Mid-term clinical outcomes and complications of primary total knee arthroplasty in hemodialysis patients: a retrospective comparative cohort study

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Abstract

Background: Numerous patients who receive hemodialysis (HD) undergo total knee arthroplasty (TKA) due to advanced knee joint arthritis. However, there are few studies that describe the clinical outcomes and complications of TKA in HD patients. This study investigated the mid-term results of TKA in patients undergoing HD.

Methods: This single-center retrospective study compared clinical and surgical outcomes following TKA in patients who were receiving HD with those who were not. We used propensity scores to match 21 knees of 18 patients who received HD to 706 knees of 569 patients who had not received HD, from a total of 727 knees (587 patients) that underwent primary unilateral TKA. The clinical outcomes were evaluated using the American Knee Society Score-knee (AKSS-knee) and AKSS-function scores. The primary surgical outcome measure was the number of knees with postoperative complications.

Results: In both the HD and non-HD groups, postoperative AKSS-knee and function scores significantly improved when compared to preoperative values. Postoperative AKSS-knee and function scores were not significantly different between the groups. The number of knees with postoperative complications was larger in the HD group than the non-HD group within the first postoperative month, 0–12 months, 12–24 months, 0–24 months, and two years after surgery. Additionally, in the HD group, more complications occurred in the first month than any subsequent month in the two years after surgery.

Conclusions: TKA improves AKSS-knee and function scores equivalently for HD patients and non-HD patients. However, HD patients develop more complications after TKA, especially within the first month. Therefore, surgeons who perform TKA for HD patients should obtain informed consent after explaining the possible complications, and HD patients should be carefully observed following TKA.

Keywords: Hemodialysis, Total knee arthroplasty, Propensity score matching, American knee society score, Complications

Background

Chronic kidney failure is a widespread global disease. At the end of 2016, there were approximately 3.7 million patients with chronic kidney failure worldwide, with more than 70% receiving hemodialysis (HD) treatment.
Patients undergoing HD tend to have advanced osteoarthritis and osteonecrosis due to both aging and β2-microgloblin, which often necessitates total knee arthroplasty (TKA) [2–4]. For patients receiving HD, the relative risk of needing TKA is more than 2.0 compared with the general population [5]. TKA is a well-known surgery for knee joint pain and disorders related to arthritis, such as osteoarthritis, rheumatoid arthritis, and osteonecrosis [6, 7]. Numerous patients receiving HD undergo TKA due to advanced knee joint arthritis. However, there are few studies that describe the clinical outcomes and complications of TKA in patients undergoing HD. Here we describe mid-term outcomes and complications of primary TKA in patients receiving HD by using a propensity score matching method.

Methods
This retrospective cohort study examined data obtained from the TKA database of our institution. The TKA database accumulates clinical data from patients who have undergone TKA, including the American Knee Society Score-knee (AKSS-knee) scores, AKSS-function scores, laboratory data, comorbidities, and postoperative complications. This was a single-center, retrospective study. The study protocol adhered to the ethical guidelines of the 1975 Declaration of Helsinki, and it was approved by the Institutional Review Board of our institution. All patients provided informed consent prior to participation in the study.

Patients
First, data from 1172 knees (959 patients) that underwent primary unilateral TKA at our institution between January 2004 and August 2018 were extracted (Fig. 1). Next, we excluded 255 knees (236 patients) that had follow-up data spanning less than two years. Then, we excluded 190 knees (136 patients) with insufficient data. Finally, we divided the remaining 727 knees into two groups: an HD group (21 knees; 18 patients) and a non-HD group (706 knees; 569 patients). All patients in this study were Japanese.

Operation
All TKA procedures were performed by senior surgeons using an air tourniquet and a medial parapatellar approach under spinal or general anesthesia, at the discretion of the anesthesiologist. The following types of implants were used: cruciate-retaining cemented implant (Vanguard Knee System [Zimmer Biomet, Indiana, USA]); posterior-stabilized cemented implant (Bi-Surface Total Knee System [Kyocera, Kyoto, Japan], NexGen LPS-Flex Knee [Zimmer Biomet, Indiana, USA], Persona [Zimmer Biomet, Indiana, USA], Scorpio NRG [Stryker, Michigan, USA], or Triathlon Total Knee System [Stryker, Michigan, USA]); or a posterior-stabilized cementless implant (Triathlon Total Knee System [Stryker, Michigan, USA]).

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**Fig. 1** Flow chart depicting the study selection process and number of knees in the hemodialysis and non-hemodialysis patient groups undergoing primary unilateral total knee arthroplasty. HD: hemodialysis
**Propensity score matching method**

To minimize confounding, a propensity score matching method was used to match HD to non-HD patients. Using logistic regression, the propensity score was calculated from the following 25 variables: age, gender, body mass index (BMI), preoperative hemoglobin count, preoperative platelet count, preoperative albumin, preoperative AKSS-knee score, preoperative AKSS-function score, history of cancer, history of stroke, history of venous thromboembolism, osteoarthritis, rheumatoid arthritis, osteonecrosis, post-traumatic arthritis, post-osteotomy arthritis, diabetes mellitus, hypertension, cardiac disease, chronic respiratory disease, psychiatric disease, spinal disease, osteoporosis, chronic liver disease, and anemia, which was defined as less than 11.0 g of hemoglobin per deciliter of blood. These variables were selected based on prior studies [8–11].

Propensity matching was then performed, using nearest neighbor matching without replacement, with each HD patient matched to four control non-HD patients. A caliper width of 0.2 of the standard deviation of the logit of the propensity score was used. To check the balance of the matches, a standardized mean difference threshold of 0.1 was set as a reference.

**Results**

**Propensity score matching**

The propensity-matched population consisted of 21 knees (18 patients) in the HD group and 71 knees (70 patients) that were matched controls. Almost every variable achieved an appropriate balance, except hypertension, history of stroke, and cardiac disease. Baseline demographics for the matched study population are shown in Table 1 and Fig. 2.

**Intragroup comparisons**

In both the HD and non-HD groups, 2 years postoperative AKSS-knee scores and function scores significantly improved compared to their respective preoperative values. However, the postoperative AKSS-knee and function scores obtained at the 2-year follow-up were not significantly different than those obtained at the last follow-up in either group (Table 2).

**Comparison between groups**

There were no significant differences between the HD group and non-HD group in the postoperative AKSS-knee and function scores that were obtained two years after surgery or at the last follow-up. There were no significant differences between the groups in the change in scores post-operation versus pre-operation. Among the individual items of the AKSS-knee and function scales, there were significant differences between the HD group and non-HD group in the AKSS-knee stability subscore at the last follow-up (24.5 ± 1.5 vs. 25.0 ± 0.0; \( P = 0.0089 \)) and the
AKSS-function walking subscore at the last follow-up (38.6 ± 16.5 vs. 46.1 ± 7.7; \(P = 0.033\)). The results for the primary and secondary outcome measures are shown in Table 3.

The number of knees with postoperative complications was greater in the HD group than the non-HD group in the first postoperative month, 0–12 months, 12–24 months, 0–24 months, and more than two years after surgery (Table 4). Additionally, in the HD group, the number of knees with postoperative complications was larger in the first month than any subsequent month in the first two years after surgery (Fig. 3). When we examined each type of complication, we found that anemia, shunt failure, carpal tunnel syndrome, and severe aortic stenosis occurred more frequently in the HD group than the non-HD group (Table 5).

**Discussion**

This study highlights two important clinical findings. First, TKA for HD patients improves their AKSS-knee and function scores, with no significant differences compared to patients who do not receive HD. Second, HD patients are more likely to develop complications after TKA than non-HD patients, especially within the first month after TKA.

Previous studies of TKA for HD patients were often simple comparisons. However, simple comparisons are difficult because the demographic and clinical characteristics of HD patients differ greatly from that of non-HD patients. In the current study, we matched demographic and clinical factors to permit a more precise analysis of TKA for HD patients by using a propensity score matching method.

Utrilla et al. [12] reported that the preoperative and postoperative AKSS-knee scores were not significantly
different between patients with or without end-stage renal disease (ESRD). However, they found that the preoperative and postoperative AKSS-function scores were significantly lower in the ESRD group than the non-ESRD group. Interestingly, there was no significant difference between groups in the mean gain in AKSS-function (45.1 vs. 43.2). In the current study, the postoperative AKSS-function scores were not significantly different between the HD and non-HD groups. This may be because the propensity score matching method included the preoperative AKSS-function scores. Based on the above results, we conclude that TKA is beneficial for patients undergoing HD. However, when we examined the individual items of the AKSS-knee and function scales, the AKSS-knee stability and AKSS-function walking scores were significantly lower in the HD group at the last follow-up, compared to the non-HD group.

Regarding instability in HD patients, Malkani et al. [13] reported that impaired musculo-skeletal function and decreased muscular tone associated with renal osteodystrophy led to increased joint laxity and subsequent dislocation in dialysis patients who underwent total hip arthroplasty. In a group of HD patients undergoing TKA, Lo et al. [14] reported one case of

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**Table 2** Intragroup comparison of AKSS-knee and AKSS-function scores

|                | Pre-operation | Two year follow-up | Last follow-up | p-value<sup>a</sup> | p-value<sup>b</sup> | p-value<sup>c</sup> |
|----------------|---------------|-------------------|---------------|---------------------|---------------------|---------------------|
| HD group       |               |                   |               |                     |                     |                     |
| AKSS Knee Score| 44.9 ± 18.8 (10–72) | 95.0 ± 9.8 (72–100) | 95.4 ± 7.7 (72–100) | < 0.0001          | < 0.0001          | 0.7684              |
| AKSS Function Score | 30.7 ± 20.9 (0–70) | 73.1 ± 27.2 (0–100) | 66.9 ± 33.0 (0–100) | < 0.0001          | < 0.0001          | 0.1567              |
| non-HD group   |               |                   |               |                     |                     |                     |
| AKSS Knee Score| 46.6 ± 16.7 (0–80)  | 96.8 ± 5.5 (69–100)  | 97.6 ± 3.4 (83–100)  | < 0.0001          | < 0.0001          | 0.2696              |
| AKSS Function Score | 33.0 ± 21.4 (0–70) | 78.9 ± 18.8 (15–100) | 79.2 ± 18.2 (15–100) | < 0.0001          | < 0.0001          | 0.8616              |

<sup>a</sup> Pre-operation vs. Two year follow-up
<sup>b</sup> Pre-operation vs. Last follow-up
<sup>c</sup> Two year follow-up vs. Last follow-up

Continuous variables are expressed as the mean ± standard deviation (range). HD: hemodialysis, AKSS: American Knee Society Score
knee instability that required casting and had a poor final functional outcome. In our study, we believe that HD patients have diminished knee stability compared with non-HD patients due to decreased muscle tone and muscle weakness. Fortunately, there were no cases of knee dislocation or instability requiring casting in our study. However, a strict approach for appropriate implant selection, component placement and preservation of the soft tissue structure should be maintained to prevent knee instability following TKA in HD patients.

The prevalence of fatigue in patients receiving renal replacement therapy ranges from 60% to as high as 97%, which is higher than the incidence of fatigue in patients who are not undergoing renal replacement therapy, owing to physiological, sociodemographic, psychological, behavioral, and dialysis-related factors [15]. In our study, fatigue may be the reason why the walking subscore of the AKSS-function scale at the last follow-up was lower in the HD group than the non-HD group. Low levels of physical activity are associated with an increased risk for

### Table 3 Comparison of primary and secondary outcome measures between the HD and non-HD groups

| Measure                                      | HD group                  | non-HD group               | p-value   |
|----------------------------------------------|---------------------------|-----------------------------|-----------|
| AKSS-knee score at the two year follow-up    | 95.0 ± 9.8 (72–100)       | 96.8 ± 5.5 (69–100)         | 0.4641    |
| Pain                                         | 48.1 ± 6.0 (30–50)        | 49.2 ± 2.8 (30–50)          | 0.7978    |
| Total range of flexion                       | 23.8 ± 3.6 (12–25)        | 24.2 ± 1.9 (14–25)          | 0.3893    |
| Stability                                    | 25.0 ± 0.0 (25–25)        | 25.0 ± 0.0 (25–25)          | 1.0000    |
| Flexion contracture                          | 1.2 ± 3.3 (0–15)          | 0.5 ± 0.9 (0–2)             | 0.7817    |
| Extension lag                                | 0.7 ± 1.8 (0–5)           | 0.5 ± 2.7 (0–20)            | 0.1175    |
| Alignment                                    | 0.0 ± 0.0 (0–0)           | 0.5 ± 2.3 (0–15)            | 0.2653    |
| Increase from preoperative score             | 50.1 ± 19.3 (26–90)       | 50.2 ± 17.1 (14–91)         | 0.8633    |
| AKSS-function score at the two year follow-up| 73.1 ± 27.2 (0–100)       | 78.9 ± 18.8 (15–100)        | 0.6314    |
| Walking                                      | 41.4 ± 14.2 (0–50)        | 45.8 ± 7.9 (20–50)          | 0.2368    |
| Stairs                                       | 33.3 ± 12.8 (0–50)        | 36.0 ± 10.8 (0–50)          | 0.6052    |
| Walking aids used                            | 2.1 ± 4.6 (0–20)          | 3.0 ± 4.9 (0–20)            | 0.2639    |
| Increase from preoperative score             | 42.4 ± 29.7 (−35–90)      | 45.9 ± 20.6 (−20–90)        | 0.8923    |
| AKSS-knee score at the last follow-up        | 95.4 ± 7.7 (72–100)       | 97.6 ± 3.4 (83–100)         | 0.9048    |
| Pain                                         | 48.8 ± 3.1 (40–50)        | 49.3 ± 1.8 (45–50)          | 0.8595    |
| Total range of flexion                       | 23.5 ± 3.6 (12–25)        | 24.2 ± 2.4 (8–25)           | 0.8083    |
| Stability                                    | 24.5 ± 1.5 (20–25)        | 25.0 ± 0.0 (25–25)          | 0.0089    |
| Flexion contracture                          | 1.2 ± 3.3 (0–15)          | 0.5 ± 1.0 (0–5)             | 0.6166    |
| Extension lag                                | 0.2 ± 1.1 (0–5)           | 0.07 ± 0.6 (0–5)            | 0.3572    |
| Alignment                                    | 0.0 ± 0.0 (0–0)           | 0.3 ± 1.5 (0–9)             | 0.3409    |
| Increase from preoperative score             | 50.5 ± 18.5 (27–90)       | 51.0 ± 16.7 (20–98)         | 0.7979    |
| AKSS-function score at the last follow-up    | 66.9 ± 33.0 (0–100)       | 79.2 ± 18.2 (15–100)        | 0.2674    |
| Walking                                      | 38.6 ± 16.5 (0–50)        | 46.1 ± 7.7 (20–50)          | 0.0330    |
| Stairs                                       | 30.0 ± 16.1 (0–50)        | 36.1 ± 9.9 (0–50)           | 0.3110    |
| Walking aids used                            | 2.1 ± 4.6 (0–20)          | 3.0 ± 4.6 (0–20)            | 0.2640    |
| Increase from preoperative score             | 36.2 ± 34.3 (−35–90)      | 46.1 ± 20.0 (10–85)         | 0.3269    |
| Postoperative length of stay (days)          | 25.4 ± 30.8 (9–154)       | 17.2 ± 3.4 (1.2–32)         | 0.4968    |
| Postoperative follow-up period (months)      | 42.2 ± 25.2 (24–98)       | 62.7 ± 30.4 (25–150)        | 0.0047    |
| Operating time (minutes)                     | 83.8 ± 14.5 (64–109)      | 80.4 ± 20.6 (46–139)        | 0.2391    |
| Anesthesia time (minutes)                    | 120.3 ± 17.3 (90–155)     | 117.8 ± 28.1 (67–214)       | 0.3473    |
| Hemoglobin count on the first postoperative day (g/dL) | 10.4 ± 1.5 (7.8–13.2)   | 10.1 ± 1.2 (7.2–13.2)       | 0.4453    |
| Hemoglobin count at one week postoperation (g/dL) | 9.3 ± 1.2 (7–11.2)       | 9.7 ± 1.3 (6.8–14.1)        | 0.3147    |
| Platelet count on the first postoperative day (×10^9/L) | 18.2 ± 6.1 (8.4–31.3)  | 17.9 ± 6.8 (5.3–34.0)       | 0.8269    |
| Platelet count at one week postoperation (×10^9/L) | 23.2 ± 7.0 (9.1–38.1)  | 25.2 ± 8.6 (3.0–50.2)       | 0.2764    |
| Volume of allogenic blood transfusion (mL)   | 1.1 ± 3.2 (0–14)          | 0.08 ± 0.5 (0–4)            | 0.0077    |

Continuous variables are expressed as the mean ± SD (range). AKSS American Knee Society Score, HD hemodialysis.
mortality among dialysis patients [16]. Therefore, exercise therapy aimed to preserve or enhance physical activity should be considered for HD patients after TKA. HD patients developed more complications after TKA than non-HD patients, especially within the first month. This may be due to predisposing conditions, such as a diminished blood supply, compromised immune system, amyloidosis, poor bone quality, electrolyte abnormalities, and impaired wound healing [9, 17, 18]. In addition, operative stress may contribute to the occurrence of complications in the first month. In the HD group, 10 out of 21 knees (47.6%) experienced adverse events in the first postoperative month, which is considered the perioperative period. The odds ratio for complications in this period was 4.47 (95% confidence interval [CI], 1.55–12.87; \( P = 0.0074 \)) when comparing the HD and non-HD groups. Similar to our study, Ottesen et al. [19] reported that dialysis-dependent patients were 2.01 times more likely to have any adverse events within 30 days of TKA. Therefore, HD patients should be carefully observed in the first month after TKA.

Additionally, Ottesen et al. [19] reported that dialysis-dependent patients were 6.71 times more likely to die within 30 days of TKA. In our study, no patients died within 30 days of TKA. However, two patients with HD died during the follow-up period. One patient died of cardiac arrest during HD 81 months after TKA at the age of 76. She had received HD for 285 months, beginning when she was 53 years old. The other patient died of septic shock 57 months after TKA at the age of 72; she had received HD for 69 months, beginning when she was 66 years old. Generally, the life expectancy of HD patients is less than half that of the general population [20]. It was not clear whether TKA affected the life expectancy of the HD patients in our study, because a long time elapsed between TKA and death in our two patients.

### Table 4

Number of knees with postoperative complications in the HD and non-HD groups

| Period          | HD group | non-HD group | p-value | Odds ratio | 95% CI       |
|-----------------|----------|--------------|---------|------------|--------------|
| Any complications within the time period |          |              |         |            |              |
| 0–12 months     | 13 (61.9)| 20 (28.2)    | 0.0085  | 4.14       | 1.49–11.51   |
| 12–24 months    | 7 (33.3) | 7 (9.9)      | 0.0149  | 4.57       | 1.38–15.13   |
| 0–1 month       | 10 (47.6)| 12 (16.9)    | 0.0074  | 4.47       | 1.55–12.87   |
| 1–2 months      | 2 (9.5)  | 1 (1.4)      | 0.1293  | 7.37       | 0.63–85.68   |
| 2–3 months      | 0 (0.0)  | 0 (0.0)      | N/A     | N/A        | N/A          |
| 3–4 months      | 2 (9.5)  | 2 (2.8)      | 0.2227  | 3.63       | 0.48–27.50   |
| 4–5 months      | 0 (0.0)  | 0 (0.0)      | N/A     | N/A        | N/A          |
| 5–6 months      | 2 (9.5)  | 1 (1.4)      | 0.1293  | 7.37       | 0.63–85.68   |
| 6–7 months      | 0 (0.0)  | 0 (0.0)      | N/A     | N/A        | N/A          |
| 7–8 months      | 1 (4.8)  | 2 (2.8)      | 0.5449  | 1.73       | 0.15–20.02   |
| 8–9 months      | 1 (4.8)  | 0 (0.0)      | 0.2283  | N/A        | N/A          |
| 9–10 months     | 1 (4.8)  | 0 (0.0)      | 0.2283  | N/A        | N/A          |
| 10–11 months    | 1 (4.8)  | 1 (1.4)      | 0.4064  | 3.50       | 0.21–58.48   |
| 11–12 months    | 2 (9.5)  | 4 (5.6)      | 0.6166  | 1.76       | 0.30–10.37   |
| 12–13 months    | 1 (4.8)  | 0 (0.0)      | 0.2283  | N/A        | N/A          |
| 13–14 months    | 0 (0.0)  | 1 (1.4)      | 1.0000  | N/A        | N/A          |
| 14–15 months    | 0 (0.0)  | 0 (0.0)      | N/A     | N/A        | N/A          |
| 15–16 months    | 0 (0.0)  | 1 (1.4)      | 1.0000  | N/A        | N/A          |
| 16–17 months    | 0 (0.0)  | 1 (1.4)      | 1.0000  | N/A        | N/A          |
| 17–18 months    | 2 (9.5)  | 0 (0.0)      | 0.0502  | N/A        | N/A          |
| 18–19 months    | 1 (4.8)  | 0 (0.0)      | 0.2283  | N/A        | N/A          |
| 19–20 months    | 0 (0.0)  | 0 (0.0)      | N/A     | N/A        | N/A          |
| 20–21 months    | 0 (0.0)  | 0 (0.0)      | N/A     | N/A        | N/A          |
| 21–22 months    | 2 (9.5)  | 2 (2.8)      | 0.2227  | 3.63       | 0.48–27.50   |
| 22–23 months    | 0 (0.0)  | 1 (1.4)      | 1.0000  | N/A        | N/A          |
| 23–24 months    | 2 (9.5)  | 2 (2.8)      | 0.2227  | 3.63       | 0.48–27.50   |
| 0–24 months     | 13 (61.9)| 25 (35.2)    | 0.0429  | 2.99       | 1.09–8.18    |
| Beyond two years| 12 (57.1)| 21 (29.6)    | 0.0364  | 3.17       | 1.16–8.66    |

Categorical variables are expressed as the number of knees (%). HD hemodialysis, N/A not applicable, CI confidence interval.
When we examined each type of complication, we found that anemia, shunt failure, carpal tunnel syndrome, and severe aortic stenosis occurred more frequently in the HD group than the non-HD group. Anemia that required allogenic blood transfusion occurred in four knees (19.1%) in the HD group during the observation period, which was more frequent than in the non-HD group (2 knees [2.8%]; \( P = 0.0230 \)). However, there were no significant differences between the groups in the hemoglobin count on the first postoperative day or in the first postoperative week. A possible reason for this result is that surgeons may have decided to utilize allogenic blood transfusion for HD patients earlier due to poor tolerance for volume load and loss [17]. Dialysis patients have a potential for hemorrhage due to the destruction of platelets by heparin during dialysis [21]. To avoid heparization, which can lead to bleeding at the surgical site, dialysis within 24 h post-operation is not recommended [21]. Therefore, adjustment of the TKA and HD schedules may enable patients to avoid allogenic blood transfusion.

Shunt failure is one of the most important complications of HD. Al-Jaishi et al. [22] reported that the primary patency rate of an arteriovenous fistula was 60% at one year and 51% at two years. As their report suggested, shunt failure was a common complication, and its frequency increased with age. Sridharan et al. [23] reported that HD access satisfaction is associated with better health-related quality of life. In our study, shunt failure occurred 6 times (6 knees in 6 patients; 28.6%) in the HD group across the whole observation period. Therefore, to improve health-related quality of life, surgeons should work closely with the dialysis care team, including the nephrologist and vascular surgeon.

Carpal tunnel syndrome is a well-known complication of HD that is caused by amyloid deposition [24]. In our study, carpal tunnel syndrome was reported 3 times in the HD group (3 knees in 3 patients; 14.3%) in the HD group during the observation period, while it did not occur in the non-HD group. Filho et al. [25] reported that patients with carpal tunnel syndrome have a high prevalence of anxiety (28.7%) and depression (37.6%). Associations between TKA, carpal tunnel syndrome, anxiety, and depression have not been explored. However, anxiety and depression are risk factors for postoperative pain-related symptoms and complications in patients undergoing primary TKA [26]. Therefore, surgeons should be aware that HD patients undergoing primary TKA may be at a greater risk for carpal tunnel syndrome, anxiety, and depression.
Aortic stenosis is another serious complication in HD patients. Several studies reported that aortic stenosis tends to occur more frequently in HD patients than the general population, due to the mechanisms of vascular calcification that are accelerated by the rise of serum calcium and phosphorus concentrations [27–29]. Taniguchi et al. [30] reported that the hazard ratios of sudden death in asymptomatic and symptomatic HD patients with severe aortic stenosis were 7.79 and 3.87, respectively. In our study, severe aortic stenosis occurred following TKA in three knees (14.3%) in the HD group during the observation period, while it did not occur in the non-HD group. Therefore, when performing TKA for HD patients, preoperative screening for aortic stenosis is important to avoid sudden death. Additionally, if the surgeon treats osteoporosis with medications such as active vitamin D preparations to prevent a periprosthetic knee fracture, the serum calcium and phosphorus concentrations should be monitored carefully to prevent aortic valve calcification [31].

Periprosthetic joint infection (PJI) is one of the most important complications in patients undergoing TKA. Lee et al. [5] reported that patients with ESRD experienced PJI more frequently than those without ESRD. In our study, PJI occurred in one knee (4.8%) in the HD group during the observation period. There were no significant differences in PJI occurrence between the HD and non-HD groups. However, in this case, the patient

| Table 5 Comparison of complications between the HD and non-HD groups during the entire observation period |
| --- | --- | --- | --- | --- | --- |
|  | HD group | non-HD group | p-value | Odds ratio | 95% CI |
| Anemia requiring allogenic blood transfusion | 4 (19.1) | 2 (2.8) | 0.0230 | 8.12 | 1.37–48.06 |
| Shunt failure | 6 (28.6) | 0 (0.0) | <0.0001 | N/A | N/A |
| Carpal tunnel syndrome | 3 (14.3) | 0 (0.0) | 0.0106 | N/A | N/A |
| Severe aortic stenosis | 3 (14.3) | 0 (0.0) | 0.0106 | N/A | N/A |
| Periprosthetic joint infection | 1 (4.8) | 3 (4.2) | 1.0000 | 0.88 | 0.09–8.96 |
| Ileus | 2 (9.5) | 0 (0.0) | 0.0502 | N/A | N/A |
| Pressure ulcer | 3 (14.3) | 2 (2.8) | 0.0763 | 0.17 | 0.03–1.12 |
| Hypoglycemia | 2 (9.5) | 0 (0.0) | 0.0502 | N/A | N/A |
| Hematoma around the knee | 2 (9.5) | 2 (2.8) | 0.2227 | 0.28 | 0.04–2.09 |
| Shoulder osteoarthritis | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Pneumomycosis | 2 (9.5) | 0 (0.0) | 0.0502 | N/A | N/A |
| Vertebral compression fracture | 2 (9.5) | 0 (0.0) | 0.0502 | N/A | N/A |
| Erythema induratum of Bazin | 2 (9.5) | 0 (0.0) | 0.0502 | N/A | N/A |
| Femoral neck fracture | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Acute cholecystitis | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Intracardiac thrombus | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Infective endocarditis | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Lumbar spinal stenosis | 2 (9.5) | 1 (1.4) | 0.1293 | 0.14 | 0.01–1.58 |
| Transient ischemic attack | 2 (9.5) | 1 (1.4) | 0.1293 | 0.14 | 0.01–1.58 |
| Subconjunctival hemorrhage | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Posterior interosseous nerve palsy | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Cervical spondylotic myelopathy | 2 (9.5) | 0 (0.0) | 0.0502 | N/A | N/A |
| Sudden cardiac arrest | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Death | 2 (9.5) | 1 (1.4) | 0.1293 | 0.14 | 0.01–1.58 |
| Distal radial fracture | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Colon carcinoma in adenoma | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Acute myocardial infarction | 1 (4.8) | 1 (1.4) | 0.4064 | 0.29 | 0.02–4.77 |
| Urinary tract infection | 2 (9.5) | 0 (0.0) | 0.0502 | N/A | N/A |
| Sepsis | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Pneumonia | 1 (4.8) | 2 (2.8) | 0.5449 | 0.58 | 0.05–6.73 |
| Ascending colonic diverticular bleeding | 1 (4.8) | 0 (0.0) | 0.2283 | N/A | N/A |
| Gastric ulcer | 1 (4.8) | 0 (0.0) | 0.4064 | 0.29 | 0.02–4.77 |

Categorical variables are expressed as the number of knees (%). HD: hemodialysis, N/A: not applicable, CI: confidence interval.
suffered from recurrent PJI that resulted in a long, 5-month hospitalization. Lee et al. [5] also reported that the length of hospital stay of ESRD patients was significantly longer than that of non-ESRD patients when there were complications, including PJI. Therefore, surgeons should pay careful attention to the symptoms of PJI in HD patients to enable early detection and treatment.

Given the complications described above, informed consent should be obtained from HD patients before TKA, after the possible complications associated with HD and the influence of operative stress have been thoroughly discussed.

This study has four limitations. First, this study used a retrospective single-center design, with a relatively small patient sample. However, we used a propensity score matching method, which we believe minimized confounding. Studies with a larger number of patients are needed in the future to correct the covariate balance for variables such as hypertension, history of stroke, and cardiac disease, which were not fully adjusted for in this study. Second, this study included mid-term results. Studies with a long-term follow-up are needed in the future. Third, we performed TKA with various types of implants; a unified implant design may produce different results. Hence, a study of TKA using a unified type of implant may be needed in the future. Finally, all patients in this study were Japanese. The prevalence of HD is higher and the hazard ratio is lower in Japanese patients compared to patients in other countries [32, 33]. Therefore, different results may be obtained in other populations.

Conclusions
TKA improved the AKSS-knee and function scores to the same extent in HD patients as in non-HD patients. However, HD patients developed more complications after TKA, especially within the first month. Therefore, surgeons who perform TKA for HD patients should obtain informed consent for surgery after explaining the possible complications, and HD patients should be carefully observed following TKA.

Abbreviations
AKSS-function: American Knee Society Score-function; AKSS-knee: American Knee Society Score-knee; BMI: Body mass index; ESRD: End-stage renal disease; HD: Hemodialysis; PJI: Periprosthetic joint infection; SD: Standard deviation; TKA: Total knee arthroplasty.

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Authors’ contributions
SK initiated the study, analyzed the data, wrote the first draft of the manuscript, and contributed significantly to the final draft of the manuscript. MS initiated and designed the study, collected data, helped with the first draft of the manuscript, and contributed significantly to the final draft of the manuscript. AK, TN, YM, TS, and SN initiated the study and collected data. AK advised the authors on statistical analyses. MM collected data, helped with the first draft of the manuscript, contributed significantly to the final draft of the manuscript, and supervised the study. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study was approved by the Ethics Committee of Saga University Hospital. All patients provided informed consent based on an opt-out policy prior to participation in this study (reference number: 2020–06-R-05).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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