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original article

## A nationwide comparison of staggered and simultaneous bilateral knee arthroplasty during a single hospitalization: Trends, risks and benefits

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## ABSTRACT

**Background:** We aimed to: (1) perform a nationwide trend analysis of staggered and simultaneous bilateral knee arthroplasty (KA); (2) investigate patient demographics and hospital characteristics in two groups; and (3) compare the outcomes of two groups with a focus on complications, length of stay (LOS) and hospitalization costs. **Methods:** Utilizing the Hospital Quality Monitoring System, we included patients who underwent bilateral KA during a single hospitalization between 2013 and 2019. Patient demographics and hospital characteristics were compared between two groups. Outcomes were compared between propensity-score matched groups using logistic and linear regression.

**Results:** During the study period, 6291 staggered bilateral KA and 6284 simultaneous bilateral KA were performed. From 2013 to 2019, the proportion of staggered bilateral KA increased from 32.74% to 59.08%. Patients who were older, were single, had more comorbidities and had a non-osteoarthritis indication for surgery tended to receive staggered bilateral KA. Compared with 3327 propensity-score matched patients undergoing simultaneous bilateral KA, patients undergoing staggered bilateral KA were associated with a significantly lower incidence of wound infection (odds ratio [OR] = 0.22; 95% confidence interval [CI], 0.07–0.65), and readmission within 30 days (OR = 0.73; 95%CI, 0.54–0.99) and 90 days (OR = 0.70; 95%CI, 0.55–0.89). However, staggered bilateral KA had higher odds of blood transfusion (OR = 1.20; 95%CI, 1.02–1.40) and deep venous thrombosis (DVT) (OR = 2.62; 95%CI, 1.82–3.98). Moreover, staggered bilateral KA can lead to higher costs (108,316.21 Chinese yuan [CNY] vs 103,367.60 CNY) and longer LOS (17.29 days vs 12.18 days) than simultaneous bilateral KA.

**Conclusion:** Our study indicates that staggered bilateral KA has become more common than simultaneous bilateral KA in China. Compared to simultaneous bilateral KA, staggered bilateral KA was associated with a lower incidence of wound infection and readmission. Staggered bilateral KA may be an alternative for patients who can't tolerate simultaneous surgery.

**The translational potential of this article:** Our study indicates that staggered bilateral KA is a safe and economical option for elderly patients who require bilateral KA but are at high clinical risk. The rising proportion of staggered bilateral KA will be a new trend in bilateral KA.

## 1. Background

Approximately 5% of patients with knee osteoarthritis present with bilateral joint pain, and up to one third of patients develop bilateral

osteoarthritis within two years of initial unilateral diagnosis [1]. With the development and clinical translation of various technology, knee arthroplasty (KA) has become a frequent and successful treatment for end-stage knee osteoarthritis [2,3]. For patients suffering bilateral

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diseases, bilateral KA can be performed simultaneously (one procedure under the same anesthesia), staggered (two separate procedures during single hospitalization) or staged (two unilateral arthroplasties in two separate hospitalizations) [4].

Previous studies supported the use of simultaneous bilateral KA as a cost-effective choice [5–7]. Patients underwent bilateral surgery during a single round of anesthesia, which reduced the hospital length of stay (LOS) and total costs for both patients and hospitals [8,9]. Moreover, compared to unilateral KA, patients had similar joint function, pain relief and degree of satisfaction after simultaneous bilateral KA [10,11]. However, numerous studies have indicated that adverse events, including the need for blood transfusion [1,12], venous thrombus embolism (VTE) [1,12], pulmonary embolism (PE) [13], myocardial infarction [13] and in-hospital death [13,14], were more prevalent in simultaneous bilateral KA than in staged bilateral KA.

To strike a balance between the benefits and the potential risks of simultaneous bilateral KA, staggered bilateral KA was considered to be an alternative [15]. However, evidence about the efficacy and safety of staggered bilateral KA is very limited. According to a meta-analysis that compared the postoperative outcomes of staggered bilateral KA, simultaneous bilateral KA and staged bilateral KA, only five relevant articles were found and they offered conflicting results [16–20]. Two studies indicated that staggered bilateral KA had significantly superior outcomes than simultaneous bilateral KA [17,18], and one study suggested that staggered bilateral KA was correlated with more complications than simultaneous bilateral KA [20]. However, these studies only included single centers and had limited sample sizes (no more than 500 patients in the staggered group). Moreover, to the best of our knowledge, trend analysis of staggered bilateral KA surgery has never been conducted. To fully understand the utilization, benefits and risks of staggered bilateral KA, studies with large sample sizes are needed.

Based on the Chinese national medical database (i.e., the Hospital Quality Monitoring System [HQMS]), we aimed to: (1) perform a trend analysis of staggered and simultaneous bilateral KA during a single hospitalization in China; (2) investigate patient demographics and hospital characteristics in staggered and simultaneous bilateral KA; and (3) compare the outcomes of staggered and simultaneous bilateral KA with a focus on complications, LOS and hospitalization costs.

## 2. Materials and methods

### 2.1. Data source

We used the HQMS, a national electronic medical record database in mainland China, which contained 230.4 million inpatient records across all 31 provincial-level administrative regions in mainland China. Since 2013, tertiary hospitals have been required to upload their inpatient discharge records. By 2019, more than 1000 hospitals had been included. Patient demographics, clinical diagnoses, procedures, and hospital characteristics were all recorded in the HQMS. Clinical diagnoses were coded in accordance with International Classification of Diseases, Tenth Revision (ICD-10) and the procedures were coded in the form of International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM). Data in HQMS from 2013 to 2019 were analyzed for our study. Detailed descriptions of this database have been previously reported [21–23]. This study was authorized by the HQMS Committee Board and approved by the institutional review board, with waiver of informed consent.

### 2.2. Selection of patients

We identified primary KA in HQMS from 2013 to 2019 based on the ICD-9-CM (81.54). We also searched other knee-related procedure codes, diagnosis codes, and free texts to avoid miscoding. Then, we excluded patients with missing demographic data. We also excluded all patients undergoing unilateral KA or staged bilateral KA during separate

admissions. The remaining patients were analyzed for national trends in the volume of staggered and simultaneous bilateral KA. Finally, we excluded patients with missing information on LOS or readmission before propensity score matching.

The participants were then stratified into two groups according to the type of surgery: (1) staggered bilateral KA (two sequential arthroplasties performed within a single admission but in two separate anesthesia) and (2) simultaneous bilateral KA (both arthroplasties were performed during the same surgical session) [17].

### 2.3. Study variables

Patient-specific information extracted from HQMS included age, sex, marital status, indication for KA and type of arthroplasty. For our research purposes, age at the time of admission was divided into four groups: < 60, 60–69, 70–79, and ≥80 years old. Marital status was divided into three categories: married, single (i.e., unmarried, divorced and widowed) and unknown. The indication for KA was divided into osteoarthritis and non-osteoarthritis. Type of arthroplasty was divided into total KA and unicompartmental KA. Comorbidities extracted included myocardial infarction, congestive heart failure, peripheral vascular disease, cerebrovascular disease, dementia, chronic obstructive pulmonary disease, rheumatic disease, peptic ulcer disease, diabetes, chronic renal disease, liver disease, tumor, hypertension and coronary artery disease [24,25]. The Charlson Comorbidity Index (CCI) was calculated [26] and divided into three categories: 0, 1–2, and 3 or more [22].

Hospitals were spread over six regions in mainland China: i.e., north, east, north-east, south-central, south-west, and north-west regions [27] and were grouped into provincial and nonprovincial hospitals. In addition, we calculated annual numbers of KA at each hospital and divided hospital volume of KA into three groups: < 250/year, 250–500/year, and >500/year [28].

### 2.4. Assessment of outcomes

The outcomes included postoperative complications, LOS and hospitalization costs in staggered and simultaneous bilateral KA. The LOS was calculated from the day of surgery to discharge in the simultaneous bilateral KA group, or from the first operation to discharge in the staggered bilateral KA group. Complications in our study included in-hospital death, blood transfusion, wound infection, deep venous thrombosis (DVT), PE, new-onset myocardial infarction, prosthetic failure within 90 days (i.e., periprosthetic fracture, dislocation, prosthetic joint infection, aseptic loosening, and other prosthetic-related complications), and re-admission within 30 and 90 days.

### 2.5. Statistical analysis

Line charts were drawn to describe changes in patient numbers and proportion of simultaneous bilateral KA and staggered bilateral KA over the years. Patient demographics and hospital characteristics were compared using chi-square test or Fisher's exact test for categorical data, and Student t-test and Mann–Whitney U test for continuous data.

Then, a propensity score-matched analysis was performed to mitigate the effects of confounding factors, which is commonly used in the presence of a large number of covariates in epidemiological studies [29]. The propensity score is the probability of treatment assignment (i.e., staggered bilateral KA) conditional on observed baseline characteristics, and is estimated by using modeling to predict treatment allocation with covariates [30]. Calendar time was divided into 7 one-year blocks from January 1, 2013 to December 31, 2019 and patients were assigned into a separate block based on their index date of KA. For example, patients undergoing KA between January 1, 2013 and December 31, 2013 would be distributed to the first block. Propensity scores were calculated by logistic regression separately in each block. The covariates included in

logistic regression consisted of patient demographics (i.e., sex, age, CCI, marital status, comorbidities, indication of surgery and type of surgery) and hospital characteristics (i.e., region, type and volume of hospital) [31]. Within each time block, staggered bilateral KA were matched 1:1 to simultaneous bilateral KA using the greedy matching method [32,33], i.e., for each patient receiving staggered bilateral KA, a patient receiving simultaneous bilateral KA with the closet propensity score was selected as a comparator from the same time block. This process was then repeated until staggered KA subjects had been matched to all simultaneous KA subjects, or until we exhausted the list of staggered KA subjects for whom a matched simultaneous KA subject could be found [32]. Standardized differences for all covariates were calculated before and after matching, with  $<0.1$  considered balance [34]. After matching, the logistic regression was used to examine the relationship between the type of bilateral KA and outcomes with the calculation of odds ratios (ORs) and 95% confidence interval (CI). Specially, the differences of LOS and total costs of two groups were compared using a linear regression model. In addition, we performed a sensitivity analysis by conducting asymmetric trimming to exclude patients whose propensity score was  $<2.5$ th percentile of the propensity score of the staggered bilateral KA group and  $>97.5$ th percentile of the propensity score of the simultaneous bilateral KA group.

All statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Statistical significance was set at  $P < 0.05$ .

### 3. Results

#### 3.1. Study population

A total of 220,557 patients undergoing primary KA were identified in HQMS from 2013 to 2019. Of these patients, 1,634 patients with missing demographic data were excluded. We also excluded all patients undergoing unilateral KA or staged bilateral KA during separate admissions.

There were 12,575 patients included for nationwide trend analysis (6291 patients in the staggered group and 6284 patients in the simultaneous group). Then, we further excluded 688 patients with missing information on LOS or readmission. Thus, a total of 11,887 patients (5867 patients in the staggered group and 6020 patients in the simultaneous group) were included before propensity score matching (see Fig. 1).

#### 3.2. Nationwide trends in bilateral KA from 2013 to 2019 in China

In 2013, among all patients undergoing bilateral KA, the percentage of staggered bilateral KA was lower than the percentage of simultaneous bilateral KA (32.74% vs 67.26%). However, the proportion of staggered bilateral KA continued to increase. Starting in 2017, the percentage of staggered bilateral KA exceeded the percentage of simultaneous bilateral KA, and the gap between them is widening. Although there was a small increase in the proportion of simultaneous bilateral KA in 2015 and 2019, the trend was not obvious. In 2019, staggered bilateral KA accounted for 59.08% of all bilateral KA procedures. The total number of bilateral KA continued to rise from 2013 to 2015 and remained roughly stable over the next five years (Fig. 2).

#### 3.3. Patient demographics and hospital characteristics

Patient demographics and hospital characteristics before matching were compared in Table 1. The mean (standard deviation [SD]) age was greater in the staggered group (66.15 [7.75]) than that in the simultaneous group (64.09 [7.40]) ( $P < 0.001$ ). Among patients over 80 years old, 189 (3.22%) patients underwent staggered bilateral KA and 64 (1.06%) patients underwent simultaneous bilateral KA ( $P < 0.001$ ). Most patients undergoing bilateral KA were female, accounting for 80.12% of the total number of patients. With regard to marital status, single patients were more likely to select staggered bilateral KA. In addition, the CCI was lower in patients undergoing simultaneous bilateral KA than in those

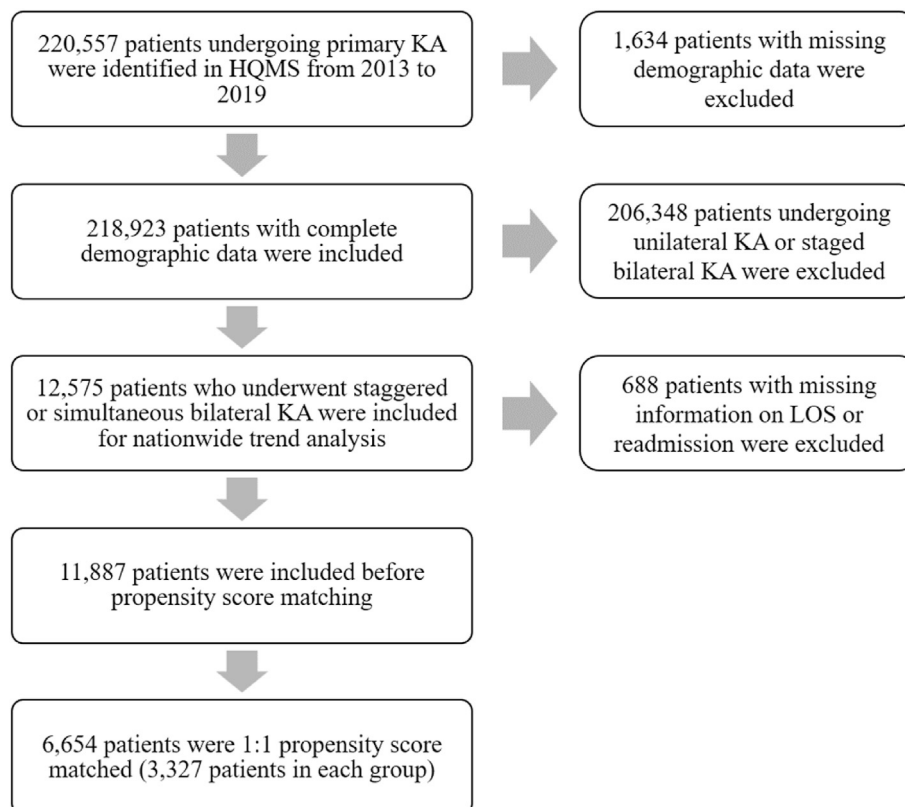


Fig. 1. Flowchart of analysis.

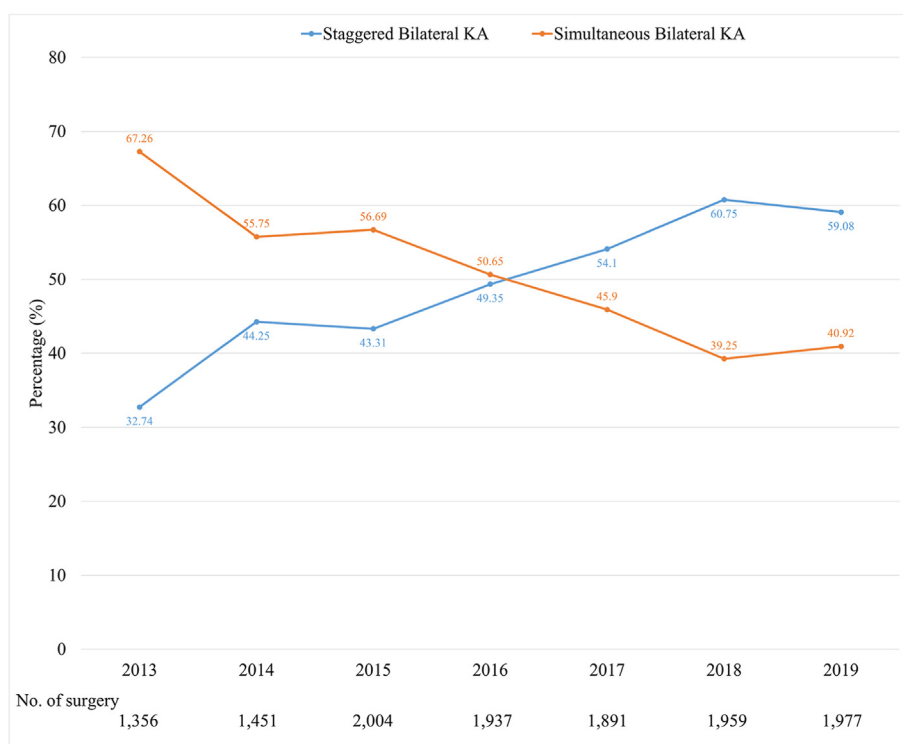


Fig. 2. Trends in staggered bilateral KA and simultaneous bilateral KA in China from 2013 to 2019.

undergoing staggered bilateral KA ( $P < 0.001$ ). A total of 5376 (91.63%) patients in the staggered bilateral KA group and 5727 (95.08%) patients in the simultaneous bilateral KA group ( $P < 0.001$ ) underwent surgery for osteoarthritis. In addition, the type of bilateral KA was also influenced by hospital characteristics. Staggered bilateral KA was more frequently performed in the south-central, south-west and north-west regions. Provincial hospitals and hospitals with higher volume tended to perform simultaneous bilateral KA. The proportion of total KA (TKA) was higher in the staggered group (5582, 95.14%) than that in the simultaneous group (5545, 92.11%) ( $P < 0.001$ ). The baseline characteristics after propensity score-matched were shown in Table 2. The characteristics of the staggered bilateral KA group and its matched comparison simultaneous bilateral KA group were well-balanced, with all standardized differences being  $< 0.1$  [34].

### 3.4. Comparison of complications, LOS and hospitalization costs after matching

Complications, LOS and hospitalization costs are compared in Table 3. The in-hospital death rate was quite low in both the staggered bilateral KA group (1, 0.03%) and the simultaneous bilateral KA group (2, 0.06%). Staggered bilateral KA was associated with a lower risk of wound infection (OR 0.22; 95%CI 0.07–0.65), readmission within 30 days (OR 0.73; 95%CI 0.54–0.99) and 90 days (OR 0.70; 95%CI 0.55–0.89) than simultaneous bilateral KA. However, staggered bilateral KA increased the incidence of blood transfusion (OR 1.20, 95%CI 1.02–1.40) and DVT (OR 2.62; 95%CI 1.82–3.98), but there was no significant difference in the incidence of PE ( $P = 0.133$ ). There was no patient in the staggered group and 3 patients (0.09%) in the simultaneous group had the new-onset myocardial infarction. In addition, there was no significant difference in the incidence of prosthetic failure within 90 days between staggered (0.24%) and simultaneous group (0.51%) ( $P = 0.071$ ). The mean LOS was longer in the staggered bilateral KA group (17.29 days) than in the simultaneous bilateral KA group (12.18 days) ( $P < 0.001$ ). In addition, the mean total costs were higher in the staggered

bilateral KA group (108,316.21 Chinese yuan [CNY]) than in simultaneous bilateral KA group (103,367.60 CNY) ( $P < 0.001$ ). Sensitivity analysis didn't alter the results.

## 4. Discussion

Though new technology (e.g., robot-assisted system) has improved the outcomes following KA [35], bilateral KA can be still challenging for both patients and surgeon. In our study, we found that staggered bilateral KA has become more common than simultaneous bilateral KA in China. Compared to simultaneous bilateral KA, staggered bilateral KA was associated with a lower incidence of wound infection and readmission, while more DVT, higher rates of blood transfusion, increased costs, and prolonged LOS were observed. To the best of our knowledge, this is the first study to use a nationwide database to compare the risks and benefits of staggered and simultaneous bilateral KA. Moreover, this study performed the first trend analysis of staggered bilateral KA.

Staggered bilateral KA was recommended as an alternative in patients with high clinical risks [17,18]. In our trend analysis, we observed this phenomenon. As the population ages, the proportion of staggered bilateral KA has been increasing. Clinicians tend to perform staggered bilateral KA rather than simultaneous bilateral KA in patients with older age and more comorbidities. Similar results have been reported by Courtney et al. who found that patients in the simultaneous group were younger and had lower body mass index and CCI than those in the staged and unilateral groups [19]. In addition, hospitals located in underdeveloped areas of China with lower surgery volumes preferred staggered bilateral KA, probably for safety reasons. In our study, the proportion of simultaneous bilateral KA was lower than that in previous studies, which is possibly due to the complex medical environment in China [36]. Using the PearlDiver Patient Records Database in the United States, Richardson et al. reported that 1673 patients underwent simultaneous bilateral KA, while only 751 patients underwent staged bilateral KA within 3 months between January 2007 and April 2015 [37]. Similarly, Koh et al. reported 368 patients undergoing staggered bilateral KA, while 820 patients

**Table 1**  
Patient demographics and hospital characteristics before matching.

| Characteristics*            | Staggered bilateral KA | Simultaneous bilateral KA | P value | Standardized difference |
|-----------------------------|------------------------|---------------------------|---------|-------------------------|
| Number of procedures        | 5867 (49.36)           | 6020 (50.64)              |         |                         |
| Age, mean (SD), year        | 66.15 (7.75)           | 64.09 (7.40)              | <0.001  | 0.271                   |
| Age groups                  |                        |                           | <0.001  |                         |
| < 60                        | 1023 (17.44)           | 1445 (24.00)              |         | 0.163                   |
| 60–69                       | 2918 (49.74)           | 3242 (53.85)              |         | 0.082                   |
| 70–79                       | 1737 (29.61)           | 1269 (21.08)              |         | 0.197                   |
| ≥ 80                        | 189 (3.22)             | 64 (1.06)                 |         | 0.149                   |
| Sex                         |                        |                           | 0.341   | 0.017                   |
| Male                        | 1187 (20.23)           | 1176 (19.53)              |         |                         |
| Female                      | 4680 (79.77)           | 4844 (80.47)              |         |                         |
| Marital status              |                        |                           | <0.001  |                         |
| Married                     | 5465 (93.15)           | 5655 (93.94)              |         | 0.032                   |
| Single                      | 350 (5.97)             | 215 (3.57)                |         | 0.113                   |
| Unknown                     | 52 (0.89)              | 150 (2.49)                |         | 0.124                   |
| Charlson Comorbidity Index  |                        |                           | <0.001  |                         |
| 0                           | 4113 (70.10)           | 4763 (79.12)              |         | 0.208                   |
| 1–2                         | 1656 (28.23)           | 1203 (19.98)              |         | 0.194                   |
| ≥3                          | 98 (1.67)              | 54 (0.90)                 |         | 0.069                   |
| Comorbidity                 |                        |                           |         |                         |
| Myocardial infarction       | 14 (0.24)              | 7 (0.12)                  | 0.112   | 0.029                   |
| Congestive heart failure    | 52 (0.89)              | 28 (0.47)                 | 0.005   | 0.051                   |
| Peripheral vascular disease | 254 (4.33)             | 103 (1.71)                | <0.001  | 0.153                   |
| Cerebrovascular disease     | 342 (5.83)             | 195 (3.24)                | <0.001  | 0.125                   |
| Dementia                    | 23 (0.39)              | 14 (0.23)                 | 0.119   | 0.029                   |
| COPD                        | 135 (2.03)             | 64 (1.06)                 | <0.001  | 0.096                   |
| Rheumatic disease           | 208 (3.55)             | 162 (2.69)                | 0.007   | 0.049                   |
| Peptic ulcer                | 39 (0.66)              | 21 (0.35)                 | 0.015   | 0.044                   |
| Diabetes                    | 797 (13.58)            | 698 (11.69)               | 0.001   | 0.060                   |
| Chronic renal disease       | 29 (0.49)              | 15 (0.25)                 | 0.028   | 0.040                   |
| Liver disease               | 248 (4.23)             | 102 (1.69)                | <0.001  | 0.150                   |
| Tumor                       | 36 (0.61)              | 44 (0.73)                 | 0.434   | 0.014                   |
| Hypertension                | 2824 (48.13)           | 2353 (39.09)              | <0.001  | 0.183                   |
| Coronary artery disease     | 296 (5.05)             | 159 (2.64)                | <0.001  | 0.125                   |
| Indication of KA            |                        |                           | <0.001  | 0.139                   |
| Osteoarthritis              | 5376 (91.63)           | 5727 (95.08)              |         |                         |
| Non-osteoarthritis          | 491 (8.37)             | 296 (4.92)                |         |                         |
| Type of surgery             |                        |                           | <0.001  | 0.124                   |
| Total KA                    | 5582 (95.14)           | 5545 (92.11)              |         |                         |
| Unicompartmental KA         | 285 (4.86)             | 475 (7.89)                |         |                         |
| Region                      |                        |                           | <0.001  |                         |
| North                       | 2116 (36.07)           | 2902 (48.21)              |         | 0.248                   |
| East                        | 1158 (19.74)           | 1615 (26.83)              |         | 0.168                   |
| North-east                  | 161 (2.74)             | 308 (5.12)                |         | 0.122                   |
| South-central               | 1046 (17.83)           | 837 (13.90)               |         | 0.108                   |
| South-west                  | 389 (6.63)             | 89 (1.48)                 |         | 0.263                   |
| North-west                  | 997 (16.99)            | 269 (4.47)                |         | 0.413                   |
| Type of hospital            |                        |                           | <0.001  | 0.486                   |
| Provincial                  | 3322 (56.62)           | 4739 (78.72)              |         |                         |
| Nonprovincial               | 2545 (43.38)           | 1281 (21.28)              |         |                         |
| Volume of hospital          |                        |                           | <0.001  |                         |
| ≥500/year                   | 688 (11.73)            | 2222 (36.91)              |         | 0.614                   |
| 250–499/year                | 2175 (37.07)           | 1554 (25.81)              |         | 0.244                   |
| <250/year                   | 3004 (51.20)           | 2244 (37.28)              |         | 0.283                   |

\*Values are frequency (%) of total unless otherwise specified.

KA: knee arthroplasty; SD: standard deviation; COPD: chronic obstructive pulmonary disease.

underwent simultaneous bilateral KA during the same period [18]. However, in China, the number of patients undergoing staggered bilateral KA and simultaneous bilateral KA between 2013 and 2019 was nearly equal.

Our study found that staggered bilateral KA was associated with a lower risk of wound infection, readmission within 30 and 90 days, which was consistent with previous studies [17,18]. Sliva et al. reviewed 332 patients undergoing staggered or simultaneous bilateral KA and found that the incidence of overall complications was 2.5 times lower in the staggered group than in the simultaneous group [17]. Forster et al. reviewed 102 staggered bilateral KA patients with a one-week interval between surgeries and found a lower incidence of complications than in the simultaneous group although the result was not statistically significant [38].

In addition, simultaneous bilateral KA was considered an

independent risk factor for infection [37,39]. We found that staggered bilateral KA was associated with a lower incidence of wound infection than simultaneous bilateral KA (OR 0.22, 95% CI 0.07–0.65). Sliva et al. found that patients undergoing simultaneous bilateral KA were 3.92 times more likely to suffer minor complications including superficial infection than those in the staggered group [17]. After comparing 245 patients undergoing staggered bilateral KA and 763 patients undergoing simultaneous bilateral KA, Memtsoudis et al. found that infection and wound dehiscence were more frequent in the simultaneous group than in the stagger group [15]. Similarly, Poultsides et al. reported that the incidence of wound infection was 3 times higher in the simultaneous group than in the staged group [16].

The in-hospital death rate was quite low in both groups (0.03% in staggered bilateral KA and 0.06% in simultaneous bilateral KA). In addition, the incidence of myocardial infarction in our study was slightly

**Table 2**  
Patient demographics and hospital characteristics after matching.

| Characteristics*            | Staggered bilateral KA | Simultaneous bilateral KA | P value | Standardized difference |
|-----------------------------|------------------------|---------------------------|---------|-------------------------|
| Number of procedures        | 3327 (50.00)           | 3327 (50.00)              |         |                         |
| Age, mean (SD), year        | 65.27 (7.36)           | 65.03 (7.50)              | 0.188   | 0.033                   |
| Age groups                  |                        |                           | 0.735   |                         |
| < 60                        | 675 (20.29)            | 682 (20.50)               |         | 0.005                   |
| 60–69                       | 1739 (52.27)           | 1764 (53.02)              |         | 0.015                   |
| 70–79                       | 843 (25.34)            | 821 (24.68)               |         | 0.015                   |
| ≥ 80                        | 70 (2.10)              | 60 (1.80)                 |         | 0.022                   |
| Sex                         |                        |                           | 0.830   | 0.005                   |
| Male                        | 665 (19.99)            | 672 (20.20)               |         |                         |
| Female                      | 2662 (80.01)           | 2655 (79.80)              |         |                         |
| Marital status              |                        |                           | 0.209   |                         |
| Married                     | 3132 (94.14)           | 3134 (94.20)              |         | 0.003                   |
| Single                      | 149 (4.48)             | 132 (3.97)                |         | 0.025                   |
| Unknown                     | 46 (1.38)              | 61 (1.83)                 |         | 0.036                   |
| Charlson Comorbidity Index  |                        |                           | 0.791   |                         |
| 0                           | 2488 (74.78)           | 2491 (74.87)              |         | 0.002                   |
| 1–2                         | 797 (23.96)            | 800 (24.05)               |         | 0.002                   |
| ≥3                          | 42 (1.26)              | 36 (1.08)                 |         | 0.017                   |
| Comorbidity                 |                        |                           |         |                         |
| Myocardial infarction       | 8 (0.24)               | 4 (0.12)                  | 0.248   | 0.028                   |
| Congestive heart failure    | 22 (0.66)              | 18 (0.54)                 | 0.526   | 0.016                   |
| Peripheral vascular disease | 67 (2.01)              | 81 (2.43)                 | 0.245   | 0.003                   |
| Cerebrovascular disease     | 156 (4.69)             | 138 (4.15)                | 0.283   | 0.026                   |
| Dementia                    | 7 (0.21)               | 11 (0.33)                 | 0.345   | 0.023                   |
| COPD                        | 58 (1.74)              | 56 (1.68)                 | 0.850   | 0.005                   |
| Rheumatic disease           | 109 (3.28)             | 96 (2.89)                 | 0.356   | 0.023                   |
| Peptic ulcer                | 14 (0.42)              | 16 (0.48)                 | 0.714   | 0.009                   |
| Diabetes                    | 458 (13.77)            | 445 (13.38)               | 0.642   | 0.011                   |
| Chronic renal disease       | 13 (0.39)              | 9 (0.27)                  | 0.393   | 0.021                   |
| Liver disease               | 72 (2.16)              | 88 (2.65)                 | 0.200   | 0.031                   |
| Tumor                       | 24 (0.72)              | 28 (0.84)                 | 0.578   | 0.014                   |
| Hypertension                | 1498 (45.03)           | 1476 (44.36)              | 0.588   | 0.013                   |
| Coronary artery disease     | 125 (3.76)             | 128 (3.85)                | 0.848   | 0.005                   |
| Indication of KA            |                        |                           | 0.921   | 0.002                   |
| Osteoarthritis              | 3109 (93.45)           | 3107 (93.39)              |         |                         |
| Nonosteoarthritis           | 218 (6.55)             | 220 (6.61)                |         |                         |
| Type of surgery             |                        |                           | 0.838   | 0.005                   |
| Total KA                    | 3125 (93.93)           | 3121 (93.81)              |         |                         |
| Unicompartmental KA         | 202 (6.07)             | 206 (6.19)                |         |                         |
| Region                      |                        |                           | 0.263   |                         |
| North                       | 1274 (38.29)           | 1255 (37.72)              |         | 0.012                   |
| East                        | 939 (28.22)            | 975 (29.31)               |         | 0.024                   |
| North-east                  | 133 (4.00)             | 145 (4.36)                |         | 0.018                   |
| South-central               | 632 (19.00)            | 598 (17.97)               |         | 0.026                   |
| South-west                  | 112 (3.37)             | 89 (2.52)                 |         | 0.040                   |
| North-west                  | 237 (7.12)             | 265 (7.97)                |         | 0.032                   |
| Type of hospital            |                        |                           | 0.068   | 0.045                   |
| Provincial                  | 2048 (61.56)           | 2120 (63.72)              |         |                         |
| Nonprovincial               | 1279 (38.44)           | 1207 (36.28)              |         |                         |
| Volume of hospital          |                        |                           | 0.241   |                         |
| ≥500/year                   | 629 (18.91)            | 628 (18.88)               |         | 0.001                   |
| 250–499/year                | 885 (26.60)            | 944 (28.37)               |         | 0.040                   |
| <250/year                   | 1813 (54.49)           | 1755 (52.75)              |         | 0.035                   |

\*Values are frequency (%) of total unless otherwise specified.

KA: knee arthroplasty; SD: standard deviation; COPD: chronic obstructive pulmonary disease.

lower than that in previous studies [6,7]. The incidence of myocardial infarction was 0.4% in the staggered group, 0 in the simultaneous group and 0 in the stage group in Sliva et al., [17]. The incidence of myocardial infarction was 0 in the simultaneous group and 0.1% in the staggered group in Niki et al., [12]. However, we only included new-onset events and the results were reasonable. We also found that staggered bilateral KA was associated with a higher risk of DVT. To the best of our knowledge, there have been no studies comparing the incidence of DVT between staggered bilateral KA and simultaneous bilateral KA. In contrast, previous studies have reported that simultaneous bilateral KA was associated with a higher rate of DVT than staged bilateral KA [40]. One possible explanation is that staggered bilateral KA leads to longer LOS, and cumulative operation and anesthesia time than simultaneous bilateral KA, and these factors are associated with a higher incidence of DVT [41,42]. Unlike DVT, the incidence of PE was similar in the two groups.

In fact, only 27% of all DVTs and 13% of distal DVTs would lead to PE [43]; and previous studies have found no difference in the incidence of PE between staggered and simultaneous bilateral KA [15,20,44].

The LOS was longer in the staggered group than in the simultaneous group, which is certainly explainable by the practice of staging itself. In addition, compared to the USA and other developed country, mean LOS in China was quite long, which may be due to the lack of well-established referral or extended care system [45]. The total hospital charges increased along with prolonged hospitalization and an increase in operations and anesthesia. These results are supported by previous studies [20,37]. In addition, the staggered group was associated with a higher incidence of blood transfusion than the simultaneous group, but we failed to calculate the total amount of blood transfused. Also, some transfusions may be preventive blood transfusions between the two procedures in the staggered group. Yoon et al. [46] found that there was no significant

**Table 3**  
Comparison of complications, LOS and hospitalization costs between two groups.

| Characteristics*                                   | Staggered bilateral KA (n = 3327) | Simultaneous bilateral KA (n = 3327) | OR (95%CI)       | P value |
|--|-----------------------------------|--------------------------------------|------------------|---------|
| In-hospital death                                  | 1 (0.03)                          | 2 (0.06)                             | 0.50 (0.05–5.51) | 0.564   |
| Readmission within 30 days                         | 72 (2.16)                         | 98 (2.95)                            | 0.73 (0.54–0.99) | 0.043   |
| Readmission within 90 days                         | 120 (3.61)                        | 169 (5.08)                           | 0.70 (0.55–0.89) | 0.003   |
| Blood transfusion                                  | 368 (11.06)                       | 313 (9.41)                           | 1.20 (1.02–1.40) | 0.026   |
| Wound Infection                                    | 4 (0.12)                          | 18 (0.54)                            | 0.22 (0.07–0.65) | 0.003   |
| DVT  | 80 (2.40)                         | 31 (0.93)                            | 2.62 (1.82–3.98) | <0.001  |
| PE   | 6 (0.18)                          | 9 (0.27)                             | 0.66 (0.24–1.87) | 0.438   |
| New-onset myocardial infarction                    | 0                                 | 3 (0.09)                             | N/A              | N/A     |
| Prosthetic failure within 90 days                  | 8 (0.24)                          | 17 (0.51)                            | 0.47 (0.20–1.09) | 0.071   |
| LOS, mean (SD), days                               | 17.29 (8.70)                      | 12.18 (5.87)                         |                  | <0.001  |
| Total hospitalization costs, mean (SD), China yuan | 108,316.21 (27,071.77)            | 103,367.60 (29,476.98)               |                  | <0.001  |

\*Values are frequency (%) unless otherwise specified.

KA: knee arthroplasty; OR: odds ratios; DVT: deep venous thrombosis; PE: pulmonary embolism; LOS: length of stay.

difference in blood loss between the simultaneous bilateral and staged bilateral groups. The average blood loss was 1299 mL in the simultaneous bilateral group compared with 1302 mL in the staged bilateral group. More studies are needed to compare the blood transfusions between staggered and simultaneous bilateral KA patients.

There are several limitations in our study. First, despite our efforts to control for errant data, our study was limited by issues inherent to administrative databases that are dependent upon proper documentation and coding. Second, we did not obtain the cause of readmission and made no further analysis. Third, restricted by the database, we were unable to study the use of prostheses and compare the long-term survival rate of prostheses between the two groups. Some important factors, such as body mass index, were not available in the HQMS, which may potentially influence the results. However, other important patient characteristics (i.e., sex, age, marriage status, CCI, comorbidity, indication of surgery, and type of surgery) were propensity score-matched, which may improve the validity of our results. Fourth, for ethical reasons, all our data are anonymized, and surgeon information is not available in this case. Thus, the seniority or operational skill of surgeons is a potential confounding factor and may influence the results. However, we have matched the region, type, and volume of hospital in our study to mitigate the influence of this confounding factor. Though hospital level is not a complete representation of seniority or operational skill of a particular surgeon, it can partly reflect the overall experience of the surgeon in that hospital. Finally, we did not collect the interval between two procedures in the staggered group, which may be associated with outcomes.

## 5. Conclusion

Our study indicates that staggered bilateral KA has become more common than simultaneous bilateral KA in China. Compared to simultaneous bilateral KA, staggered bilateral KA was associated with a lower incidence of wound infection and readmission, while more DVT, higher rates of blood transfusion, increased costs, and prolonged LOS were

observed. Staggered bilateral KA may be an alternative for patients who are unable to tolerate simultaneous surgery.

## Authors' contributions

Qiao Jiang: Manuscript writing; Data collection; Data analysis; Study conceive; Participated in the design of the study; Data interpretation; Project coordination, Huizhong Long: Manuscript writing; Data collection; Data analysis; Study conceive; Participated in the design of the study; Data interpretation; Project coordination, Dongxing Xie: Data collection; Data analysis; Study conceive; Participated in the design of the study; Data interpretation, Xiaoxiao Li: Data curation; Investigation; Methodology; Validation; Writing - review & editing, Haibo Wang: Data curation; Validation; Methodology; Validation; Writing - review & editing, Chao Zeng: Project administration; Supervision; Writing - review & editing, Guanghua Lei: Project administration; Supervision; Writing - review & editing.

## Ethics approval

This study was authorized by the HQMS Committee Board and approved by the institutional review board of Xiangya hospital, with waiver of informed consent.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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