Joint Diseases and Related Surgery

Jt Dis Relat Surg
2024;35(1):244-248

CASE SERIES

Does medullary diameter to stem width ratio and stem length affect outcomes of revision total knee arthroplasties? A case series

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ABSTRACT

Objectives: This study aimed to investigate the relationship between the ratio of stem size to intramedullary canal diameter, stem length, and functional outcome in revision total knee arthroplasty (RTKA) procedures, which remains largely unexplored in the current literature.

Patients and methods: A single surgeon series of RTKA procedures performed between October 2014 and November 2022 were included in this case series, and data were analyzed retrospectively. A total of 32 patients (27 females, 5 males; mean age: 73.2±8.1 years; range, 52 to 88 years) were identified, with a minimum follow-up period of five months and a maximum of eight years. Filtering the patients based on >24 month follow-up, we were left with 13 patients aged between 65 and 88 (mean 74.85±6,854) years. The latest X-rays of patients were analyzed, and the ratio of intramedullary canal diameter to stem width was calculated for both femur and tibia in both anteroposterior and lateral planes. Household income, preoperative C-reactive protein, erythrocyte sedimentation rate, comorbidities, body mass index, and implant dimensions were also recorded. Postoperative Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Short Form-12 (SF-12) scores, and range of motion (ROM) measurements were used to evaluate functional outcome.

Results: A moderate negative relationship between the tibial canal fill ratio (CFR) in anteroposterior views and ROM of the patients was noted. Additionally, a significant positive correlation was found between SF-12 physical score and CFR in lateral view. A moderate level of correlation between femoral CFR in anteroposterior views was also established. Due to insufficient data, joint ROM data did not show normal distribution. Therefore, a cutoff value indicating the relationship between the stem size and knee ROM could not be calculated using receiver operating characteristic analysis. Multiple regression analysis did not yield significant results, suggesting that hypothesized predictor variables were not sufficient to predict the variation in functional scores. Otherwise, no clear statistical importance or correlation between functional scores, such as WOMAC or SF-12, and CFR was found.

Conclusion: In conclusion, the findings suggest that other factors, such as other patient characteristics, surgical techniques, or implant designs, may have a more substantial impact on the functional outcomes in RTKA patients.

Keywords: Arthroplasty, aseptic loosening failure, ratio, revision, stem.

Aseptic loosening, septic failure, and ligamentous laxity or instability are regarded as top reasons for implant failure in total knee arthroplasty (TKA), followed by periprosthetic fractures.[1] Septic and aseptic loosening are also the top reasons for revision TKA (RTKA), followed by malalignment and polyethylene wear.[2] Due to the lack of bone and soft tissue support, it is difficult to achieve perfect fixation and stability of the implants in RTKA patients.[3] Extension stems play a key role in maintaining the stability of RTKA implants. No clear, up-to-date guideline exists for the selection of the extension stems. Parsley et al.[4] first introduced the term canal fill ratio (CFR), which is the ratio of the intramedullary canal's diameter to the stem width. The relationship between the CFR, stem length, and prosthesis stability was

Received: March 17, 2023
Accepted: October 18, 2023
Published online: November 24, 2023

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Doi: 10.52312/jdrs.2023.1108

Citation: Ozer H, Baymurat AC, Ahmadov A, Selek HY, Abdulaliyev F, Ozel T. Does medullary diameter to stem width ratio and stem length affect outcomes of revision total knee arthroplasties? A case series. Jt Dis Relat Surg 2024;35(1):244-248. doi: 10.52312/jdrs.2023.1108.

analyzed by Lee et al.;[5] however, no data originating from Türkiye investigating the correlation between CFR, stem length, and functional outcomes have been published. We aim to retrospectively investigate the relationship between these parameters and functional outcomes in RTKA procedures performed in a single tertiary center by a single surgeon.

PATIENTS AND METHODS

A total of 32 patients (27 females, 5 males; mean age: 73.2±8.1 years; range, 52 to 88 years) who had their RTKA operation performed for any reason, including re-revisions, in the Gazi University Faculty of Medicine, Department of Orthopedics and Traumatology between October 2014 and November 2022 were included in the retrospective analysis. The analysis was performed on two datasets, the first of which included all 32 patients with a minimum and maximum follow-up period of five months and eight years, respectively. The second dataset included 13 patients who had a minimum of 24 months of follow-up.

All revision surgeries were performed by the same senior surgeon specializing in joint reconstruction. For all revision implants, the cemented method was used for tray fixation, while stem fixation was cementless, also called hybrid fixation method. Based on ligamentous instability and amount of bone loss, semiconstrained implants or hinged implants were preferred. Disruption of both collateral ligaments and or posterior capsule involvement, previous usage of hinged implants, or extensor mechanism disruption called for the use of hinged implants. Septic loosening cases were treated in two stages; the first included removal of implants, debridement, and placement of antibiotic-loaded cement.[6] Acute phase reactants (C-reactive protein [CRP], erythrocyte sedimentation rate [ESR], and white blood cells) and clinical statuses were followed, and upon improvement, the second stage of insertion of final implants was performed. Patients with CRP values >5 mg/L underwent infectious disease screenings, such as routine urine tests. Patients with suspected urinary tract infections were given proper antibiotherapy and retested until remission of the known infection. The patients with suspected infections of other systems were referred to the clinic of infectious diseases, and operations were delayed until remission. The patients were not operated on until further approval was received from the department of infectious diseases. All RTKA operations were performed using the three-step technique.[7] Tourniquets, tranexamic acid, and antibiotic-loaded cements were used to fix the implants.

Age, sex, other demographic data, side of operation, implant manufacturers, implant sizes including dimensions of used stems, femoral and tibial component, preoperative values of CRP and ESR, comorbidities, reason for revision, and body mass index (BMI) were recorded. Functional outcome was evaluated with Western Ontario

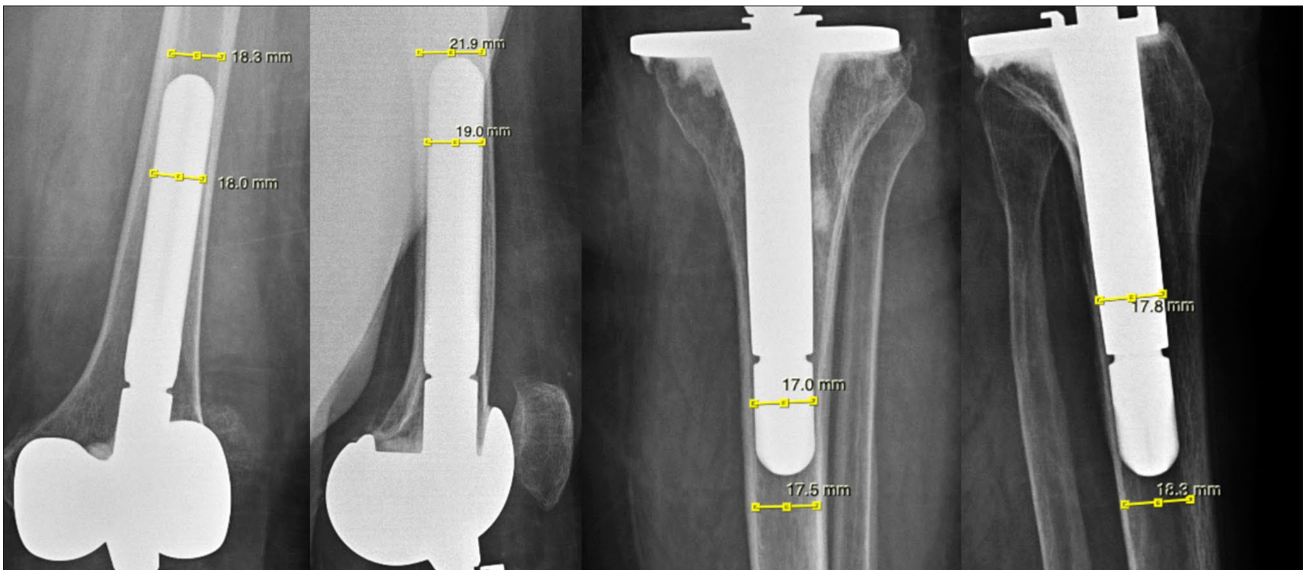

FIGURE 1. For both the tibia and femur, the intramedullary space was measured first, then the stem size was evaluated using the hospital's built-in picture archiving and communication system (ExtremePACS 2015 version 4.3) in both planes. Measurements were not calibrated to centimeters but were enough to provide accurate ratios, which was acceptable in our case.

TABLE I

Demographic data of all 32 patients involved in this study

Reason of reoperation	Age	F STM	TSTM	INSERT	ssIMFAP	ssIMTAP	ssIMFLAT	SSIMTLAT	SF12 PCS	SF12 MCS	WOMAC POST	ROM
R2	71	15*100	15*100	12	1.18	1.34	0.83	0.88	24.96	47.30	58.33	0-35
R1	83	13*100	12*100	10	0.95	1.52	0.78	0.79	48.29	47.58	19.79	20-60
R1	73	13*100	12*100	10	0.74	0.85	1.00	0.68	30.13	49.32	21.88	0-100
R2	76	8*100	12*100	13	1.11	0.89	0.97	0.66	40.94	46.14	9.38	0-100
R1	78	17*100	30*100	12	0.79	0.88	0.90	1.00	57.80	44.02	10.41	0-110
R1	67	8*100	8*100	10	0.73	0.77	0.92	0.82	45.49	56.74	19.79	0-110
R2	83	13*100	16*100	12	0.70	0.65	0.81	0.79	44.09	61.59	28.12	0-110
R1	67	14*155	12*155	12	0.74	0.75	0.82	0.85	55.60	39.07	7.29	0-100
R2	65	12*100	10*100	12	0.88	0.87	1.00	0.91	46.50	32.34	10.42	0-110
R1	63	16*100	13*100	12	0.89	0.68	0.81	0.70	48.14	60.22	29.16	0-90
R1	59	-	13*30	10	-	0.66	-	0.59	54.61	44.61	5.21	0-110
R1	72	-	12*120	11	-	0.85	-	0.61	48.44	53.00	15.63	0-90
R2	68	16*100	14*100	12	0.74	0.62	0.75	0.63	50.53	48.46	17.71	0-110
Primary	83	13*155	16*100	14	0.68	0.98	0.68	0.75	48.20	54.40	30.20	0-90
R1	75	15*100	13*100	14	0.60	0.64	0.87	0.74	48.09	57.00	26.04	0-110
Primary	83	15*155	15*100	12	0.68	0.82	1.00	0.85	38.27	45.07	22.92	0-100
R1	81	12*155	14*100	10	0.79	0.72	0.69	0.95	51.38	41.27	22.92	0-100
R2	52	12*100	12*100	14	1.00	0.76	0.93	0.88	56.18	48.47	21.87	0-100
R1	83	14*100	30*100	10	0.74	0.77	0.67	0.67	37.08	54.45	30.20	10-90
R2	73	15*100	11*100	12	0.80	0.66	0.83	0.87	44.81	56.68	25.00	0-80
R2	81	16*100	12*100	10	0.70	0.67	0.66	0.57	42.74	54.26	29.17	0-100
R2	75	-		-	0.98	0.98	0.97	1.00	47.68	42.94	21.87	0-110
R2	88	15*120	14*120	13	1.00	1.00	0.97	0.86	38.58	42.62	17.71	0-110
Primary	64	15*120	14*120	10	0.80	0.75	0.90	0.73	47.35	57.79	16.67	0-110
R2	76	17*100	16*155	13	0.83	1.00	0.76	0.83	38.70	40.47	22.92	0-80
Primary	80	16*100	15*30	10	0.81	0.87	0.75	0.61	45.90	60.07	9.38	0-110
Primary	74	12*155	13*30	10	0.62	0.80	0.62	0.74	47.68	42.94	27.08	0-90
Primary	68	16*100	12*100	10	0.63	0.94	0.67	0.85	52.11	56.77	15.63	0-100
R2	73	15*100	12*100	12	0.88	0.83	1.00	0.60	38.58	42.62	29.17	0-60
R1	66	14*155	14*100	14	1.00	1.00	0.75	1.29	58.23	50.16	15.63	0-100
Primary	72	15*100	13*30	12	0.78	0.98	0.66	0.83	51.09	38.78	21.88	0-90
R2	71	17*100	13*30	10	0.82	0.97	0.80	0.87	55.24	45.78	17.71	0-110

F STM: Femur stem dimensions; TSTM: Tibial stem dimensions; INSERT: Polyethylene insert size; ssIMPFAP: Stem Size to Intramedullary ratio (Canal Fill Ratio) of the Femur in AP (Anteroposterior) Radiographic view; ssIMTAP: Stem Size to Intramedullary ratio (Canal Fill Ratio) of the Tibia in AP view; SSIMFLAT: Stem Size to Intramedullary ratio (Canal Fill Ratio) of the Femur in Lateral View; SSIMTLAT: Stem Size to Intramedullary ratio (Canal Fill Ratio) of the Tibia in Lateral View; SF12: Short Form 12; PCS: Physical component score; MCS: Mental component score; WOMAC POST: Postoperative WOMAC (The Western Ontario and McMaster Universities Arthritis Index) questionnaire scores; ROM: Range of motion; R1: (n=12) routine RTKA due to implant failures as a result of aseptic loosening; R2: (n=13) underwent complex revision surgeries due to infected implants.

and McMaster Universities Osteoarthritis Index (WOMAC) and Short Form-12 (SF-12) mental and physical evaluation questionnaires. Postoperative range of motion (ROM) was measured using a goniometer. Postoperative X-rays were evaluated in anteroposterior (AP) and lateral planes, and the femur and tibial intramedullary space-to-stem diameter ratio, also known as CFR, was calculated (Figure 1).

Statistical analysis

Statistical analysis was performed using IBM SPSS version 28.0 software (IBM Corp., Armonk, NY, USA). Descriptive statistics showed that the skewness and kurtosis values for most of the variables were relatively small, indicating that the distributions are approximately symmetrical and close to a normal distribution. Due to the small sample size, the Shapiro-Wilk test was performed. The correlation between CFR, other descriptive parameters, and functional outcomes were analyzed. The relationship between the numerical data was examined using the Pearson product-moment correlation coefficient. Multiple regression analysis was performed to explore the predictive value of femoral and tibial stem width and length and CFR values on the aforementioned functional scores. Control for other relevant variables, such as age and BMI, was done to identify their unique contributions to the outcomes. Normality, linearity, and covariance were examined by preliminary analysis. A p-value <0.05 was considered statistically significant.

RESULTS

Demographic data of the patients, such as age, sex, and household income, are displayed in Table I. None of the patients evaluated had undergone or had need for revision surgery during the follow-up period. Insert size, tibial CFR measurements in AP view, postoperative WOMAC scores, and all stem size measurements showed significant departures from normality (p<0.05). The mean CFR for femoral and tibial components in AP views was 0.819±0.14 and 0.858±0.193, respectively, and in lateral views was 0.825±0.122 and 0.795±0.149, respectively. For 27 (84.4%) of all patients the Persona® Revision Knee implants (Zimmer Biomet, Warsaw, Indiana, USA) were used. Three (9.4%) patients got implanted with the Legion™ Revision System (Smith+Nephew, Hertfordshire, UK), and one patient received the Revision Knee System (DePuy Synthes Inc., Warsaw, IN, USA). A single patient had severe bone loss classified as Grade 3 according to AORI (Anderson Orthopedic Research Institute) classification of bony defects, and the patient received long stemmed tumor resection prosthesis provided by Implantcast GmbH (Buxtehude, Hamburg, Germany).

Twenty-five percent of the patients had high (monthly >15,000 Turkish lira), 56.3% had medium (monthly 5,000-15,000 Turkish lira), and 18.8% had low (monthly <5,000 Turkish lira) household income. The mean BMI of operated patients was 30.1±4.75 (range, 22.7 to 43). Mean preoperative CRP and ESR values were 5.51±2.73 mg/L and 27.07±16.91 mm/h, respectively. The most frequent comorbidity of the patients was hypertension, with 65.6% (n=21).

There was a moderate negative relationship between the tibial CFR in AP views and ROM of the patient (r=–0.624, n=32, p≤0.001). A moderate level of correlation between femoral CFR in AP views was also established (r=–0.385, n=30, p=0.036). Due to limited number of patients included, ROM data did not show normal distribution; therefore, a cutoff value indicating the relationship between stem size and knee ROM could not be calculated using receiver operating characteristic analysis. Otherwise, no clear statistical importance or correlation between functional scores, such as WOMAC or SF12, and CFR were found (Table II).

When the correlation analysis was performed on the second dataset with a minimum 24 months follow-up (n=13), femoral stem length demonstrated a weak positive correlation with the SF-12 physical component score (r=0.331), indicating that patients with longer femoral stems tended to have higher functional scores.

TABLE II
Table summarizing the r values for Pearson product-moment correlation

	SSTAP	SSTLAT
SF12PCS	0.223	0.072
SF12MCS	0.127	0.107
WOMAC	0.199	0.897
ROM	0.001	0.744
	SSFAP	**SSFLAT**
SF12PCS	0.286	0.151
SF12MCS	0.139	0.251
WOMAC	0.475	0.328
ROM	0.023	0.474

SSTAP: CFR of tibia in AP radiographic view; SSTLAT: CFR of tibia in Lateral radiographic view; SF12: Short Form 12; PCS: Physical component score; MCS: Mental component score; WOMAC: The Western Ontario and McMaster Universities Arthritis Index; ROM: Range of motion; SSFAP: Stem size of the femur in anteroposterior; SSFLAT: Stem size of the femur in lateral view. The data was analyzed using SPSS.

DISCUSSION

To the best of our knowledge, this is the first study evaluating correlation of CFR and functional outcome in RTKA in a Turkish population.[8] Previously, the relation of the stem size and fixation method with the mechanical failure of the RTKA implants have been analyzed, and both fully cemented and hybrid modular stems were reported to achieve a high stability, particularly when the CFR is maximized.[8,9] Many published studies show CFR's impact on reducing RTKA failure, where a CFR >0.85 can be considered a cut-off to substantially decrease the rate of aseptic loosening.[5,10] Although our evaluation of data and patients yielded no statistically important correlation between the CFR and improvement of WOMAC or SF-12 scores, we could observe higher (worse) WOMAC scores of the patients with CFR <0.70.

There are some limitations to our study. First, patient numbers could be considered insufficient, which hindered a solid retrospective analysis. Moreover, the lack of data, such as designs of the stems used (cylindrical or conical), prevented an in-depth analysis of implant types. Finally, most of the data were from recent years, and the follow-up period was <2 years in the majority of the patients. Larger scale research including data from multiple centers or national arthroplasty registers could yield more substantial results.

In conclusion, the results from this retrospective study suggest that the correlation of CFR, stem length measurements, and functional outcomes were generally weak or nonsignificant, and other factors, such as other patient characteristics, surgical techniques, or implant designs, may have a more substantial impact on the functional outcomes in RTKA patients. Based on available data, it could be speculated that although better ROM could be achieved by less CFR of implants, it would not be worth sacrificing the proven safety against aseptic loosening to gain more ROM.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Performed the measurements: A.A.; Were involved in planning and supervised the work: A.A., H.O., A.B., H.Y.S.; Processed the collected data, AA performed the analysis, drafted the manuscript and designed the figures: A.B., F.A., T.O.; Aided in interpreting the results and worked on the manuscript: A.A., A.B.; All authors discussed the results and commented on the manuscript.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

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