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Clinical Outcomes of Offset Stem Couplers with or without Cone Augmentation in Revision Total Knee Arthroplasty

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Abstract

Intramedullary stems are often required in patients undergoing revision total knee arthroplasty (rTKA) to achieve stable fixation. Significant bone loss may require the addition of a metal cone to maximize fixation and osteointegration. The purpose of this study was to investigate clinical outcomes in rTKA using different fixation techniques. We conducted a single-institution retrospective review of all patients who received a tibial and femoral stem during rTKA between August 2011 and July 2021. Patients were separated into three cohorts based on fixation construct: press-fit stem with an offset coupler (OS), fully cemented straight (CS) stem, and press-fit straight (PFS) stem. A subanalysis of patients who received tibial cone augmentation was also conducted. A total of 358 patients who underwent rTKA were included in this study, of which 102 (28.5%) had a minimum 2-year follow-up and 25 (7.0%) had a minimum 5-year follow-up. In the primary analysis, 194 patients were included in the OS cohort, 72 in the CS cohort, and 92 in the PFS cohort. When stem type alone was considered, there was no significant difference in rerevision rate ($p = 0.431$) between cohorts. Subanalysis of patients who received augmentation with a tibial cone demonstrated that OS implants led to significantly higher rates of rerevision compared with the other two stem types (OS: 18.2% vs. CS: 2.1% vs. PFS: 11.1%; $p = 0.037$). The findings of the present analysis demonstrate that CS and cones in rTKA may provide more reliable long-term outcomes compared with press-fit stems with OS.

Level III Evidence Retrospective Cohort Study.

Keywords
- ► offset stem
- ► cemented straight stem
- ► press-fit stem
- ► cone
- ► revision total knee arthroplasty
- ► outcomes

Total knee arthroplasty (TKA) is one of the most commonly performed procedures in the United States.[1] As the number of primary cases continue to rise, the rates of revision have similarly trended upward.[2,3] Although multiple revision implant systems have been developed, revision TKA (rTKA) portends some unique problems that are less frequently encountered during primary TKA.[4] As a result, several challenges remain in the management of rTKA.

In the revision setting, significant bone loss can make implant fixation difficult.[5,6] To optimize patient outcomes and limit the risk of reoperation, stable fixation during rTKA is paramount. As a result, surgeons often rely upon various implant constructs, including intramedullary stems and cones.[7] Biomechanical studies have shown that stem use increases mechanical stability by transferring load over a larger area and reducing strain at the bone-component

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interface.[8–10] This limits implant lift off and micromotion at the bone implant interface to maximize joint stability and surgical outcomes.[11] Indications for the use of stems during rTKA also include bone stock that is insufficient to support the primary implant alone.[12] When supplemented with a metal cone, maximal osteointegration can be achieved.[13]

The type of stem fixation technique during rTKA remains largely surgeon dependent, as support exists for both the cemented and press-fit hybrid technique.[14] Most of the current research offers equivocal results when comparing the different fixation methods. A recent study by Kemker et al examined outcomes of 133 rTKA for 122 patients, with 40 cemented and 93 hybrid model implants. Follow-up ranged from 2 to 114 months with an average follow-up of 25 months, and the researchers found no significant difference in outcomes between cemented and hybrid stems.[15] Similar results were reported in a meta-analysis by Wang et al that explored outcomes from 17 studies.[7] While some literature exists demonstrating superior anatomic alignment with offset stem use compared with straight stems, there has been no data supporting differences in patient outcomes between fixation methods.[16,17] Furthermore, very little research has compared the peri- and postoperative outcomes of the various fixation techniques with and without cone augmentation. As a result, this study sought to determine differences in operative outcomes based on rTKA fixation technique.

Methods

Study Design

We conducted a single-institution retrospective review of all patients who underwent rTKA with both a tibial and femoral stem between August 2011 and July 2021. Three-hundred fifty-eight patients and 29 surgeons were included in the study. All surgeries were performed at an urban, academic, tertiary orthopaedic hospital. Institutional review board approval was obtained prior to this analysis. Two-hundred seventy-nine patients underwent rTKA due to aseptic failure and 79 patients required revision due to infection. Patients were separated into three cohorts based on fixation construct: press-fit stem with an offset coupler (OS) ($n = 194$), fully cemented straight (CS) stem ($n = 72$), and press-fit straight (PFS) stem ($n = 92$). A subanalysis of patients who received both a tibial and femoral stem and tibial cone augmentation was also conducted. Choice of fixation was based on surgeon preference. All patients participated in our institutional-wide comprehensive total joint pathway program, which involves uniform protocols for perioperative care including venous thromboembolism (VTE) prophylaxis and infection prevention. In addition, all patients received a standard institutional postoperative rehabilitation protocol, as well as a standard postoperative pain protocol.

Data Collection

We collected patient demographic data including sex, age, smoking status, race, body mass index (BMI), and Charlson Comorbidity Index (CCI) using our institution's electronic medical record system (Epic Caboodle. version 15; Verona, WI) running on Microsoft SQL Server Management Studio 2017 (Redmond, WA). Information on stem, OS, and cone usage was also collected. Perioperative data such as surgical time (minutes), length of stay (LOS, days), discharge disposition, readmission rates, and revision rates were also evaluated. Surgical time was derived from calculating the time difference between the initial skin incision and the completion of skin closure. LOS was calculated by taking the difference in time between the admission date and discharge date.

Statistical Analysis

To confirm our study was adequately powered, a post hoc power analysis ($\alpha = 0.05$; power = 80%) was performed using G*Power, v3 (Erdfelder, Faul, & Buchner, Germany).[18] Baseline characteristics between cohorts were assessed using descriptive statistics. Statistical differences in numeric, continuous variables were detected using analysis of variance, whereas chi-squared ($\chi 2$) test was utilized for categorical variables. Values were considered statistically significant if the p-value was less than 0.05. All statistical analyses were performed using SPSS v25 (IBM Corporation, Armonk, New York).

Results

Patient Population

A total of 358 patients who received both a tibial and femoral stem during rTKA were identified. Of these patients, 102 (28.5%) had a minimum 2-year follow-up and 25 (7.0%) had a minimum 5-year follow-up. There were no significant differences in sex ($p = 0.854$), age ($p = 0.395$), smoking status ($p = 0.142$), race ($p = 0.198$), BMI ($p = 0.819$) or CCI ($p = 0.386$). A complete comparison of all demographic variables is outlined in ►**Table 1**.

Tibial and Femoral Stem rTKA

Primary analysis comparing stem type alone found no significant differences in LOS ($p = 0.718$), discharge disposition (0.462), readmission rate (0.883), and rerevision rate (0.431). Patients who received PFS implants had significantly shorter surgical times compared with all other cohorts (PFS: 143.95 ± 61.72 vs. OS: 170.39 ± 43.57 vs. CS: 162.83 ± 50.53; $p < 0.001$). Although patients in the CS cohort had the longest LOS, these values were not statistically significant ($p = 0.718$). Patients who received CS stems had higher rates of discharge to home compared the two other stem types, but these values were not significant ($p = 0.462$). Patients who received PFS implants had higher rates of readmission, while patients who underwent rTKA with OS implants had higher rates of rerevision; but neither of these values were significant ($p = 0.883$ and $p = 0.431$, respectively). A full comparison of perioperative variables between stem types can be found in ►**Table 2**.

Subanalysis of Tibial Cone Augmentation

Subanalysis comparing patients who received both tibial and femoral stems as well as tibial cone augmentation was

Table 1 Demographic data

	Offset ($n=194$)	Cemented straight ($n=72$)	Press-fit straight ($n=92$)	p-Value
Sex				
Male	72 (37.1%)	26 (36.1%)	31 (33.7%)	0.854
Female	122 (62.9%)	46 (63.9%)	61 (66.3%)	
Age (years, ± SD)	64.68 ± 9.89	66.50 ± 10.10	65.26 ± 8.94	0.395
Smoking status				
Never smoker	90 (46.4%)	36 (50.0%)	55 (59.8%)	0.142
Former smoker	82 (42.3%)	32 (44.4%)	32 (34.8%)	
Current smoker	22 (11.3%)	4 (5.6%)	5 (5.4%)	
Race				
White	93 (47.9%)	34 (47.2%)	51 (55.4%)	0.198
Black or African American	40 (20.6%)	22 (30.6%)	21 (22.8%)	
Other	61 (31.4%)	16 (22.2%)	20 (21.7%)	
BMI (kg/m^2, ± SD)	32.91 ± 7.06	32.42 ± 5.88	32.46 ± 6.75	0.819
CCI (±SD)	4.45 ± 2.60	4.40 ± 2.17	4.04 ± 1.95	0.386

Abbreviations: BMI, body mass index; CCI, Charlson Comorbidity Index; SD, standard deviation.

Table 2 Outcomes following tibial and femoral stem revision

	Offset ($n=194$)	Cemented straight ($n=72$)	Press-fit straight ($n=92$)	p-Value
Surgical time (minutes ± SD)	170.39 ± 43.57	162.83 ± 50.53	143.95 ± 61.72	<0.001
LOS (days ± SD)	3.53 ± 2.26	3.77 ± 2.72	3.68 ± 2.02	0.718
Discharge disposition				
Home	70.1%	77.8%	71.7%	0.462
Facility	29.9%	22.2%	28.3%	
Readmission	8.2%	9.7%	9.8%	0.883
Rerevision	16.0%	9.7%	14.1%	0.431

Abbreviations: LOS, length of stay; SD, standard deviation.

performed. Subgroups were stratified based on stem type, with 44 patients in the OS stem plus cone group, 48 in the CS stem plus cone group, and 27 in the PFS stem plus cone group. Patients who received OS stems with a tibial cone had significantly higher rates of rerevision compared with the other two stem types augmented with a tibial cone (OS: 18.2% vs. CS: 2.1% vs. PFS: 11.1%, $p=0.037$). Causes for rerevision among OS patients with tibial cone augmentation included infection ($n=4$) and instability ($n=4$). There were no significant differences in surgical time ($p=0.699$), LOS ($p=0.125$), discharge disposition ($p=0.872$), or readmission ($p=0.521$). All subanalysis data are outlined in ►**Table 3**.

Discussion

This study sought to determine the outcomes of rTKA in the setting of tibial and femoral stem placement, with and without tibial cone augmentation. Our results indicate that PFS stems without cone augmentation had significantly shorter surgical times compared with all other stem types. This makes intuitive sense, as preparation of the tibia to accept a PFS stem takes less time than fully cementing the stem. However, in patients requiring tibial cone augmentation, the use of CS stems produced the lowest rates of rerevision without requiring significantly longer operative times than alternative stem types with tibial cones.

Surgeons performing rTKA face several challenges related to difficult surgical exposure, removal of components, bone loss, and choice of ideal fixation technique.[19,20] Revision surgery, therefore, carries a much higher risk of failure compared with primary TKA, with some studies reporting rTKA failure rates as high as 22.8%.[21,22] Establishment of sufficient osteointegration and joint stability in rTKA is vital in optimizing patient outcomes. This can be achieved using various combinations of intramedullary stems with or without use of a metaphyseal cone.

Notably, this study determined that PFS stem use was associated with the shortest operative times, while producing similar clinical outcomes, in patients undergoing rTKA without cone augmentation. These findings are in line with

Table 3 Subanalysis of tibial cone augmentation

	Offset ($n = 44$)	Cemented straight ($n = 48$)	Press-fit straight ($n = 27$)	p-Value
Surgical time (minutes ± SD)	170.66 ± 37.05	166.21 ± 35.51	151.07 ± 49.84	0.699
LOS (days ± SD)	3.01 ± 1.93	2.88 ± 1.59	3.29 ± 2.71	0.125
Discharge disposition				
Home	88.6%	91.7%	88.9%	0.872
Facility	11.4%	8.3%	11.1%	
Readmission	6.8%	12.5%	14.8%	0.521
Rerevision	18.2%	2.1%	11.1%	0.037

Abbreviations: LOS, length of stay; SD, standard deviation.

much of the current literature in rTKA outcomes as a function of stem implant technique. A prospective study by Kosse et al found no difference in implant micromotion or clinical outcomes assessed at various checkpoints up to 6.5 years post-rTKA in patients who received cemented versus uncemented stems without cones.[14] Similarly, a meta-analysis by Wang et al examined 17 studies and found no significant difference in failure rate, reoperation, aseptic loosening, or infection in rTKA comparing cemented stems without cones to uncemented stems without cones.[7] Interestingly, a study by Edwards et al found that while rerevision rates for cemented and noncemented stems without cone augmentation were comparable, cementless diaphyseal engaging stems had a lower rate of radiographic failure than cemented stems.[23] However, these radiographic differences did not result in clinical differences.

Analysis of patients who required tibial cone augmentation demonstrated that CS stem use was associated with the lowest rate of rerevision compared with alternative stem options. Cone augmentation adds an additional variable that must be considered when comparing differences in outcomes among each surgical technique. Use of cones is often necessary to achieve adequate metaphyseal implant fixation in patients with massive bone defects classified as Anderson Orthopedic Research Institute types 2B and 3.[24] However, very little research exists exploring outcomes among patients who underwent rTKA with uncemented versus cemented stems with cone augmentation. A study by Alipit et al determined that use of a short fully cemented tibial stem with a cone achieved similar micromotion during simulated stair descent compared with cementless press-fit stem.[25] Furthermore, a study by Jacquet et al found that short fully cemented tibial stems with cone augmentation produced identical rates of joint survivorship and superior functional outcomes compared with use of a long uncemented stem with cone augmentation following rTKA.[26] The findings of this study contradict previous results, whereby patients who received CS stems with tibial cone augmentation had significantly lower rates or rerevision surgery compared with those who received long uncemented stems. Of the patients who required OS implants, however, half of the rerevision cases were secondary to instability. This could indicate that, when cone augmentation is also required, techniques involving predominantly cement fixation provide greater long-term implant stability compared with other models.

Although CS stems produced superior rerevision rates in patients with tibial cone augmentation, no such difference was found in patients who did not have a tibial cone. Tibial cones are typically indicated for reconstruction of major bone defects and bone loss.[27] Similarly, CS implants are typically indicated for large bone defects or poor bone quality.[10] While CS stems are thought to have superior initial implant stability and allow more flexibility in component positioning and sizing,[10] current research demonstrates no significant difference in revision rate between patients who undergo rTKA with cemented versus uncemented stems.[7,28] However, no existing literature explores the impact of cemented versus uncemented stems on revision rates in patients who have tibial cone augmentation. Results from this study demonstrated lower rerevision rates without significantly lengthened surgical times in patients requiring rTKA with a CS stem and tibial cone augmentation. One possible explanation for this finding relates to the principle of zonal fixation. Most patients undergoing rTKA require stem implantation to link zone 1, the epiphysis, with zone 3, the diaphysis, to achieve adequate stability.[6,29] However, additional fixation through the use of metal cones in zone 2, the metaphysis, is advantageous in patients with poor bone quality such as sclerotic or osteoporotic bone.[29] In this subset of patients, cement is required to achieve adequate implant fixation between the cone and the stem and tibial base plate.[29] As a result, patients with major bone defects requiring tibial cones may benefit from the potential added stability of CS stems.

OS stem use was associated with the longest surgical times and, when augmented with a tibial cone, the highest rerevision rate. Primary indications for OS stem use include anatomical mismatch of the optimal position of the femoral or tibial component and the intramedullary canal, yet minimal research exists comparing outcomes of rTKA with offset stems versus alternative stem fixation options.[16] A study by Innocenti et al examined 40 rTKA patients at a mean follow-up of 3.5 years and found that offset stem use produced radiographically superior results in regard to re-establishing an accurate joint line compared with straight stem use.[17] However, they found no clinical differences between stem type use. While Innocenti et al found no clinical differences between stem options, the researchers only compared 40 patients who had an offset stem or straight stem without specifically exploring cementation status. Conversely, we compared OS stems to CS straight stems and PFS stems and found OS stems to be associated with significantly increased surgical times and rerevision rates.

The correlation between increased operative time and adverse postoperative outcomes following primary TKA is well established.[30–32] However, recent research now demonstrates that extended surgical times may also be associated with increased risk for adverse postoperative outcomes in rTKA. A study by Chen et al examined 14,769 rTKA patients and found that each 15-minute increase in surgical time was associated with increased risk for wound complications and extended hospital LOS.[33] A similar study by Garbarino et al found that shorter operative times were associated with decreased LOS following rTKA.[34] As a result, maximizing efficiency and decreasing surgical time in the operating room can provide an opportunity improve postoperative outcomes. The shorter operative times associated with use of PFS stems without cone augmentation may provide surgeons an opportunity to limit adverse postoperative outcomes without increasing risk for unfavorable events. The reduced revision rate associated with the use of CS stems in patients requiring tibial cones should also warrant specific consideration. Utilization of CS stems in this subset of patients may optimize patient outcomes without significantly lengthening surgical times, and thus should be considered in patients without specific contraindication. Furthermore, OS stem use in patients with and without tibial cone augmentation may lead to adverse outcomes such as lengthy operative times and increased rerevision rate. Therefore, surgeons should consider PFS stems without an OS or CS stem use as an alternative when applicable.

Limitations

This study is not without limitations. The retrospective nature of the study provides an opportunity for selection bias to have been introduced, which we attempted to mitigate by systematically controlling for demographic differences and confounding variables. Furthermore, no patient reported outcomes (PROs) were used to assess patient outcome and surgical technique. Understanding differences in patient perspective regarding surgical outcomes would provide additional insight as to whether an operative technique produces superior results. The subanalysis comparing cone augmentation only included patients who received a tibial and femoral stem with tibial cone augmentation. Therefore, this precludes our study from making recommendations for patients who require other stem and cone combinations. Despite these limitations, the findings from the study remain valid in supporting that OS implants with tibial cone augmentation produce significantly higher rates of rerevision compared with other constructs.

Conclusion

In patients undergoing rTKA with tibial and femoral stem revision, all construct types produce similar postoperative outcomes. However, in patients with tibial cone augmentation, CS stem use may produce superior outcomes without significantly lengthening surgical times. As a result, surgeons should consider using CS stems in patients requiring tibial cone augmentation in rTKA. In patients not requiring tibial cone augmentation, surgeons may adhere to their preferred method of fixation without concern for inferior outcomes. Future studies should be directed toward determining differences in PROs related to patient satisfaction based on fixation method in patients undergoing rTKA.

Conflict of Interest
None declared.

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