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KNEE ARTHROPLASTY

Comparison of traditional PS versus kinematically designs in primary total knee arthroplasty

Ittai Shichman[1] · Christian T. Oakley[1] · Jeremiah Thomas[1] · Ivan Fernandez-Madrid[1] · Morteza Meftah[1] · Ran Schwarzkopf[1]

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Abstract

Purpose Kinematically designed total knee arthroplasty (TKA) aims to restore normal kinematics by replicating the function of both cruciate ligaments. Traditional posterior-stabilized (PS) TKA designs, on the other hand, simplify knee kinematics and may improve TKA cost-effectiveness. The purpose of this study was to compare outcomes of patients who underwent primary TKA using either a traditional PS or kinematically designed TKA.

Methods This retrospective study examined all patients who underwent primary TKA using either a kinematically or a traditional PS designed TKA implant, with a minimum follow-up of 2 years. Patient demographics, complications, readmissions, revision rates and causes, range of motion (ROM) and patient reported outcomes (KOOS, JR) were compared between groups. Kaplan–Meier survivorship analysis was performed to estimate freedom from revision, and multivariate regression was performed to control for confounding variables.

Results A total of 396 TKAs [173 (43.7%) with a kinematic design, 223 (56.3%) with a traditional design] with a mean follow-up of 3.48 ± 1.51 years underwent analysis. Revision rates did not differ between groups (9.8% vs. 6.7%, $p = 0.418$). In Kaplan–Meier analysis at 2-year follow-up, freedom from all-cause revision (96.4% vs. 93.1%, $p = 0.139$) were similar between groups. The two cohorts had no significant difference in aseptic loosening at 2 years (99.6% vs. 97.1, $p = 0.050$) and at latest follow up (92.7% vs. 96.4%, $p = 0.279$). KOOS, JR scores and post-operative ROM were similar between groups.

Conclusion This study demonstrated similar mid-term outcomes following the use of both a kinematically designed and a traditionally designed implant in primary TKA patients.

Level of evidence Retrospective study—III.

Keywords Total knee arthroplasty · Traditional · Posterior stabilized · Outcomes · Complications · Revision

Introduction

Total knee arthroplasty (TKA) is generally accepted as the definitive treatment for advanced knee arthritis after patients fail non-operative treatments [1]. Although surgical techniques and implant designs have improved, as evidenced by excellent survivorship and long-term results, no more than 80–55% of patients feel satisfied after undergoing TKA [2–5]. Recent changes in component geometry and modularity in posterior-stabilized (PS) designs have led to improved short- and long-term results [6–8] and permitted greater surgical flexibility in balancing during severe osteoarthritis cases with instability [9].

The femoral component of most TKA implant systems has a multi-radius sagittal profile mimicking the geometry of the normal distal femur, which was thought to have a changing center of rotation during knee flexion [10]. Nevertheless, symmetric posterior condyle designs have been shown to provide the same kinematic motion and articulation as asymmetric femoral component designs [11]. Kinematically designed TKA implants intended to improve knee kinematics by more closely approximating a normal knee through an assortment of different characteristics such as an asymmetric femoral component, and a relatively concave medial and slightly convex lateral tibial polyethylene insert with different thickness on the medial and lateral sides, replicating constitutional tibial varus. The function of both the

✉ Ittai Shichman
Ittai.Shichman@nyulangone.org

[1] Department of Orthopedic Surgery, NYU Langone Health, 301 East 17th Street, New York, NY 10003, USA

ACL and PCL may be replicated by a post-cam mechanism that engages posteriorly and anteriorly [12, 13]. The goal of these knee systems is to provide "guided motion" that facilitates kinematics that align more closely with the native knee [14]. Despite several studies demonstrating close to normal kinematic motion with kinematic designed TKAs, their kinematic profile still differs from the native knee [15, 16].

As opposed to the kinematically designed implant systems, the traditional designed implant systems have a symmetrical distal and posterior condyle design [17]. The traditional designs were introduced to facilitate a simplified surgical approach with improved cost-effectiveness. As implant designs become more advanced and diverse, selecting the ideal implant design to achieve better patient outcomes is becoming more challenging. Given this, the purpose of this study was to compare clinical outcomes and implant survivorship in patients who underwent primary TKA with either a traditional PS or kinematically designed TKA implant at a minimum of 2-year follow-up. We hypothesize that patient clinical outcomes would not differ between the two implant types.

Materials and methods

This retrospective study examined all patients over the age of 18 who underwent primary TKA with a kinematical or traditional PS design TKA implant between March 2015 and September 2019 at a single urban institution, which comprises a large academic medical center and a tertiary orthopedic specialty hospital. Patients were separated into two cohorts based on the utilized implant design: Journey II Bi-Cruciate Stabilized TKA System (Journey II system, Smith & Nephew, Memphis, TN) were included in the kinematically designed implant group and Legion PS (Legion Total Knee System, Smith & Nephew, Memphis, TN) in the traditional group. Overall, a total of 862 TKAs were performed at our institution during this study period using kinematic or symmetric designs. All TKAs performed for oncologic reasons or with less than 2-year postoperative follow-up were excluded from this analysis. Ultimately, 466 (54.0%) patients were excluded, yielding 396 (46.0%) patients. Of these, 173 (43.7%) underwent TKA with kinematic design and 223 (56.3%) underwent TKA with traditional PS articulation. Patient records and data were de-identified as part of our institutional quality improvement program; however, human-subjects review by our Institutional Review Board (IRB) was obtained prior to this study.

Data collection

Patient demographic data including age, gender, race, body mass index (BMI; kg/m^2), American Society of Anesthesiology (ASA) classification, and smoking status were collected. In addition, clinical data including length of stay (LOS; days), surgical time (minutes), discharge disposition, 90-day readmission, and all-cause revisions were collected from our electronic patient medical record system, Epic (Epic Caboodle. version 15; Verona, WI) using Microsoft SQL Server Management Studio 2017 (Redmond, WA). Characteristics of revision TKA (rTKA) including indication for revision and revised components were gathered from review of operative reports.

LOS was evaluated in days spent in the hospital following surgery, and surgical time was calculated as the time difference between initial skin incision and skin closure. Revision was defined as any procedure requiring return to the operating theatre that was related to the ipsilateral knee and required a change of implants. The categories for discharge disposition included discharge home with either self-care or home health services, discharge to a skilled nursing facility, or discharge to an acute rehabilitation center. Readmissions within 90-days and all re-revisions were dichotomized as yes/no.

All patients were followed postoperatively at various time points, including 2 weeks, 6 weeks, 3 months, 6 months, 1-year and 2-year post-operatively. Knee range of motion was evaluated by the operating surgeons and reported from the preoperative and at latest follow-up office visit.

Outcome measures

The primary outcomes included the freedom from all-cause re-revision, freedom from aseptic revision, and freedom from aseptic loosening. The secondary outcomes included perioperative data, such as surgical time, LOS, discharge disposition, 90-day readmission, incidence of revision due to periprosthetic joint infection (PJI), instability or dislocation, periprosthetic fracture, arthrofibrosis, revision of the femoral, insert, tibial, and patellar components, pre- and post-operative patient ROM, patient-reported outcomes (PROS) measured by the Knee Injury Osteoarthritis Survey (KOOS, JR) and other postoperative adverse events.

Statistical analysis

All data were organized and collected using Microsoft Excel software (Microsoft Corporation, Richmond, WA). A binary variable was created to identify patients who underwent TKA with traditional or kinematically designed implants. Demographic and clinical baseline characteristics of study participants were described as means with standard deviations (SD) for continuous variables and frequencies with percentages for categorical variables. Statistical differences in continuous and categorical variables were detected using independent sample *t* test and chi-squared (χ^2) tests, respectively.

Survivorship was analyzed and presented graphically using the Kaplan–Meier method. Outcomes and survivorship data were calculated using time of latest follow-up. Patients who died with the implant in situ and patients lost to follow-up were considered censored at the date of death and last follow-up, respectively. Multivariate binary logistic regressions were performed to control for potential confounding demographic variables. These regression models were used to compare our primary outcomes measures between the two cohorts. A *p* value of less than 0.05 was considered to be significant. All statistical analyses were performed using SPSS v25 (IBM Corporation, Armonk, New York).

Results

At baseline, patients in the traditional implant group had higher proportions of male patients (49.8% vs. 37.0%, $p=0.011$), were slightly older (62.3 ± 8.8 vs. 65.6 ± 8.9 years, $p<0.001$), higher proportions of white race (67.7% vs. 48.0, $p<0.001$), higher ASA scores ($p=0.018$) and higher proportions of former and current smoking status ($p=0.002$) (Table 1). Operative time did not differ significantly between the groups, and hospital LOS (2.56 ± 1.09 days vs. 2.9 ± 1.41 days, $p=0.015$) was lower in the kinematic implant group. For discharge disposition patients in the traditional cohort were less likely to be discharged home (79.8% vs. 90.8%, $p=0.004$) and more likely to be discharged to a skilled nursing facility (17.5% vs. 7.5%, $p=0.007$) (Table 2). The incidence of readmissions did not significantly differ between groups ($p=0.196$). In the kinematic implant group, 5 (2.9%) patients were readmitted within 90 days of the operation (one acute PJI, one aseptic wound dehiscence, one for pain from spinal stenosis, one for DVT and 1 UTI). In the symmetric group, 15 (6.7%) patients were readmitted within 90 days (five acute PJI, three aseptic wound dehiscence, one deep vein thrombosis, two cellulitis, one anemia, one acute renal failure, one hypokalemia and one pericardial effusion).

At mean follow-up of 3.48 ± 1.51 years, freedom from all-cause revision was similar for both groups (96.4% vs. 93.1%, $p=0.418$). Seventeen (9.8%) patients in the kinematic implant group required revisions (six for aseptic loosening, five for PJI, one for instability, three for arthrofibrosis, and two for extensor mechanism disruption). Fifteen (6.7%) traditional patients required revisions (six for aseptic loosening, five for PJI, three for arthrofibrosis and one for Nickel metal allergy). From preoperative to latest follow-up, improvements in ROM and delta ROM change did not significantly differ between groups. KOOS, JR scores improved significantly from baseline to 3 months and 1-year post operatively. No significant changes in 1-year KOOS, JR score were found between groups (Table 2).

In Kaplan–Meier survivorship analysis, patients with traditional and kinematically designed implants had similar freedom from all-cause revision at 2-year (96.4% vs. 93.1%, $p=0.139$) and at latest follow-up (87.4% vs. 88.1%, $p=0.099$) (Fig. 1). Freedom from revision due to a aseptic indications at

Table 1 Demographic characteristics of included patients

	Kinematic ($n=173$)	Traditional ($n=223$)	*p* value
Male—no. (%)	64 (37.0)	111 (49.8)	0.011
Age (years)	62.3 ± 8.8	66.6 ± 8.9	< 0.001
BMI (kg/m^2)	33.0 ± 6.6	32.1 ± 6.1	0.169
Race—no. (%)			< 0.001*
White	83 (48.0)	151 (67.7)	
African American	44 (25.4)	43 (19.3)	
Asian	10 (5.8)	2 (0.9)	
Other	36 (20.8)	27 (12.1)	
ASA—no. (%)			0.018
1	7 (4.0)	1 (0.5)	
2	93 (53.8)	108 (48.6)	
3	72 (41.6)	107 (48.2)	
4	1 (0.6)	6 (2.7)	
Smoking status			0.002
Never smoker	113 (65.3)	113 (50.7)	
Former smoker	44 (25.4)	94 (42.2)	
Current smoker	16 (9.2)	16 (7.2)	

ASA American Society of Anesthesiologists, *BMI* body mass index, *kg* kilogram, *m* meter, *no*. number

*$p<0.05$

Table 2 Clinical outcomes of included patients

	Kinematic ($n=173$)	Traditional ($n=223$)	p value
Operative time (minutes)	101.3 ± 27.1	96.8 ± 31.6	0.577
LOS (days)	2.56 ± 1.09	2.90 ± 1.41	0.015
Discharge disposition			0.010
Home	157 (90.8)	178 (79.8)	0.004
Skilled nursing facility	13 (7.5)	29 (17.5)	0.007
Acute care center	3 (1.7)	6 (2.7)	0.174
90-day readmission—no. (%)	5 (2.9)	15 (6.7)	0.196
Revision—no. (%)	17 (9.8)	15 (6.7)	0.418
Aseptic revision—no. (%)	12 (6.9)	10 (4.5)	0.467
Reasons for revision—no. (%)			0.565
Aseptic loosening	6 (3.5)	6 (2.7)	0.623
PJI	5 (2.9)	5 (2.2)	0.760
Instability/dislocation	1 (0.6)	0 (0.0)	1.000-
Arthrofibrosis	3 (1.7)	3 (1.3)	0.896
Extensor mechanism disruption	2 (1.2)	0 (0.0)	0.994
Nickel metal allergy	0 (0.0)	1 (0.4)	0.983
KOOS, JR[a]			
Preop	43.5 ± 12.2	46.4 ± 16.4	0.430
3 month	64.3 ± 16.4	69.2 ± 14.1	0.328
Delta change from Preop	20.9 ± 16.9	20.2 ± 17.6	0.201
1 year	71.8 ± 14.4	73.1 ± 12.1	0.088
Delta change from Preop	26.2 ± 16.7	24.0 ± 15.4	0.052
ROM[a]			
Preop	110.2 ± 13.7	107.6 ± 14.1	0.145
Postop[b]	113.8 ± 11.6	113.8 ± 16.8	0.612
Delta change	3.2 ± 15.4	6.0 ± 18.2	0.196

KOOS, JR Knee Injury and Osteoarthritis Outcome Score for Joint Replacement, *LOS* length of stay, *no.* number, *PJI*, periprosthetic joint infection, *Preop* preoperative, *Postop* postoperative

[a]Multivariate regression was performed to control for potentially confounding demographic variables

[b]Postoperative measurements were recorded at the latest follow-up

*$p < 0.05$

2 years was higher for the traditional group, however, at latest follow-up, freedom from revisions due to aseptic indications was similar (90.7% vs. 92.9%, $p = 0.129$) (Fig. 2). Notably, both cohorts had similar survivorship from revision due to aseptic loosening at 2-years (99.6% vs. 97.1%, $p = 0.050$), and at latest follow-up (92.7% vs. 96.4%, $p = 0.279$) (Fig. 3). In multivariate binary logistic regression, current smoking status was significantly associated with risk for all-cause revision [3.09 (1.00–9.51), $p = 0.0495$]. There were no significant associations between other baseline characteristics and all-cause revision, aseptic revision, and revision due to aseptic loosening (Table 3).

Discussion

This study's most important findings are that both traditional and kinematically designed implants confer excellent outcomes, both patient cohorts had similar clinical outcomes and implant survivorship.

The kinematically designed implant system assessed in this study is a second-generation BCS total knee system [12]. While many surgeons noted good results with the first-generation system, more recent studies have observed superior results in the second-generation design assessed

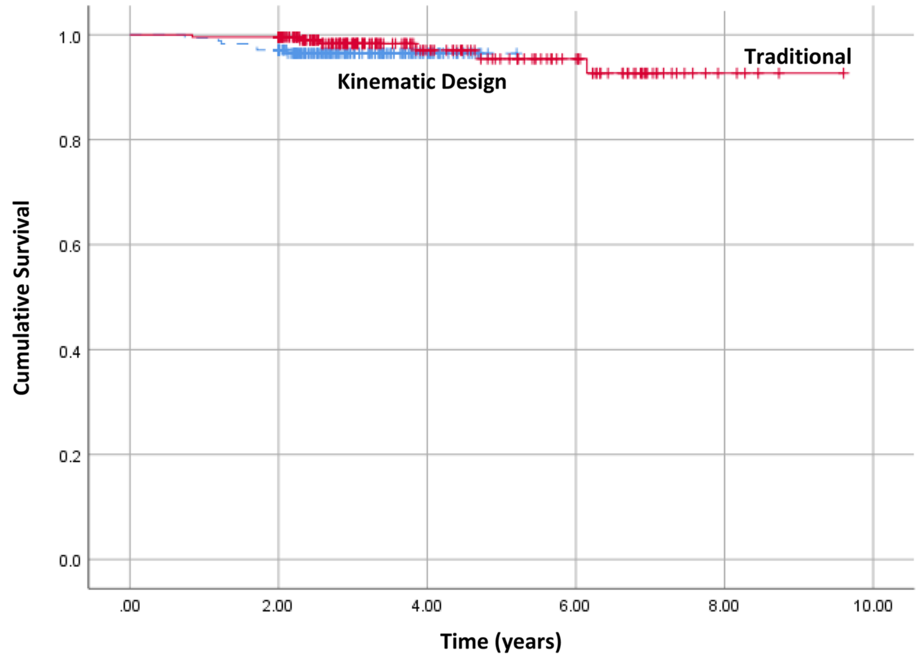

Fig. 1 Kaplan–Meier survivorship analysis for freedom from all-cause revision. 2-year: Traditional: 96.4%, Kinematic: 93.1%, $p = 0.139$. Latest follow-up: traditional: 87.4%, kinematic: 88.1%, $p = 0.099$

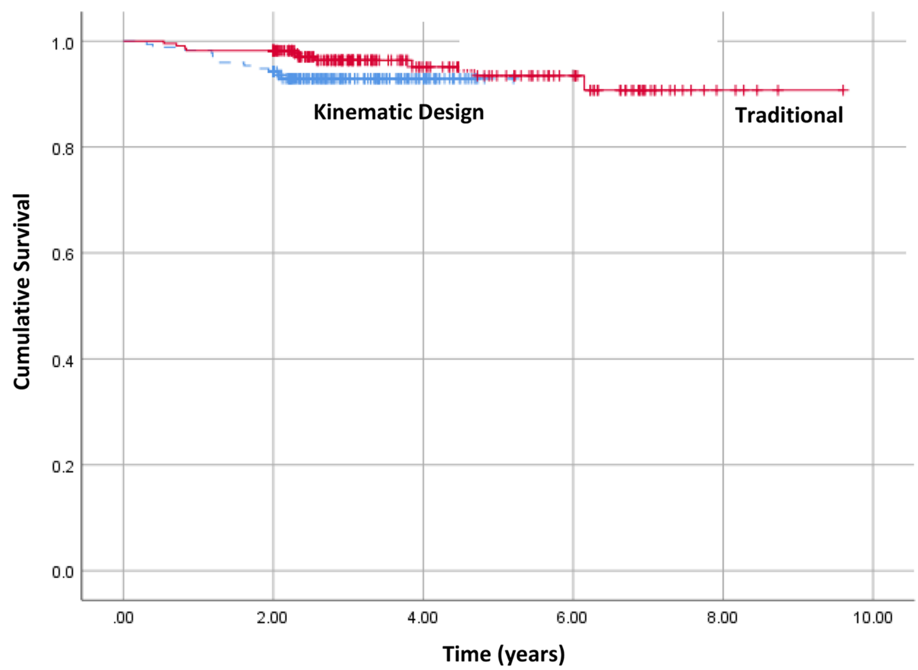

Fig. 2 Kaplan–Meier survivorship analysis for freedom from revision due to aseptic indications. 2-year: traditional: 98.2%, kinematic: 94.2%, $p = 0.034$*. Latest follow-up: traditional: 90.7%, kinematic: 92.9%, $p = 0.129$

in our study [18, 19]. In a cohort of 140 TKAs, Christen et al. found the second-generation design to be associated with a five times lower risk of reoperation and revision compared to the first-generation device (2.1% vs. 10.3%) [12]. Additionally, in the largest multi-center cohort examining 2059 primary TKAs using the second-generation system, Harris et al. demonstrated an all-cause revision rate of 3.2% at a median follow-up time of 4.2 years, of which 33% were due to PJI and 21% of revisions were due to aseptic loosening [20]. Our cohort demonstrated similar distributing of revision indications. Importantly, the study by Harris et al. presented the overall incidence of revision due to aseptic loosening and not freedom from revision due to aseptic loosening as calculated by Kaplan–Meier analysis. While evidence on aseptic loosening of kinematic TKA designs is scarce, our kinematic cohort freedom from aseptic loosening at mean follow-up of 3.48 years was consistent with modern TKA PS designs [12, 20–22].

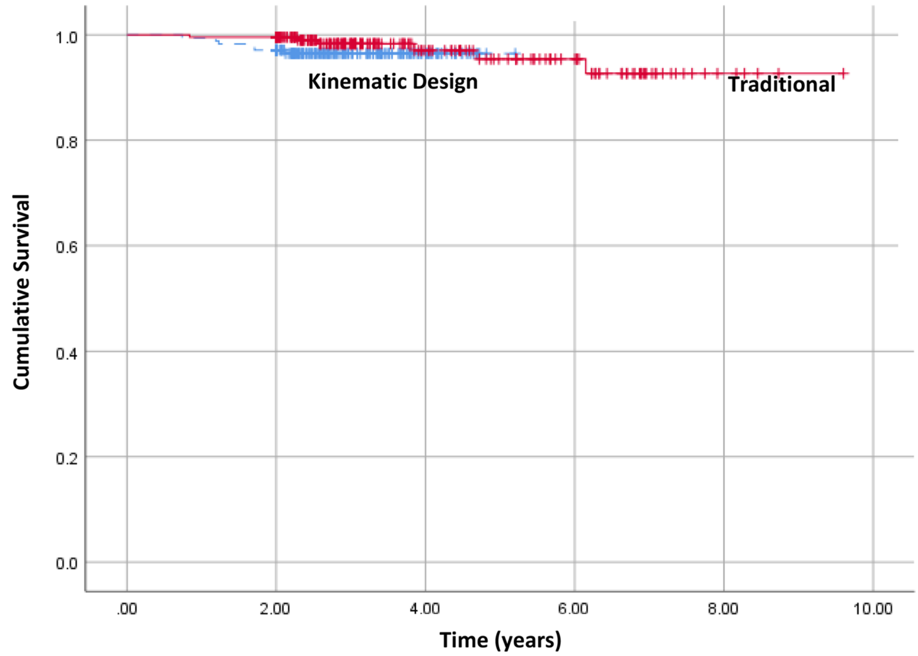

Fig. 3 Kaplan–Meier survivorship analysis for freedom from revision due to aseptic loosening. 2-year: Traditional: 99.6%, kinematic: 97.1%, p =0.049*. Latest follow-up: traditional: 92.7%, kinematic: 96.4%, $p = 0.279$

Table 3 Binary logistic regression analysis for baseline characteristics associated with revision rates in patients (values reported as unstandardized beta [95% confidence interval])

	All-cause revision	*p* value	Aseptic revision	*p* value	Revision due to Aseptic loosening	*p* value
Traditional (vs. kinematic)	0.71 (0.31–1.62)	0.418	0.70 (0.26–1.84)	0.467	0.72 (0.19–2.73)	0.62
Male (vs. female)	1.47 (0.64–3.38)	0.368	1.30 (0.49–3.42)	0.597	2.00 (0.50–7.97)	0.326
Age (per one year increase)	0.97 (0.92–1.01)	0.162	0.95 (0.90–1.00)	0.050	0.98 (0.91–1.06)	0.649
BMI	1.01 (0.94–1.07)	0.878	0.98 (0.91–1.06)	0.645	1.05 (0.95–1.16)	0.378
Race						
White	–	–	–	–	–	–
African American	2.00 (0.75–5.32)	0.165	1.74 (0.55–5.58)	0.349	3.23 (0.65–16.00)	0.151
Asian	1.36 (0.15–12.18)	0.782	1.64 (0.18–15.38)	0.664	5.87 (0.50–68.94)	0.159
Other	1.53 (0.52–4.47)	0.441	2.05 (0.63–6.72)	0.234	2.29 (0.38–13.92)	0.368
ASA classification	1.25 (0.61–2.56)	0.545	1.18 (0.50–2.78)	0.705	1.46 (0.44–4.82)	0.540
Smoking status						
Never smoker	–	–	–	–	–	–
Former smoker	1.43 (0.60–3.44)	0.420	1.81 (0.69–4.72)	0.227	3.05 (0.81–11.41)	0.098
Current smoker	3.09 (1.00–9.51)	0.0495	0.47 (0.06–4.08)	0.495	–	–

ASA American Society of Anesthesiologists, *BMI* body mass index

The traditional TKA system, on the other hand, is based on a first generation PS system which has been commonly used for the last two decades [23]. In an analysis of 469 TKAs with long-term follow using this system, McCalden et al. presented an excellent all-cause survival rate of 96.4% at a follow-up time of 15 years [24]. In a more recent cohort including 2815 TKAs using two symmetric posterior condylar designs with posterior stabilized inserts (Genesis II and Legion, Smith & Nephew, Memphis, TN), Demcoe et al. found all-cause implant survivorship rates of 98.2% at 2 years [25]. Our traditional design cohort showed similar results with a 96.4% freedom from all-cause revision rate at the same follow-up time. Importantly, this current study we present novel evidence on the freedom from aseptic loosening rates of this implant design. Interestingly, the traditional group had superior freedom from aseptic loosening at 2-year follow up, however, similar freedom from aseptic loosening was observed between groups at latest follow-up.

These findings suggests that this two modern designs have similar mid-term clinical outcomes. The traditional cohort patients were slightly older, had slight worse ASA scores which might explain longer length of stay for this group.

There is paucity of literature comparing different kinematic implant designs. In a clinical and fluoroscopic study, Digennaro et al. reported that the studies kinematic designed knee (Journey II BCS, Smith & Nephew, Memphis, TN) showed statistically significant better ROM compared to fixed radius PS design TKA [Scorpio NRG (Stryker) system)] [15]. They hypothesized that the increased ROM could be due to guided kinematic patterns that favor posterior femoral rollback and possibly produce better patellofemoral kinematics, leading to improved KOOS scores reported in the Kinematic group. These results were reproduced in a similar study by Mugnai et al., suggesting that the bearing geometry and kinematic pattern of guided-motion prosthetic designs can affect the functional outcomes and complication types of primary TKA cases [26].

Numerous studies have examined the kinematics of knees implanted with a kinematic bearing [27–29]. Van Duren et al. performed a fluoroscopic kinematical comparison of ten kinematic knees to native knees [16]. The study found that the kinematic implants showed no paradoxical anterior movement and sufficient posterior femoral roll back, which engaged the anterior and posterior cam-post mechanisms. Additionally, the patella tendon angle/knee flexion angle and patella flexion angle/knee flexion angle kinematic profiles observed for the kinematic group aligned more with that of native knees compared to other TKA implant designs [16]. Kiyohara et al. performed an in-vivo comparison of cruciate-retaining, PS, and BCS implants and found that the BCS designs achieved significantly greater posterior femoral rollback and axial rotation than the other implants [30]. However, this study included kinematics analysis alone with no clinical reported outcomes. In an in-vivo study comparing the kinematic knee design to a PS design, Murakami et al. reported that physiological knee kinematics, including double knee action and stable tibiofemoral AP translation, were associated with the kinematic design, with a higher frequency of posterior cam-post contact than for the PS design. This study concluded that design evolution and variability, including asymmetrical articular geometry directly influenced the knee kinematics during gait, however patient reported outcomes measured by the Knee Society Scores were similar between both groups [31].

Literature comparing a kinematically designed and traditional implant systems are scarce. In a randomized comparison between the kinematic and a traditional first-generation design, Ward et al. found superior kinematic restoration of both designs compared to former studies that examined similar older implants design [32]. Additionally, the kinematic implant group had a greater patellar tendon angle in full extension, suggesting partial restoration of the role of the ACL. However, patient reported outcomes were similar in both groups. In agreement with this study, no differences were found in 1-year post-operative patient reported outcomes scores measured by KOOS, JR which in line with previously reported data on PS implant designs [33]. Lastly, in an in-vivo fluoroscopic kinematic study demonstrated improved post-operative ROM to 109 degrees for knees implanted by the kinematic system [16]. These were conferred with the reports of Catani et al. who reported a post-operative passive ROM of 118 ± 11.3 degrees in a cohort of 16 kinematic knees. On the other hand, Laskin et al. reported a mean maximum knee flexion of 113 degrees in a cohort of 100 knees implanted with a first generation traditional knee design [34]. In the largest study to date examining ROM in both kinematic and traditional designs, we found similar post-operative improvements in ROM across both groups, which support the findings of the above-mentioned studies. Lastly, the increased incidence of surgical complications such as revisions is well established in the literature [35, 36]. Lim and colleagues have found that smokers are at increased risk of earlier revision TKA when compared to non-smokers and ex-smokers [37]. Additionally, in a recent systematic review, He et al. concluded that smoking was associated with higher revisions post TKA [38]. Similarly, this study demonstrated that current smoking status was associated with threefold increased risk of all-cause revision. These results highlight the need for clinicians to encourage smoker patients to quit smoking prior to primary TKA.

Limitations

This study was retrospective, and therefore, selection bias and the possibility of errors in recorded data cannot be controlled for. Furthermore, although both cohorts demonstrated statistically similar demographic characteristics, indication for primary TKA was not collected and may have influenced our results. Importantly, a large percentage of the patients that met inclusion criteria was not included for not meeting a minimum 2-year follow up. This is secondary to the fact that our institute is a large referral center. Patients seeking surgical care may in times reside far away. This may limit the ability to complete long term follow up especially for uncomplicated postoperative course. Moreover, although one design may confer superior survival in the long-term, our study was underpowered to adequately assess differences between constructs, as the incidence of events for the primary outcomes was lower than estimated during the study period. Therefore, it cannot be ruled out that one design may confer superior long term survival. Additionally, while this study comprises the largest cohort comparing kinematic and traditional TKA designs, the mean follow-up time of our investigation is limited. Our analysis also may not have captured all revisions performed at outside institutions. While this raises the possibility that we underestimated the true revision rate, this study our findings are in line with previous studies, so missed cases likely did not alter our findings.

Conclusion

The traditional and kinematic designs confer similar mid-term implant survival rates and overall knee ROM, patient reported outcomes and complications. Future studies with longer follow-up are warranted to better define which design yields superior clinical outcomes in primary TKA.

Author contributions All authors contributed to the study conception and design. Conceptualization was performed by RS and MM. Material preparation, data collection and analysis were performed by IS and JT. All statistical analysis was performed by Christian Oakley. Data validation was performed by IFD. The first draft of the manuscript was written by IS and CO Ittai and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

Declarations

Conflict of interest The authors declare that no funds, grants, or other support were received during the preparation of this manuscript. I.S, C.O, J.T, I.VM have nothing to disclose. M.M. reports being a paid consultant for Conformis and Intelijoint, have stock options from Caira surgical and Constance and received royalties from Innomed. Zimmer and R.S reports IP royalties from Smith & Nephew, being paid consultant for Smith & Nephew, Intelijoint, have stock options from Intelijoint, Gauss Surgical and receives research support from Smith & Nephew and Intelijoint.

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