Results of Statistical Analysis

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## RESULTS

In 2011, there were 239,950 TKA among 28,808,011 beneficiaries in the study, while in 2015, there were 262,013 TKA among 30,177,710 beneficiaries. When the expected rate of TKA was based on adjustment for age, sex, and race/ethnicity, the OER varied widely among HRRs (Supplemental figure 1-map). The highest OER of 1.72 was in Idaho Falls, ID, while the lowest OER of 0.63 was in Newark, NJ. HRRs with the highest OER were predominantly white, while HRRs with the lowest OERs had large proportions of ethnic minorities (Supplemental table 1). Despite adjustment of the expected rates for race/ethnicity, significant correlations remained between the OER and the racial composition of the HRR, indicating residual confounding (Supplemental figure 2). Therefore, subsequent analyses used race-specific models to generate the expected number of TKA. Because whites comprised 84.64% of the sample, our analyses focused on associations among whites.

Among whites, the clinical characteristics of beneficiaries varied widely among HRR, with for example, the percent of poor beneficiaries ranging from 0.83% to 3.33%, and those with dementia ranging from 0.63% to 2.63%. (Supplemental table 2). Adjustment for indicators of knee osteoarthritis, comorbidities, and socioeconomic status resulted in OERs that were somewhat less divergent, with 10th and 90th percentiles of X and X, compared to X and X for OERs based on age and sex-adjustment (Supplemental figure 3 and Supplemental table 3). However, substantial regional variation in OERs remained after adjustment for patient characteristics, with high OER in several HRR in the upper Midwest and mountain west, and low OER in the New York City region and south Florida (Figure 1 and Supplemental table 4).

HRRs that included more rural residents had generally higher OER than those that were less rural (Figure 2). HRRs whose residents had fewer outpatient visits for knee complaints also had higher OER than those whose residents had more such visits. There was no association between the OER and the proportion of Medicare Advantage beneficiaries in an HRR. In contrast, HRRs with more TKA surgeons per capita had higher OERs than those with fewer surgeons per capita.

HRRs with high OERs tended to have high OERs among patients with very low estimated probabilities of TKA as well as those with higher estimated probabilities of TKA, while HRRs with low OERs tended to have low OERs across quartiles of estimated probability of TKA (Figure 3). This pattern suggests that HRRs with high OERs were less discriminating in performing TKA across a spectrum of beneficiaries with varying likelihood of TKA, and that HRRs with low OERs were universally more discriminating. Consistent with this interpretation, rates of TKA among beneficiaries with dementia, peripheral vascular disease, and leg ulcers were higher in HRRs with high OERs, as were rates among healthy 65 to 69 year-olds (Figure 4).

The number of TKA surgeons per HRR ranged from 48 to 1047. Most surgeons regardless of HRR performed between X and X TKA annually (Figure 6). Look for thresholds at 60.

We limited the analysis of blacks and Hispanics to those HRRs that had at least 15,000 black or Hispanic Medicare beneficiaries to provide stable OER estimates. This number corresponded to the lowest HRR population in the analysis of whites. Among blacks, there was comparatively little variation in OERs among the 42 HRRs studied, with a range from 0.59 to 1.38 (Supplemental table 5).

Among Hispanics, OERs ranged from X to X among the X HRRs that were examined (Supplemental table 5). HRRs with high OERs in whites also tended to have higher OERs among blacks and Hispanics (Figure 5). However, there was no association between TKA surgeon density in an HRR and the OER among blacks or Hispanics (Figure 6).

## Figures

Figure 1. Observed-to-expected ratios for rates of total knee arthroplasties among white Medicare beneficiaries age 65 to 89 in 2011-2015, by Health Referral Region. Ratios greater than 1.0 indicate higher than expected rates of total knee arthroplasty, while ratios less than 1.0 indicate lower than expected rates.

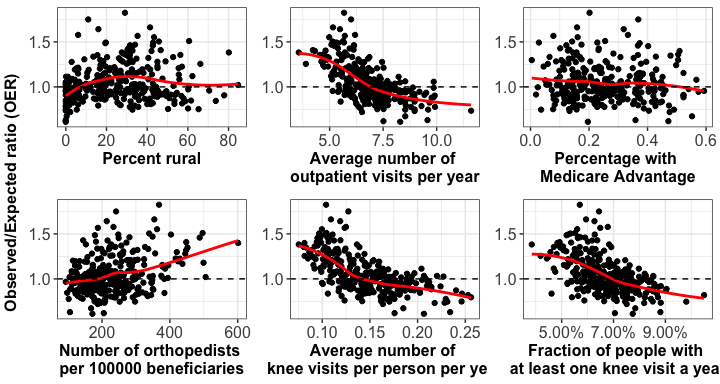


Figure 2. Associations between the percent of beneficiaries living in rural areas, the number of outpatient visits for knee complaints, the percent of beneficiaries in Medicare Advantage plans, and the number of surgeons performing total knee arthroplasties per 10,000 beneficiaries in the and the observed-to-expected ratio for rates of total knee arthroplasty among white Medicare beneficiaries in each Health Referral Region.

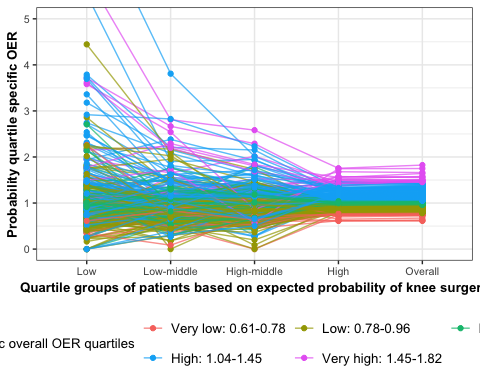


Figure 3. Observed-to-expected ratios for rates of total knee arthroplasty in each Health Referral Region among white Medicare beneficiaries, stratified by beneficiary’s expected probability of total knee arthroplasty. Expected probabilities were stratified into quartiles from very low (on the left) to highest (on the right), and quartile-specific observed-to-expected ratios were computed for each region.

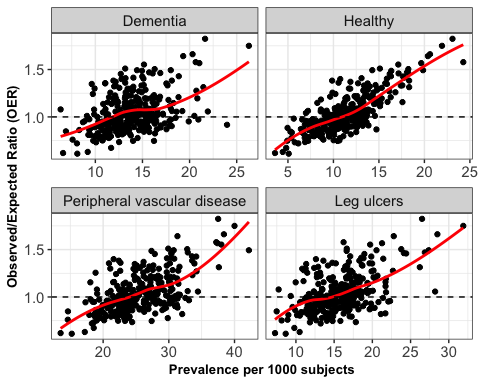


Figure 4. Associations between rates of total knee arthroplasty among white Medicare beneficiaries with either dementia, peripheral vascular disease, leg ulcers, or who were age 65 to 69 with no comorbidities and the observed-to-expected ratio for rates of total knee arthroplasty by Health Referral Region.

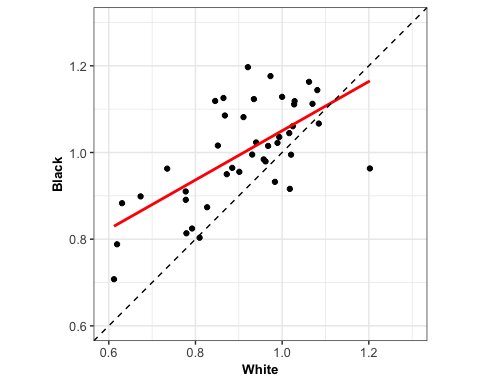


Figure 5. Association between the observed-to-expected ratios for rates of total knee arthroplasty between white and black Medicare beneficiaries. Associations between the observed-to-expected ratios for rates of total knee arthroplasty in white and black Medicare beneficiaries and the number of surgeons performing total knee arthroplasties per 10,000 beneficiaries in the Health Referral Region. HRRs for blacks are restricted to those with at least 15,000 black beneficiaries.

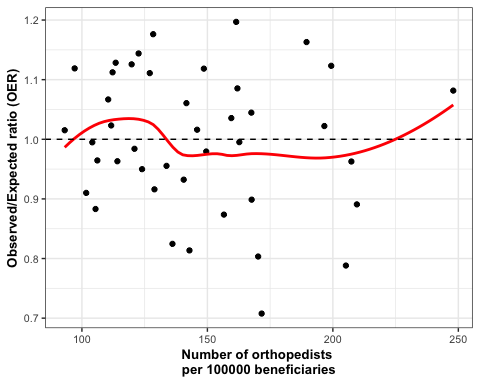


Figure 6. Association of the OER among blacks with the number of orthopedists per 100000 beneficiaries in a HRR.

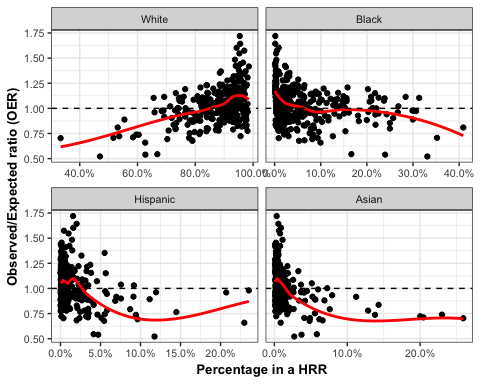
## SUPPLEMENTAL TABLES & FIGURES

| **HRR** | **OER** | **City** | **State** | **White** | **Black** | **Hispanic** | **Asian** | **Other** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lowest 10 |  |  |  |  |  |  |  |  |
| 297 | 0.521 | Bronx | NY | 47.00% | 33.11% | 11.75% | 2.73% | 5.41% |
| 289 | 0.539 | Newark | NJ | 62.71% | 23.97% | 4.70% | 3.72% | 4.90% |
| 303 | 0.544 | New York | NY | 66.85% | 16.64% | 4.15% | 5.83% | 6.54% |
| 127 | 0.659 | Miami | FL | 62.67% | 9.94% | 22.97% | 0.87% | 3.56% |
| 284 | 0.677 | Hackensack | NJ | 79.01% | 5.30% | 5.45% | 4.83% | 5.40% |
| 288 | 0.682 | New Brunswick | NJ | 78.86% | 6.49% | 2.02% | 6.62% | 6.02% |
| 79 | 0.694 | San Bernardino | CA | 70.31% | 8.17% | 9.63% | 6.17% | 5.72% |
| 150 | 0.703 | Honolulu | HI | 33.38% | 0.89% | 0.38% | 25.92% | 39.43% |
| 301 | 0.705 | East Long Island | NY | 77.85% | 9.35% | 2.38% | 4.89% | 5.53% |
| 156 | 0.707 | Chicago | IL | 51.65% | 35.20% | 5.11% | 4.10% | 3.93% |
| Highest 10 |  |  |  |  |  |  |  |  |
| 195 | 1.417 | Mason City | IA | 98.55% | 0.18% | 0.13% | 0.12% | 1.03% |
| 201 | 1.424 | Wichita | KS | 93.99% | 2.24% | 1.12% | 0.80% | 1.85% |
| 321 | 1.439 | Bismarck | ND | 95.54% | 0.09% | 0.04% | 0.11% | 4.22% |
| 371 | 1.455 | Sioux Falls | SD | 96.54% | 0.20% | 0.14% | 0.22% | 2.90% |
| 423 | 1.484 | Salt Lake City | UT | 93.73% | 0.38% | 1.44% | 1.12% | 3.33% |
| 196 | 1.547 | Sioux City | IA | 95.26% | 0.31% | 1.02% | 0.78% | 2.63% |
| 277 | 1.574 | Lincoln | NE | 96.96% | 0.51% | 0.44% | 0.63% | 1.46% |
| 421 | 1.603 | Ogden | UT | 94.31% | 0.90% | 1.60% | 0.91% | 2.28% |
| 422 | 1.643 | Provo | UT | 95.54% | 0.14% | 2.02% | 0.55% | 1.75% |
| 152 | 1.720 | Idaho Falls | ID | 95.40% | 0.14% | 1.57% | 0.32% | 2.58% |

**Supplemental Table 1:** Racial composition in the HRRs with the highest and lowest OER when adjusted for age, race and sex

| **variable** | **Min** | **10%** | **Median** | **90%** | **Max** |
| --- | --- | --- | --- | --- | --- |
| acutemi | 0.30% | 0.55% | 0.75% | 0.96% | 1.53% |
| afib | 4.97% | 6.78% | 8.28% | 9.46% | 10.63% |
| age | 72.27 | 73.39 | 73.96 | 74.56 | 75.06 |
| breast | 2.93% | 3.80% | 4.29% | 4.85% | 5.91% |
| chf | 11.98% | 15.70% | 20.26% | 25.44% | 34.13% |
| ckd | 6.26% | 10.66% | 13.19% | 15.79% | 22.11% |
| colorectal | 1.42% | 1.75% | 2.21% | 2.57% | 3.08% |
| copd | 10.97% | 16.02% | 21.88% | 27.84% | 35.17% |
| dementia | 5.98% | 8.12% | 10.41% | 12.46% | 18.60% |
| depress | 6.87% | 9.89% | 11.94% | 13.68% | 16.29% |
| diab | 11.21% | 16.65% | 21.63% | 25.51% | 34.23% |
| endometrial\_past | 0.35% | 0.49% | 0.68% | 0.88% | 1.18% |
| hememalignancy | 1.17% | 1.51% | 1.70% | 1.98% | 2.73% |
| hiv | 0.02% | 0.04% | 0.06% | 0.11% | 1.02% |
| ihd | 24.05% | 29.85% | 39.11% | 49.29% | 59.63% |
| knee\_patient | 5.88% | 8.36% | 9.75% | 11.24% | 12.65% |
| kneesymptoms | 3.27% | 4.88% | 5.92% | 7.46% | 9.62% |
| koa | 3.85% | 5.40% | 6.76% | 8.00% | 10.49% |
| liver | 3.16% | 4.47% | 5.75% | 7.68% | 17.55% |
| lung | 0.35% | 0.84% | 1.09% | 1.39% | 1.80% |
| male | 42.69% | 44.33% | 45.74% | 48.02% | 52.18% |
| mcare | 0.43% | 10.94% | 23.58% | 42.60% | 59.32% |
| obese | 23.49% | 30.94% | 36.51% | 40.38% | 47.30% |
| op\_visits | 3.56 | 5.30 | 6.81 | 8.52 | 11.61 |
| physjob | 8.28% | 12.02% | 14.80% | 18.32% | 26.76% |
| poor | 2.08% | 4.83% | 8.00% | 13.39% | 35.66% |
| prostate | 3.22% | 3.89% | 4.55% | 5.51% | 7.18% |
| pvd | 6.67% | 11.04% | 16.28% | 22.05% | 30.63% |
| race | 33.30% | 74.04% | 90.09% | 96.64% | 98.55% |
| rural | 0.00% | 1.24% | 24.05% | 50.33% | 84.71% |
| smoking | 9.05% | 17.08% | 22.28% | 26.38% | 29.79% |
| stroke | 7.05% | 8.90% | 11.86% | 14.22% | 17.00% |
| ulcers | 1.73% | 2.66% | 3.36% | 4.37% | 5.88% |
| zscore | -6.77 | -2.19 | 0.90 | 6.09 | 12.96 |

**Supplemental Table 2:** Distribution of demographic and clinical characteristics across HRRs



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## .. ..- attr(\*, "valid.unit")= int 8  
## .. ..- attr(\*, "unit")= chr "pt"  
## ..$ debug : NULL  
## ..$ inherit.blank: logi TRUE  
## ..- attr(\*, "class")= chr [1:2] "element\_text" "element"  
## $ plot.caption :List of 11  
## ..$ family : NULL  
## ..$ face : NULL  
## ..$ colour : NULL  
## ..$ size : 'rel' num 0.8  
## ..$ hjust : num 1  
## ..$ vjust : num 1  
## ..$ angle : NULL  
## ..$ lineheight : NULL  
## ..$ margin : 'margin' num [1:4] 5.5pt 0pt 0pt 0pt  
## .. ..- attr(\*, "valid.unit")= int 8  
## .. ..- attr(\*, "unit")= chr "pt"  
## ..$ debug : NULL  
## ..$ inherit.blank: logi TRUE  
## ..- attr(\*, "class")= chr [1:2] "element\_text" "element"  
## $ plot.tag :List of 11  
## ..$ family : NULL  
## ..$ face : NULL  
## ..$ colour : NULL  
## ..$ size : 'rel' num 1.2  
## ..$ hjust : num 0.5  
## ..$ vjust : num 0.5  
## ..$ angle : NULL  
## ..$ lineheight : NULL  
## ..$ margin : NULL  
## ..$ debug : NULL  
## ..$ inherit.blank: logi TRUE  
## ..- attr(\*, "class")= chr [1:2] "element\_text" "element"  
## $ plot.tag.position : chr "topleft"  
## $ plot.margin : 'margin' num [1:4] 5.5pt 5.5pt 5.5pt 5.5pt  
## ..- attr(\*, "valid.unit")= int 8  
## ..- attr(\*, "unit")= chr "pt"  
## $ strip.background :List of 5  
## ..$ fill : chr "grey85"  
## ..$ colour : chr "grey20"  
## ..$ size : NULL  
## ..$ linetype : NULL  
## ..$ inherit.blank: logi TRUE  
## ..- attr(\*, "class")= chr [1:2] "element\_rect" "element"  
## $ strip.placement : chr "inside"  
## $ strip.text :List of 11  
## ..$ family : NULL  
## ..$ face : NULL  
## ..$ colour : chr "grey10"  
## ..$ size : 'rel' num 0.8  
## ..$ hjust : NULL  
## ..$ vjust : NULL  
## ..$ angle : NULL  
## ..$ lineheight : NULL  
## ..$ margin : 'margin' num [1:4] 4.4pt 4.4pt 4.4pt 4.4pt  
## .. ..- attr(\*, "valid.unit")= int 8  
## .. ..- attr(\*, "unit")= chr "pt"  
## ..$ debug : NULL  
## ..$ inherit.blank: logi TRUE  
## ..- attr(\*, "class")= chr [1:2] "element\_text" "element"  
## $ strip.text.x : NULL  
## $ strip.text.y :List of 11  
## ..$ family : NULL  
## ..$ face : NULL  
## ..$ colour : NULL  
## ..$ size : NULL  
## ..$ hjust : NULL  
## ..$ vjust : NULL  
## ..$ angle : num -90  
## ..$ lineheight : NULL  
## ..$ margin : NULL  
## ..$ debug : NULL  
## ..$ inherit.blank: logi TRUE  
## ..- attr(\*, "class")= chr [1:2] "element\_text" "element"  
## $ strip.switch.pad.grid: 'unit' num 2.75pt  
## ..- attr(\*, "valid.unit")= int 8  
## ..- attr(\*, "unit")= chr "pt"  
## $ strip.switch.pad.wrap: 'unit' num 2.75pt  
## ..- attr(\*, "valid.unit")= int 8  
## ..- attr(\*, "unit")= chr "pt"  
## $ axis.title :List of 11  
## ..$ family : NULL  
## ..$ face : chr "bold"  
## ..$ colour : NULL  
## ..$ size : NULL  
## ..$ hjust : NULL  
## ..$ vjust : NULL  
## ..$ angle : NULL  
## ..$ lineheight : NULL  
## ..$ margin : NULL  
## ..$ debug : NULL  
## ..$ inherit.blank: logi FALSE  
## ..- attr(\*, "class")= chr [1:2] "element\_text" "element"  
## - attr(\*, "class")= chr [1:2] "theme" "gg"  
## - attr(\*, "complete")= logi TRUE  
## - attr(\*, "validate")= logi TRUE

**Supplemental Figure 2:** Association of OER based on age, race and sex adjustment with racial composition in the HRR

**Supplemental Table 5:**