, we will review the various prosthetic knee hinge models that have

been used since 1975, with the purpose of analysing their indications and results.

Indications for hinged implants in primary total knee arthroplasty

In 2014, Gerhke et al analysed the role of hinges in primary total knee arthroplasty (TKA).⁴⁸ They stated that the use of hinged implants in primary TKA should be restricted to selected indications and mainly for elderly patients. Potential indications for a rotating hinge or pure hinge implant in primary TKA include collateral ligament insufficiency, severe varus or valgus deformity ($> 20^\circ$) with relevant soft-tissue release and relevant bone loss, as well as insertions of collateral ligaments, gross flexion-extension gap imbalance, ankylosis and hyperlaxity. They found that although the results reported in the literature were inconsistent, clinical outcomes generally depended on implant design, adequate technical use and appropriate indications. Given the revision of implants with long cemented stems can be challenging, they concluded that an effort should be made in the future to use shorter stems in modular versions of hinged implants.⁴⁸

Indications for rotating hinge prostheses for revision TKA

In 2018, Kouk et al published a review of the literature on rotating hinge prostheses for complex revision TKA.⁴⁹ The findings of this study showed that rotating hinge knee implants demonstrate good survivorship, in the range of 51% to 92.5% at ten years post-operatively. Complication rates were in the range of 9.2% to 63%, with infection and aseptic loosening as the most common complications. Rotating hinge knee prostheses were most commonly indicated for infection, aseptic loosening, instability and bone loss. They had good outcome scores and survivorship, but continued to have high complication and revision rates. This implant was a good option when used appropriately for patients who were not candidates for less constrained devices.⁴⁹

Table 1. Summary of hinge knee prosthesis designs published in the literature since 1975

Design	References
Walldius	1, 2
Guepar	3–8
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Rotaflex	15, 16
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Modular rotating-platform hinge	18, 19
S-ROM mobile-bearing hinge prosthesis	20, 21
Endo-Model rotating hinge prosthesis	22–36
Hinged Limb Preservation System (LPS) model	37
Custom-made rotating hinge model	38–41
NexGen rotating hinge knee model	42, 43
EnduRo model	44, 45
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Walldius hinge arthroplasty

In 1975, Phillips and Taylor evaluated a series of 57 patients (67 Walldius prostheses) implanted between 1966 and 1972.¹ In just eight cases they used cement. In 81% of the cases the result was successful, whereas in 19% the result was considered a failure. There were two early infections and two late infections. Two arthrodeses had to be performed in two of the unsuccessful cases. The authors considered that the Walldius prosthesis was a good alternative to knee arthrodesis.

In 1977, Küsswetter and Baumann published a series of 45 Walldius prostheses with a mean follow-up of three years.² There was an infection rate of 11% and a rate of good and excellent results of 75%. Cement was always used. The authors considered that, despite the high complication rate, the Walldius prosthesis was a promising technique.

Guepar hinge knee arthroplasty

In 1976, Deburge and Guepar published a series of 292 Guepar prostheses, of which 103 had > two years of follow-up. His indication for this prosthesis was extremely damaged and unstable knees.³ The infection rate was 6.6%. For these authors, patellar pain with this prosthetic model was a significant unresolved concern.

In 1981, Schurman published a series of 49 patients (66 prostheses) with a follow-up of one year to 5.5 years.⁴ The average age of the patients was 69 years and the complication rate was 58% (23% patellar dislocation or subluxation, 26% extensor lag and 9% deep infection).

In 1981, leNobel and Patterson published 113 prostheses: 83 Guepar valgus-hinge prostheses and 30 prostheses with collinear femoral and tibial components.⁵ Only 92 prostheses could ultimately be evaluated, with a mean follow-up of 19 months. The results were excellent in 32 cases, good in 22, fair in 8 and poor in 30. Patellar

subluxation occurred in 28% of the valgus prostheses and in 10% of the straight prostheses. The chemical synovitis created by the disintegration of the silastic bumper led to failure, with significant problems necessitating further operations in some knees.

In 1983, Duquenois et al analysed 145 prostheses of the 195 implanted between 1970 and 1981.⁶ There were 23 complications (11 infections, eight loosening and four post-operative fractures of the tibia or femur). The authors concluded that a hinge prosthesis should be used only in cases of severe deformity or in cases of severe instability.

In 1997, Cameron et al published a study on 58 patients undergoing Guepar II prosthesis.⁷ They performed the procedure in patients requiring revision, for whom the conditions were such that only a totally constrained implant was considered to be appropriate. In seven patients, the implant was press-fitted; in 51, it was cemented. Five patients required fusion or revision and eight died < two years after the procedure, leaving 45 for review. Follow-up was two to 13 years. The clinical rating was 18% excellent, 20% good, 20% fair and 42% poor. Post-operative problems include infection (13%), aseptic loosening (7%), quadriceps lag (16%) and extensor mechanism problems (16%). These authors stated that the indications for a hinge prosthesis in 1997 were anteroposterior instability with a very large flexion gap, complete absence of the collateral ligaments and complete absence of a functioning extensor mechanism.⁷

In 2014, Aubriot et al published a series of 184 prostheses implanted before 1974.⁸ Nineteen had to be extracted. In 27% of the cases there was painful patellar displacement that required reoperation in 10% of the cases. The infection rate was 8.3%. There was prosthetic loosening in 16% of cases, of which 6% required reoperation. Of the 99 cases with a follow-up of five to eight years, 60% had excellent or good results, 29% fair and 11% poor. These authors concluded that the choice of this prosthesis should be limited to special cases. To prevent complications, the use of a patellar prosthesis, of reinforced models and of cementing under pressure was advisable.⁸

Kinematic rotating hinge total knee arthroplasty

In 1987, Rand et al published the first study with the kinematic rotating hinge design.⁹ The indication for use of this prosthesis was either ligamentous instability, loss of bone or both. These authors analysed 36 prostheses (19 primaries, 17 revisions) with a mean follow-up of 50 months (29–79). According to the Hospital for Special Surgery (HSS) clinical scale, there were 14 excellent results, 12 good, five fair and five poor. The infection rate was very high: 44% (16% infection, 22% patellar instability and 6% implant rupture). The conclusion was that this

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implant should be used only in knees in which there is a functional absence of a collateral ligament that cannot be managed by soft-tissue reconstruction.⁹

In 1989, Shaw et al analysed 38 knees (20 primaries and 18 revisions) in which a kinematic rotating hinge had been implanted.¹⁰ Using the Brigham and Women's Hospital and Harvard Medical School knee rating system, 80% of primary knees and 61% of revision knees were rated as good to excellent. The infection rate was 7.8% (one primary prosthesis, two revisions). Some 21% of the primary prostheses and 36% of the revisions presented patellar instability. According to Shaw et al, the kinematic rotating hinge prosthesis is intended for use in arthroplasty cases in which there is a functional absence of collateral ligament stability.

In 2008, Deehan et al analysed 72 salvage knee procedures performed between 1983 and 1997 using a kinematic rotating hinge prosthesis.¹² The survival analysis revealed a best-case 10-year implant survival of 90%. Deehan et al stated that this constrained hinged prosthesis remained a viable option in cases of gross deformity, bone loss and failed multiple previous surgical procedures.

Blauth hinge prosthesis

In 1988, Hassenpflug et al published the results of 463 Blauth hinge prostheses, with a mean follow-up of 43 months (1 to 15).¹³ There was 1.3% aseptic loosening and 2.6% infections. After ten years, there was a probability of 89% that a prosthesis would not show a deep infection or loosening. In 1991, Blauth and Hassenpflug analysed 511 prostheses with a follow-up of one to 15 years.¹⁴ There was 1.2% aseptic loosening and 3.3% infections. The survival analysis showed a probability of 89% that a prosthesis would not have a deep infection or loosen.

Rotaflex hinged total knee arthroplasty

In 1994, Wilkinson and Douglas reported two cases of Rotaflex hinged TKAs in which the components forming the hinge mechanism had fractured.¹⁵ In one case, this was in the high-density polyethylene sleeve bush of the tibial bearing; in the other case, it was the titanium retaining peg of the tibial component. In 1998, David et al published a series of 25 Rotaflex prostheses, having a complication rate of 80%.¹⁶ Among these were four arthrodeses and two amputations. Thus, the authors stated that this prosthesis should not be used, despite its continued availability.

Modular rotating hinges

In 2000, Barrack et al analysed 14 knees (13 patients) that underwent prosthetic revision with a modular rotating

hinge design. The mean follow-up was 51 months (two to six years).¹⁷ Indications for revision were aseptic loosening of a hinged prosthesis (eight knees), loosening and bone loss associated with chronic extensor mechanism disruption (two knees), component instability with chronic medial collateral ligament disruption (three knees) and comminuted distal femur fracture (one knee). Short-term clinical and radiographic results were encouraging and suggested that a second-generation modular rotating hinge component can be used successfully in selected salvage revision cases.

In 2006, Jones et al reported excellent mid-term results with no mechanical failures and positive bone remodeling in 65 patients using a modular rotating hinge prosthesis.¹⁸ Primary indications included medial or lateral collateral loss, massive bone loss, and metaphysis and cortical shell, which included collateral origins or insertions and severe flexion gap imbalance. Indications for a hinge in primary TKA included patients with neuromuscular deficits, such as polio or flail knee, who require the hyperextension stop.

In 2006, Neumann et al reported on 24 salvage knee revisions using a modern-generation, modular, rotating hinge total knee prosthesis.¹⁹ The minimum follow-up was 36 months (mean 56 months). Indications for revision included aseptic loosening combined with bone loss and gross collateral ligament instability in all cases. One patient needed a revision due to patellofemoral subluxation.

S-ROM hinge implantation

In 2001, Jones et al analysed 15 patients receiving 16 S-ROM mobile-bearing hinge total knee prostheses (one primary and 15 revisions).²⁰ The average age of the patients was 63 years (33 to 83). The minimum follow-up was two years (27 months to 71 months). There was one complication non-related to surgery (a traumatically ruptured patellar tendon). According to Jones et al, a high rate of satisfactory results were obtained when using this mobile-bearing hinge knee prosthesis for these indications.

In 2013, Deehan et al reported implantation of 36 S-ROM third-generation hinge devices (four primaries and 33 revisions).²¹ The indication for the procedure was a combination of massive bone loss or ligamentous insufficiency. Principal indications included aseptic loosening or massive osteolysis (24 cases), infection (eight cases) and peri-prosthetic fracture (four cases). All the patients exhibited either grade 2 (n = 12) or grade 3 (n = 25) Anderson Orthopaedic Research Institute bone loss or a grade 3 medial ligament deficiency. The mean age of the patients was 72 years (43 to 87). The minimal follow-up was five years. One patient experienced implant failure (71 months) and one patient suffered late deep infection (36 months). Four patients needed patellar resurfacing for

persistent pain. The 5-year survivorship was 86%. Deehan et al concluded that although the S-ROM prosthesis could offer satisfactory medium-term results for complex end-stage knee disease, there was a high rate of debilitating anterior knee symptoms.²¹

The Endo-Model rotating hinge prosthesis

Between 2004 and 2018, 14 articles on the Endo-Model design have been published.²²⁻³⁶

In 2004, Pradham et al indicated the procedure in selected complex cases.²² Also in 2004, Petrou et al analysed 100 cemented Endo-Model rotating hinge prosthesis TKAs.²³ These authors considered this prosthesis to be ideally suited to the replacement of the deformed knee when the use of an unconstrained design might be questionable.

In 2004, Pacha-Vicente et al reported the dislocation of a rotating hinge knee prosthesis with antidislocation design.²⁴ In 2008, Mavrodontidis et al indicated the procedure in cases of serious axial deformity and collateral ligament deficiency and in patients with rheumatoid arthritis.²⁵ In 2009, Guenoun et al stated that this prosthesis should therefore be restricted to selected indications, notably in view of the fact that less-constrained prostheses confer superior results.²⁶

In 2011, Gudnason et al indicated the procedure in elderly patients with severe co-morbidities.²⁷ For Yang et al (2012), the indications for this prosthesis were severe primary osteoarthritis (OA) with substantial ligament laxity, severe rheumatic arthritis with extreme ligament instability and bone loss, supracondylar nonunion, Charcot arthropathy and post-traumatic osteoarthritis OA.²⁸ In 2012, Lozano et al stated that this prosthesis can be a useful tool to deal with severely and morbidly obese patients affected by severe OA associated with marked axial deviations, ligament instability or bone defects.²⁹ According to Efe et al (2012), this prosthesis must be indicated in selected cases of advanced primary OA associated with severe bone loss, ligamentous instability or comminuted fractures, and in revision situations.³⁰

In 2013, Bistolfi et al recommended this prosthesis for cases of instability and revision.³¹ In 2013, Bistolfi et al recommended use of this implant for revision TKA, especially in patients with severe instability and bone loss.³² In 2014, Sanguineti et al indicated this implant in complex primary and revision knee arthroplasty.³³

In 2015, Rodríguez-Merchán et al indicated the procedure for elderly patients with instability following TKA.³⁴ In 2016, Felli et al indicated this prosthesis in complex primary and revision knee arthroplasty in the majority of patients with severely affected rheumatoid knees.³⁵ In 2018, Helito et al indicated this implant for elderly patients with instability following TKA.³⁶

Table 2 shows the main data from the 15 publications between 2004 and 2018 on the Endo-Model rotating hinge prosthesis ²²⁻³⁶. Figure 1 shows a rotating hinge knee prosthesis (Endo-Model) implanted as a primary TKA in an elderly patient with severe varus deformity. Figure 2 shows an Endo-Model rotating hinge in a revision TKA due to severe instability and ligamentous insufficiency of the primary TKA.

LPS hinged prosthesis

In 2012, Friesenblicher et al analysed 40 patients with an LPS TKA.³⁷ Four fractures of the metal yoke occurred in four cases (failure rate: 10%). Furthermore, a second fracture occurred in two patients. The overall revision-free prosthetic survival was 57% at 38 months and prosthetic survival until yoke fracture was 86% at 38 months.

Custom-made rotating hinge

In 2012, McGrath et al reported a patient with type 2 congenital tibial deficiency and disabling knee OA in whom a custom-made rotating hinge knee replacement was successfully performed.³⁸ It allowed continued mobilization with a below-knee prosthesis, preventing the need for an above-the-knee amputation.

In 2012, Sewell et al used 11 custom rotating hinge primary TKAs in eight patients (three men, five women) with skeletal dysplasia.³⁹ They used the Stanmore Modular Individualised Lower Extremity System (SMILES) custom-made rotating hinge TKA. The mean age of the patients was 57 years (41 to 79) and the mean follow-up was seven years (3 to 11.5). Four complications were found, including a patellar fracture following a fall, a tibial periprosthetic fracture, persistent anterior knee pain and aseptic loosening of a femoral component needing revision. This study demonstrated that custom primary rotating hinge TKA in patients with skeletal dysplasia is effective at alleviating pain, with a satisfactory range of motion (ROM) and improved function. It compensates for bony deformity and ligament deficiency and diminishes the likelihood of corrective osteotomy. Patellofemoral joint complications are common and the functional result is poorer than with primary TKA in the general population.³⁹

In 2012, Sewell et al reported the role of a custom rotating hinge TKA in patients with spina bifida and severe neuromuscular dysfunction.⁴⁰ These authors concluded that for patients such as these with bone deformity, this design alleviated pain, restored stability and ameliorated early knee dysfunction; however, there was a significant risk of extensor mechanism complications and the functional results were poorer than primary TKA in the general population.

Table 2. Main data and results of the Endo-Model rotating hinge prostheses^{22–36}

Author	Year	Patients and results	Comments
Pradhan et al ²²	2004	These authors analysed 50 patients receiving 51 Endo-Model rotating hinge prosthesis with an average follow-up of four years (2 to 6). Clinical and radiological results were reviewed at the latest follow-up. Five patients died from unrelated causes. Reasons for revision were infection (n = 23), aseptic loosening (n = 23), implant failure (n = 3), stiffness (n = 1) and peri-prosthetic fracture (n = 1). The average number of previous surgeries from and including the primary arthroplasty was three (1 to 14). Seven patients needed plastic surgery for soft-tissue cover. There was notable improvement in the pain, stability, ROM and mobility of the patients with an improvement in the Hospital for Special Surgery (HSS) knee score (35.9 to 72.17). Post-operatively, 11 (22%) had an excellent HSS grade, 22 (44%) a good grade, 10 (19%) a fair grade and 8 (15%) a poor grade. A significant number of our patients had an extremely low pre-operative HSS score; for these patients, an improvement to a fair grade HSS score was a satisfactory and realistic result. Forty-four (86%) patients were satisfied with the result of the revision surgery, 3 (6%) were non-committal and 4 (8%) were disappointed. Comparing revision for infection vs aseptic loosening, 22 (95%) patients out of 23 were satisfied in the aseptic loosening group vs 17 (74%) out of 23 were satisfied in the infected group.	In selected complex cases, salvage revision surgery showed encouraging results in the short to medium term.
Petrou et al ²³	2004	These authors analysed 100 cemented Endo-model rotating hinge TKAs in 80 patients with a mean age of 70 years (56 to 85). The mean follow-up was 11 years (7 to 15). Good or excellent results were found in 91% of the knees. Model survival at 15 years was 96.1%. There were two deep infections, one dislocation and one supracondylar fracture. There was no loosening, malalignment, migration or wear.	These authors considered this Endo-model rotating hinge prosthesis to be ideally suited for replacement of a deformed knee when the use of an unconstrained design is questionable.
Pacha-Vicente et al ²⁴	2008	These authors used Endo-Model prostheses (Waldermar Link GmbH & Co, Hamburg, Germany) for difficult knee reconstructions. In a series of 192 consecutive prostheses, they found two cases of femorotibial dislocations. An increased flexion laxity allowed excessive distraction and hence implant dislocation after antidislocation feature loosening.	There are no other reports in the literature regarding dislocation of a rotating-hinge knee prosthesis with antidislocation design.
Mavrodontidis et al ²⁵	2008	A total of 136 knees were treated with the Endomodel rotating hinge knee prosthesis as primary total knee arthroplasty (TKA). The indications for surgery included osteoarthritis (110 knees), rheumatoid arthritis (18 knees) and osteonecrosis (8 knees). Patients were divided into four study groups according to follow-up duration. Group A was followed up for 10 to 15 years, group B for 8 to 10 years, group C for 5 to 8 years and group D for 2 to 5 years. The HSS knee score, as well as each parameter individually, showed statistically significant improvement in all groups post-operatively. A total of 88.23% were rated as excellent, 3.67% as good and 8.08% as fair.	The results suggest that the Endomodel rotating hinge prosthesis can be considered a good alternative for primary TKA in cases of serious axial deformity and collateral ligament deficiency and in rheumatoid arthritis patients.
Guenoun et al ²⁶	2009	These authors analysed 85 Endo-Modell (Link) rotating hinge knee prostheses (61 women, 24 men). The mean age at surgery was 72.4 years (32 to 92). Fifty-two arthroplasties were primary and 33 were revisions either for loosening (n = 24) or deep infections (n = 9). The mean follow-up was 36 months ± 22 (0 to 75). Complications were found in 24 patients (28.2%): 9 deep infections, 4 patellar complications and 3 cases of aseptic loosening. No significant difference was seen between the primary arthroplasties and the revisions regarding all complication types. A significant relation was established between the occurrence of a complication and presence of several associated co-morbidity factors (obesity, heart disease, diabetes, etc.).	These prostheses should be restricted to selected indications, notably in view of the fact that less constrained prostheses give superior results.
Gudnason et al ²⁷	2011	These authors evaluated the result of 42 revision TKAs in 38 patients using the Endo-model rotating hinge total knee prosthesis after a minimum of 6 years, with 10-year implant survival as our primary outcome measure. Only revision TKAs performed due to aseptic loosening were included; the Swedish Knee Arthroplasty Register was consulted in order to ensure that patients unavailable for clinical follow-up had not been revised elsewhere. The mean follow-up was after 8.8 years (6 to 18), the mean age at revision surgery was 72 years (55 to 88) and most patients had severe medical co-morbidities (n = 31). At follow-up, 4 knees had been re-revised due to aseptic loosening and 5 further knees underwent re-revision due to other reasons. With implant revision due to aseptic loosening as the endpoint, 10-year survival was 89.2%, and with implant revision due to any reason 10-year survival was 65.1%. 11 patients (13 knees) eligible for clinical follow-up were evaluated according to the HSS knee score, the Knee Society scores (KSS) and by plain radiography. Mean HSS score was 67 (36 to 90), mean KSS-knee was 85 (73 to 96) and mean KSS-function was 29 (0 to 100). Radiography showed that no implant was in need of revision.	The results of this study indicated that revision arthroplasty of the knee with the rotating hinge prosthesis can be performed with satisfactory or good results in an elderly population with severe co-morbidities.
Yang et al ²⁸	2012	These authors reviewed 50 cases (40 patients) at a mean follow-up of 15 years (10 to 18) who underwent primary TKA using Endo-Modell (Link®). Overall, the rotating hinge arthroplasty resulted in improved knee functioning. The KSS score improved from a pre-operative mean of 38 points to a post-operative mean of 73 points; the functional score improved (n.s.) from 36 points to 47 points. The mean ROM at the most recent clinical follow-up evaluation was 102°. However, all (100%) patients required some form of assisted devices for walking and a relatively large number of deep infections (14%) were found.	Reconstruction with a rotating hinge total knee prosthesis provided substantial improvement in function and reduction in pain. However, the possibility of assisted walking and the high rate of deep infection should be taken into account.
Lozano et al ²⁹	2012	Results were studied in 111 knees, operated in a 3-year period; the mean follow-up was 28 months. Joint balance enhancement and limbs mechanical axis correction were achieved after surgery. There were 6 deep infections and 16 patients referred post-operative anterior knee pain. WOMAC index scores disaggregated by gender and body mass index (BMI) showed better results in obese patients (specifically, those with a BMI of 35 to 40 kg/m ²) and in men. Although the lack of a control group did not allow definite conclusions and despite a non-negligible complication rate.	The Endo-Model TKA can be a useful tool to deal with severely and morbidly obese patients affected of severe OA associated with marked axial deviations, ligament instability or bone defects.

(continued)

Table 2. (continued)

Author	Year	Patients and results	Comments
Efe et al ³⁰	2012	A total of 49 prostheses in 45 patients were clinically reviewed during follow up: 21 of these were implanted in primary and 28 in revision situations. Results were assessed using commonly used scores (KSS, UCLA Activity, Lequesne) and a visual analogue scale after a mean follow up of 56 months for 49 prostheses. Implant survival was analysed using the Kaplan–Meier method. There were no significant differences in the clinical examination and evaluation scores between the two groups. Survival rates at final follow-up were 95% after primary implantation and 76% in revision procedures. The risk of prosthesis loss (odds ratio 5.7) was significantly higher after revision procedures.	The findings of this study showed that rotating hinge knee prostheses provided good clinical and functional results in selected cases of advanced primary OA associated with severe bone loss, ligamentous instability or comminuted fractures. They also provided good results in revision situations. However, the failure rate was significantly higher in cases of revision surgery.
Bistolfi et al ³¹	2013 (June)	These authors assessed a series of 98 rotating hinge knee arthroplasties Endo-Modell (Waldemar LINK GmbH and Co, Hamburg, Germany) implanted for knee OA. The HSS knee score and the KSS were used for the clinical and radiographic evaluation. Log-rank or Wilcoxon tests were used to test the statistical significances and the Kaplan–Maier method was used to calculate the implant survival probability. After a median follow-up of approximately 174 months, the clinical scores showed a statistically significant improvement from the pre- to post-operative period. The complication rate was high and the cumulative implants survival rate was 88.7% at 1 year, 85.9% at 5 years, 79.8% at 10 years and 75.8% at 15 years.	The Endo-Modell rotating hinge implants demonstrated no significant risk of aseptic loosening and the hinge was not a primary cause of failure. However, the overall failure rate was higher than that of unhinged implants; therefore, this prosthesis was recommended for cases of instability and revision rather than primary knee arthroplasty.
Bistolfi et al ³²	2013 (October)	Fifty-three revision TKAs were performed using the Endo-Modell (Waldemar LINK GmbH and Co, Hamburg, Germany) rotating hinge prosthesis; 7 (13.2%) patients underwent partial revision of a previous Endo-Modell. All patients were assessed pre-operatively, 3 and 6 months post-operatively, and annually thereafter using the HSS knee score and the Knee Society Roentgenographic Evaluation System (KS-RES). Mean follow-up was 155 months (78 to 240), with 32 patients examined at the final follow-up. All HSS knee scores increased from pre-operatively to last follow-up. No statistically significant differences were found in the HSS knee scores between septic and aseptic revisions and between total or partial revisions. Progressive radiolucent lines were detected in 8 (25%) patients. Implant failure occurred in 11 (20.7%) patients; the cumulative survival of the implants was 80.4% at 150 months for the final 32 patients.	The authors recommended use of this implant for revision TKA, especially in patients with severe instability and bone loss.
Sanguineti et al ³³	2014	These authors evaluated the functional and clinical results in a series of patients treated with the rotating hinge Endo-Model prosthesis either for primary or revision TKA. Between 1997 and 2009, we implanted 123 Endo-Model prosthesis (118 patients) at our institution. At the time of this study we could evaluate 45 prosthesis (25 primary and 20 revision TKAs) from the clinical and radiological site, with average follow-up of 42 months. During the follow-up period, 3 patients reported complications, which in 2 cases finally led to revision with explantation. Mean survival of the implants attested at 93%. The average post-operative clinical Knee Society score in the evaluated series was 94.2, the functional one 78.7. The average ROM was 0° to 108°. No signs of joint instability or misalignment were noted. Pain was present in a minority of patients, but always to a mild/occasional extent.	These authors stated that the Endo-Model prosthesis provide excellent pain relief, restoration of walking capacity and intrinsic knee stability both in complex primary and in revision knee arthroplasty, with good or excellent results in the majority of patients and an acceptable complication rate.
Rodriguez-Merchan et al ³⁴	2015	These authors reviewed 96 rotating hinge arthroplasties. The average age of the patients was 79 years (75 to 86); the minimum follow-up was 5 years (mean 7.3 years (5 to 10)). Patients were evaluated clinically (Knee Society score) and radiographically (position of prosthetic components, signs of loosening, bone loss). At a minimum follow-up of 5 years (mean 7.3 years (5 to 10)), Knee Society pain scores improved from 37 pre-operatively to 79 post-operatively, and function scores improved from 34 to 53. ROM improved on average from -15° of extension and 80° of flexion before surgery to -5° of extension and 120° of flexion at the last follow-up (p = 0.03). No loosening of implants was observed. Non-progressive radiolucent lines were identified around the femoral and tibial components in 2 knees. One patient required reoperation because of a periprosthetic infection.	Revision arthroplasty with a rotating hinge design provided substantial improvement in function and a reduction in pain in elderly patients with instability following TKA.
Felli et al ³⁵	2016	These authors assessed a series of 38 patients with rheumatoid arthritis (RA) implanted with the Endo-Model(®) rotating hinge knee prosthesis for primary or revision surgery (mean follow-up 6.1 years; mean age at surgery 71.5 years). At the time of surgery, the mean duration of RA was 13.2 years. Patients were evaluated clinically and radiographically and the KSS was used. Implant survival at the most recent follow-up was 91.7%. The mean final knee flexion was 102.7°. The mean KSS was 93.5 (excellent) and 67.1 (good) for clinical and functional score, respectively. Mild pain was present in 10 patients. No sign of malalignment or residual instability was found. No evidence of loosening or implant failure was observed in radiographs.	The Endo-Model(®) rotating hinge knee prosthesis provided excellent pain relief, functional recovery and intrinsic knee stability both in complex primary and in revision knee arthroplasty in the majority of patients with severely affected rheumatoid knees.
Helito et al ³⁶	2018	This study included 9 patients submitted to a TKA, of which 6 were primary and 3 were revisions, using exclusively the Endo-Model™ implant. These patients were followed for an average of 12 months and evaluated with functional scores, such as the Knee injury and Osteoarthritis Outcome Score (KOOS), KSS, and visual analogue pain scale (VAS). There were statistically significant improvements in all scores evaluated in every patient. Only one complication occurred post-operatively (apraxia of the peroneal nerve) and did not require surgery revision.	The use of a rotating hinge implant for knee arthroplasty is a new option in elderly patients with instability following TKA. The initial results were satisfactory.

In 2015, Rahman et al used a custom rotating hinge TKA in patients with poliomyelitis-affected limbs.⁴¹ They used 14 customized SMILES rotating hinge knee systems

in 13 patients (three men, ten women). All the patients had painful unstable knees with hyperextension. The mean age of the patients was 66 years (51 to 84). The

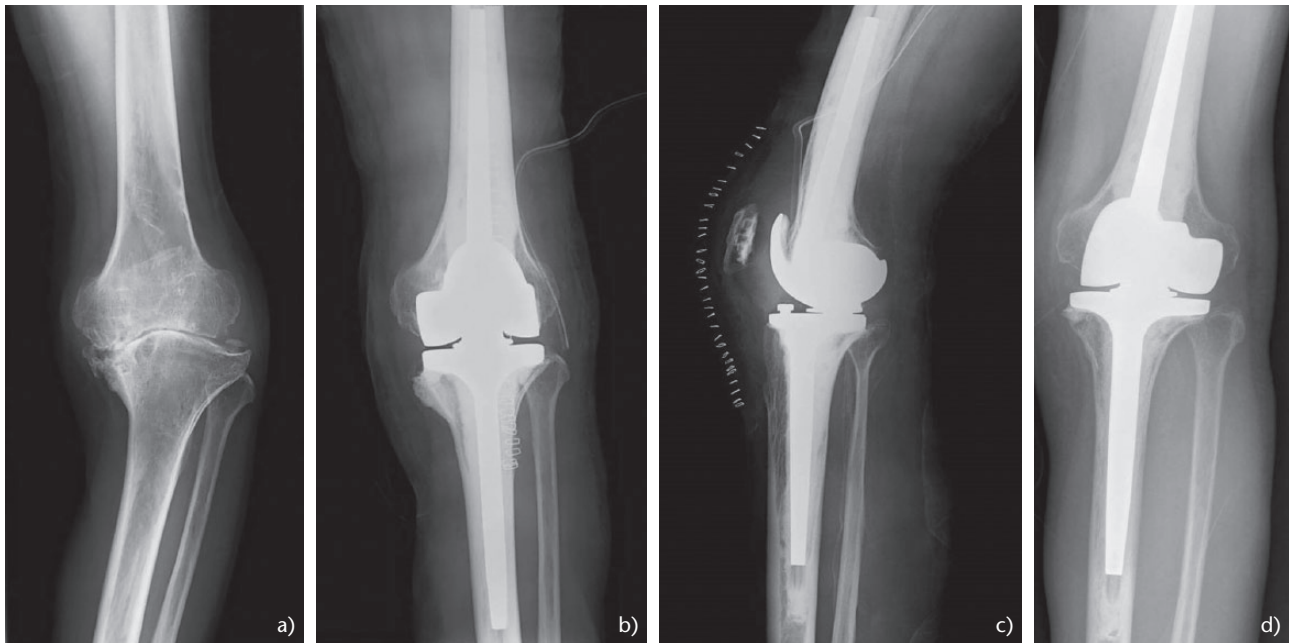


Fig. 1 Rotating hinge knee prosthesis (Endo-Model) implanted as a primary TKA in a 74-year-old man with severe varus deformity. (a) Pre-operative anteroposterior (AP) view; (b) immediate post-operative AP radiograph; (c) immediate post-operative lateral view; (d) AP view 7 years after the procedure. The result was satisfactory.

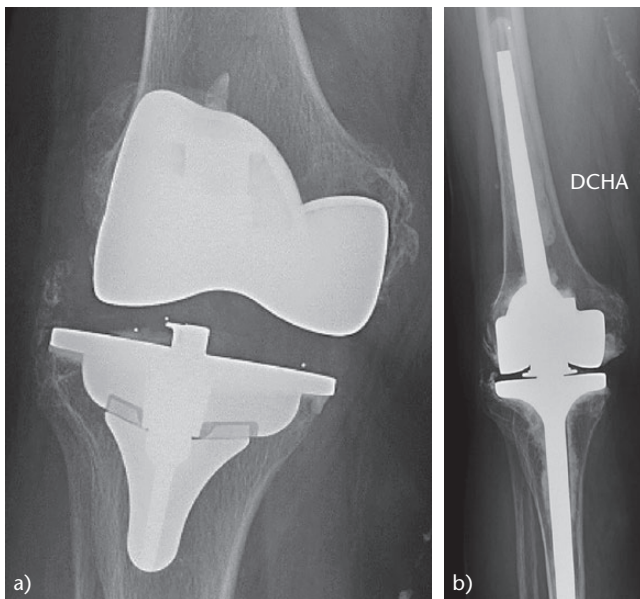


Fig. 2 Rotating hinge knee prosthesis (Endo-Model) in a revision TKA due to severe instability and ligamentous insufficiency of the primary TKA in an 82-year-old woman. (a) Pre-operative anteroposterior (AP) radiograph showing subluxation of the primary TKA; (b) AP radiograph 5 years after the procedure. The result was good.

patients were followed up clinically, radiologically and functionally with the Oxford knee score (OKS). The mean follow-up was 72 months (16 to 156). There were no

immediate or early complications. One patient fell and sustained a peri-prosthetic fracture at seven months, needing revision to a longer stem. Radiological evaluation showed satisfactory alignment with no signs of loosening in all cases. Mean OKS improved from 11.6 to 31.5 post-operatively. The rotating hinge SMILES prosthesis was effective at alleviating pain and improving function in patients with poliomyelitis. The prosthesis compensated well for ligamentous insufficiency as well as for any associated osseous deformity.⁴¹

The NexGen rotating hinge knee

In 2012, Bistolfi et al analysed 31 prostheses implanted in 29 patients. The average age of the patients was 73 years.⁴² The average follow-up was 60.3 months (32 to 100). Indications for surgery were aseptic loosening (n = 23), septic loosening (n = 4), tibiofemoral instability (n = 3) and wear (n = 1). The HSS knee score and the Knee Society Roentgenographic Evaluation System were used. Statistical and cumulative survival rate analyses were performed. The HSS knee score results indicated statistically significant improvement; the total score increased from 65.5 pre-operatively to 88.4 post-operatively. Average ROM increased from 90.9° pre-operatively to 114.4° post-operatively. Radiographs showed no peri-prosthetic bone fractures or implant ruptures. Radiolucent lines were found in 20 of 26 patients and were progressive in two patients (both revised). Complications occurred in ten

patients. Rotating hinge knee implants provided acceptable mid-term outcomes for revision knee surgery with ligamentous instability. According to Bistolfi et al, the high rate of failure was more related to the complex surgery and to the status of the patients than to the hinged mechanism.⁴²

In 2012, Rajgopal et al analysed the mid-term results of 46 NexGen rotating hinge prostheses in difficult primary and complex revision situations.⁴³ The mean follow-up was 62 months. This prosthesis produced satisfactory results in difficult revision circumstances associated with major bone loss, instability or peri-prosthetic fracture. The prosthesis also provided satisfactory results in select cases of advanced primary OA.

The EnduRo rotating hinge prosthesis

In 2014, Giurea et al analysed 152 EnduRo rotating hinge prostheses (90 primary arthroplasties, 62 revisions).⁴⁴ Knee Society Score (KSS), Western Ontario and McMaster Osteoarthritis Index (WOMAC), OKS and ROM were evaluated before surgery, three months post-operatively, 12 months post-operatively and annually thereafter. KSS, WOMAC, OKS and ROM showed significant improvements between the pre-operative and the follow-up evaluations. There were 14 complications (9.2%) leading to revision surgery, predominantly peri-prosthetic complications. This study showed excellent clinical results for the EnduRo TKA.

In 2017, Böhler et al analysed 50 patients (24 primary arthroplasties and 26 revisions), with a minimum follow-up of five years.⁴⁵ Clinical and radiographic examinations were performed pre-operatively as well as post-operatively after three and 12 months and yearly thereafter. The KSS, WOMAC, OKS and ROM were used for clinical assessment. KSS, WOMAC, OKS and ROM significantly improved between the pre-operative and the follow-up assessments. The overall survival rate with revision for any reason as an endpoint was 77.9% after five years. The number of complications was higher in the revision group. The EnduRo prosthesis provided highly satisfying clinical and functional outcomes in severe primary and in revision cases. Implant-associated complications were uncommon. However, in revision arthroplasties, the risk of complications was very high, mostly related to previous joint infections and poor soft-tissue quality.⁴⁵

The Noiles rotating hinge knee prosthesis

In 1988, Kester et al evaluated the mechanical failure modalities of the Noiles rotating hinge knee prosthesis.⁴⁸ The study revealed serious design flaws in the Noiles knee prosthesis that, unless corrected, would preclude the use of the implant in either primary or revision knee surgery.

The Finn rotating hinge

In 2000, Westrich et al analysed 24 knees in 21 patients who received a Finn rotating hinge for primary (nine knees) or revision (15 knees) TKA.⁴⁹ The Finn prosthesis at early follow-up (33 months on average) provided excellent pain relief, restoration of walking capacity and stabilization, without evidence of early mechanical failure.

Failures of rotating hinge prostheses

In 2000, Wang and Wang reported two early catastrophic failures of rotating hinge total knee prostheses.⁵⁰ The two prostheses dislocated as a result of mechanical failure of the prosthetic component within five months of initial implantation.

In 2011, Schwarzkopf et al reported two cases of fracture of the tibial metal post in the rotating hinge of a revision TKA.⁵¹

In 2013, Chuang et al reported a case of rotating hinge knee megaprosthesis failure due to breakage of the isolated tibial polyethylene stopper.⁵²

In 2013, Manzano and Scharzkopf reported a case of isolated disengagement of the rotating hinge mechanism due to severe flexion gap imbalance, causing subsequent posterior dislocation of the hinge and anterior knee dislocation in a patient with a history of multiple TKA revisions.⁵³ This case suggested the importance of soft-tissue balancing, appropriate patellar tracking and use of a long cylindrical, minimally tapered rotating stem in hinge arthroplasty to minimize hinge dislocation.

In 2014, Biswas et al reported a case of disengagement of the hinge-post extension in a contemporary rotating hinge knee prosthesis originally implanted during revision surgery for instability and extensor mechanism insufficiency.⁵⁴ According to these authors, design modifications, including more secure locking mechanisms and side-specific implants, could prevent this complication.

In 2018, Sandiford et al reported three cases of catastrophic failure of the stem in rotating hinge revision TKA prostheses.⁵⁵ These authors stated that metaphyseal support needs to be optimized in order to minimize load transfer to the stem and to the junction (and the risk of fracture) if a modular component is used.

Biomechanical studies

In 2003, Ward et al reported a biomechanical analysis on dislocation of rotating hinge TKAs.⁵⁶ The study showed that the shorter the stem and the greater its taper, the greater the instability and laxity at any given amount of articular distraction.

In 2013, Friesenblicher et al evaluated stability of rotating hinge knee prostheses in a biomechanical study.⁵⁷ This

report showed that rotating hinge prostheses with long and cylindrical pegs have the highest stability at any given amount of distraction. Designs with shorter and markedly tapered pegs could become unstable under conditions of mild joint distraction, which must be investigated in future *in vivo* studies.

Comparative studies

In 2012, Friesenbichler reported an *in vivo* testing of knee stability after rotating hinge TKA, comparing two knee systems: LPS (LPS/M.B.T.; DePuy, Warsaw, Indiana) and S-ROM Noiles prostheses (DePuy).⁵⁸ The results for medial and lateral lift-off during flexion and extension in ultrasonography were comparable, whereas the measured distraction of the LPS/M.B.T was lower compared with the S-ROM Noiles prostheses.

In 2013, Smith et al reported a comparison of mechanical and non-mechanical failure rates associated with rotating hinged TKA in non-tumour patients.⁵⁹ A total of 271 hinged TKAs were analysed to determine survivorship and factors affecting survivorship. A median survivorship of 6.9 years was found for the best-case cohort (n = 111) and 4.1 years for the poorest-case group (n = 174). Of the 111 patients, 51 (45.9%) experienced a failure that needed re-operation, with more than half of these (29/51, 56.9%) due to non-mechanical modes of failure. This study suggests that the hinge TKA is well designed and provides acceptable survivorship in healthy patients who do not have non-mechanical complications.⁵⁹

Rotating hinge total knee arthroplasty after osteomyelitis

In 2007, Nishitani et al reported a rotating hinge TKA in an 80-year-old patient with genu recurvatum after osteomyelitis of the distal femur.⁶⁰ Four years later, the patient ambulated painlessly with one cane. He had no extensor lag and his ROM was 0 to 15°.

Miscellaneous

In 1997, Rinta-Kiikka et al analysed 48 (18 kinematic hinge and 30 Link Endo-Model) rotating hinged knee prostheses.⁶¹ The average follow-up was 63 months. In the latest assessment, there were ten patients (20.8%) regarded as having unsatisfactory outcomes and 35 patients (79.2%) having satisfactory outcomes. Some 84% of the patients were subjectively satisfied with the procedure, mostly because of the painless outcome. These authors recommended the rotating hinged prostheses for severely unstable knees pending revision.

In 2008, Joshi and Navarro-Quilis analysed the outcomes of 78 revision TKAs using a rotating hinge device.⁶²

The mean follow-up was 7.8 years. Only patients requiring revision arthroplasty due to aseptic loosening were included. Reasons for revision were malalignment with or without polyethylene wear (n = 47), instability (n = 24), extensor mechanism failure (n = 3) and peri-prosthetic fracture (n = 4). Nineteen patients had complications related to the prosthesis design (mostly minor complications). Fifty-seven patients (73%) had excellent results. These authors stated that for extreme conditions, such as gross instability of the medial collateral ligament, massive bone loss, comminuted fracture and chronic dysfunction of the extensor mechanism, there is a place for hinged revision implant surgery.⁶²

In 2010, Hernández-Vaquero and Sandoval-García reported 26 hinged TKAs (five primary and 21 revisions) in the presence of ligamentous deficiency.⁶³ The mean age of the patients was 77 years; the mean follow-up was 46 months (24 to 107). Three patients needed re-operations: one had a supracondylar peri-prosthetic fracture treated by open reduction and internal fixation, whereas the other two had peri-prosthetic infections. These authors stated that this prosthetic design should be reserved for severe ligamentous deficiencies in elderly and sedentary patients or whenever revision surgery techniques fail.

In 2012, Massin et al reported six cases of removal of infected cemented hinge knee prostheses using extended femoral and tibial osteotomies.⁶⁴ This procedure facilitated the removal of infected cemented components and of the cement mantle, mainly in the absence of loosening, without compromising re-implantation of a new knee prosthesis.

In 2014, Kowalzewski et al analysed 12 primary knee replacements using a rotating hinge knee prosthesis.⁶⁵ The minimum follow-up was ten years. Indications for the procedure included gross joint destruction, significant axial deformities and contracture with a dysfunctional medial collateral ligament in all cases. Three patients required marginal wound excision with resuturing, which thereafter healed uneventfully. These authors concluded that the rotating hinge knee prosthesis can be used as a salvage implant in patients with medial collateral ligament deficiency, contracture and gross joint destruction.

In 2015, Farid et al analysed 142 single third-generation design, rotating hinge prostheses (11 primary arthroplasties and 131 revisions).⁶⁶ The mean follow-up was 57 months. Prosthetic survival was 73%. Successful two-stage re-implantation for prosthetic infection was 78.4%; however, the subsequent infection rate was 22%.

In 2017, Cottino et al reported the long-term results after TKA with 349 contemporary rotating hinge prostheses.⁶⁷ At a mean of four years, loosening of components was found in 13 (3.7%). At the most recent follow-up, 59 revision procedures and 25 re-operations had been

performed. The cumulative incidence of any revision was 9.7% at two years and 22.5% at ten years. The cumulative incidence of revision for aseptic loosening was 1.7% at two years and 4.5% at ten years. Metaphyseal cones were used in 114 knees (28%). Survivorship analysis showed a trend toward a lower risk of revision and re-operation in patients with metaphyseal cones, despite their use in the most severe of bone defects.

In 2018, Kearns et al studied 79 knees in 76 patients (16 men and 60 women) who underwent implantation of a rotating hinge knee of a single design for either a complex primary (14 knees) or revision TKA (65 knees).⁶⁸ The mean age of the patients was 66.7 years (39 to 89). The study included 19% undergoing a rotating hinge knee implantation for peri-prosthetic joint infection and 32.9% who had concomitant extensor mechanism repair. At a minimum of two years, 13 patients had died and four were lost to follow-up, leaving 62 knees in 59 patients who were followed for a mean of 55.2 months (24 to 146). The rate of complications was 38.7%. The most common complications were peri-prosthetic fracture, extensor mechanism rupture and peri-prosthetic infection. Estimated survival was 70.7% at five years. These authors stated that despite improvements in design and biomaterials, there remains a relatively high complication rate associated with the use of a modern rotating hinge knee implant.⁶⁸

In 2018, Boelch et al analysed 51 revision TKAs with rotating hinge systems (26 Link Endo-Model and 25 EnduRo) in patients with gross ligament instability.⁶⁹ At 12-months follow-up, both prosthetic designs provided significant improvement in pain and function scores after TKA revision for gross instability. Two patients (8%) in the EnduRo group and one patient (3.8%) in the Endo-Model group had to be revised for infection. These authors found slight advantages in favour of the Endo-Model; however, no design yielded superior results throughout the study.

Conclusions

A recent review of the literature has shown that rotating hinge knee implants have good survivorship, in the range of 51% to 92.5% at ten years post-operatively. Complication rates are in the range of 9.2% to 63%, with infection and aseptic loosening as the most ordinary complications. Rotating hinge knee prostheses are most usually indicated for infection, aseptic loosening, instability and bone loss. They have good outcome scores and survivorship, but still have high complication and revision rates. The implant is a good alternative when used properly for patients who are not candidates for less constrained implants.

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