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Construction of an Administrative Osteoarthritis Severity Index

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Objective. Electronic health record (EHR) databases are a powerful resource to investigate clinical trajectories of osteoarthritis (OA). There are no existing EHR tools to evaluate risk for knee arthroplasty (KA). We developed an OA severity index (OASI) using EHR data and demonstrate the index's association with time to KA.

Methods. This retrospective cohort study used 2010-2018 nationally distributed Optum EHR data. Eligible patients were 45 to 80 years old with a new diagnosis of knee OA in 2011-2012 and no prior KA. The OASI was a sum of first instance of x-ray imaging, advanced imaging, intra-articular injection, nonsteroidal anti-inflammatory drugs, and opioids. Principal components analysis index (PCI) score was also explored. Extended Cox proportional hazard models assessed time-dependent OASI and time to KA.

Results. Among 16,675 eligible patients, 12.7% underwent KA. Median follow-up time was 72 months. Adjusted OASI models showed each additional event almost doubled the risk for KA (adjusted hazard ratio = 1.80, 95% confidence interval: 1.75-1.86). Similar results were observed for PCI.

Conclusion. The sum OASI performs well identifying patients who would undergo KA and offers simplicity versus the PCI. Although replication in other cohorts is recommended, the OASI appears to be a novel and valid means to measure clinical OA severity in research studies using large EHR-based cohorts.

INTRODUCTION

Osteoarthritis (OA) is one of the most common disabling and painful conditions in the United States (1). Symptomatic knee OA affects more than 14 million individuals in the United States and results in health care costs of $185 billion annually via pharmacological treatments, clinician visits, and surgical costs (2,3). Given the common and debilitating nature of knee OA, understanding the trajectory and identifying risk factors for end-stage disease (ie, knee arthroplasty [KA]) is critical to developing interventions to slow knee OA progression. Although several clinical measures exist to quantify knee OA severity, such as the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) or Knee injury and Osteoarthritis Outcomes Score (KOOS), these are rarely used in day-to-day clinical practice (4,5). Further, knee OA presents challenges in cohort studies given the slow nature of progression, with 6 to 7 years required to detect clinical change (6,7).

Big data approaches via administrative data sets offer an ideal vetting ground for investigation and hypothesis generation before investing in prospective cohort studies. These approaches are relatively inexpensive and lack the hurdles of participant recruitment and retention. Further, administrative data sets can include higher numbers of difficult-to-recruit patients and those less likely to participate in research studies because of more severe illness or distrust of medical research.

However, in designing administrative cohort studies, investigators must account for what interventions a patient undergoes prior to enrollment in the cohort and while enrolled in the cohort, particularly if the outcome of interest is KA or time to KA. KA is considered definitive treatment for end-stage disease. To undergo KA, most patients must undergo imaging and/or fail several nonsurgical therapies, such as oral nonsteroidal anti-inflammatory drugs (NSAIDs), or procedures, such as intra-articular steroid injections (8,9). Instances of imaging and treatments are readily identified in electronic health records (EHR) via physician prescribing, *Current Procedural Terminology* (CPT) codes, and *International Classification of Diseases, Ninth Revision* (ICD-9) and *International Classification of Diseases, Tenth Revision* (ICD-10) codes (10). Other disease states have

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SIGNIFICANCE & INNOVATION

- A novel administrative knee osteoarthritis severity index (OASI) is described.
- The count of incident events of imaging or treatment was sufficient to predict outcomes.
- The OASI allows further exploration and vetting of hypotheses in knee osteoarthritis.
- The OASI advances methods in studying knee osteoarthritis using administrative data.

been investigated using these tactics. For instance, Ting et al (11) demonstrated the viability of a big data approach using commonly coded markers regarding rheumatoid arthritis severity via Veterans Health Affairs data. As such, this presents an attractive way to approach OA severity.

This study uses administrative EHR data to construct an OA severity index (OASI) for use in retrospective cohort studies. Additionally, we evaluated the face validity of the OASI by determining if higher OASI scores are associated with a greater risk for KA.

PATIENTS AND METHODS

Participants. All measures were created from an Optum deidentified EHR database containing five million patients, 18 years of age or older, distributed throughout the United States who were active in 2010-2018. Optum EHR data come from ambulatory and hospital patient encounters in academic and nonacademic health care systems and include patients with private and government health insurance and those without insurance.

The primary inclusion criterion was a first knee OA diagnosis in 2011 or 2012. Knee OA was defined using ICD-9 codes (715.16, 715.26, 715.36, 715.96, 716.56, 716.66, 716.86, 716.96) and ICD-10 codes (M17.x, M12.569, M12.869, M13.169, M13.869). Patients with a knee OA diagnosis in 2010 were excluded because we were interested in new diagnoses of knee OA. New diagnoses after 2012 were excluded to allow 7 years of follow-up time to detect incident KA. Patients must also have had at least 1 year of activity in the Optum data set prior to knee OA diagnosis (to ensure data available to exclude patients with prior knee replacement), no evidence of prior knee replacement, and at least 6 months of follow-up time (n = 16,680). The minimum follow-up time of 6 months was to ensure ample time to receive initial treatment for new knee OA. Patients were also excluded if missing demographic information. Five patients were excluded with missing sex, leaving an eligible sample of 16,675 patients. Variable definitions are shown in Supplementary Table 1 and a detailed description of the sampling approach is shown in Figure 1.

Outcome variable. The outcome of interest was KA, as defined by CPT or ICD-9 and ICD-10 procedure codes. These CPT codes represent both unicompartmental and total KA because it is difficult to discern partial verses total KA via CPT codes. However, these likely represent mostly total KA, given the relatively low utse of partial KA compared with total KA (12). See Supplemental Table 1 for specific codes used. As stated above, patients must have at least 6 months of follow-up time between knee OA diagnosis and KA. This was considered the minimum plausible progression between first diagnosis and KA. Follow-up time was measured as months from new knee OA diagnosis to KA or censoring, which was the last available encounter date if KA did not occur.

Primary exposure. The primary exposure of interest was OASI measured from baseline to the end of follow-up. This index was computed at each 6-month time interval based on binary presence (1 = yes and 0 = no) of six different treatments and interventions for knee OA including 1) knee x-ray, 2) knee advanced imaging (such as magnetic resonance imaging or computed tomography), 3) intra-articular injection (steroid or hyaluronic acid), 4) NSAID prescription (oral or topical), 5) opioid prescription, and 6) physical therapy. Once an intervention occurred in follow-up, patients were classified as having that intervention for the remainder of follow-up periods. The primary index was a time-varying, cumulative addition (range 0-6) of occurrence of OASI components, which was reassessed every 6 months of follow-up until KA or censoring.

A second methodology was employed to compute the OASI to investigate whether it could provide more information and better predict time to KA. A principal components analysis (PCA) was conducted to summarize all factors into a single weighted index score (PCA score). This method has been used previously to construct summary indices for other constructs (13). PCA was conducted on ϕ correlation coefficients rather than tetrachoric correlations because treatment variables represent the presence or absence of an intervention (discrete distribution) and not an underlying continuous latent construct. A PCA was conducted during the initial baseline period (first 6 months of follow-up) to determine the weights associated with each index component, and these weights were applied to the remaining 6-month intervals. In other words, the PCA-based index increases over time as a patient receives more OASI components, but the relationship between the components does not change.

Covariates. Covariates included sociodemographic variables such as age at OA diagnosis, sex, race, and geographic region as well as comorbidities identified with ICD-9 or ICD-10 diagnostic codes such as the Romano–Charlson comorbidity index, depression, anxiety, and obesity. These covariates were identified because they have been associated with differences in rates of KA (6,14–20).

To account for morbidity and mortality risk, we adjusted for the Romano–Charlson Comorbidity Index (21). A higher comorbidity index indicates worse health. Depression and anxiety were

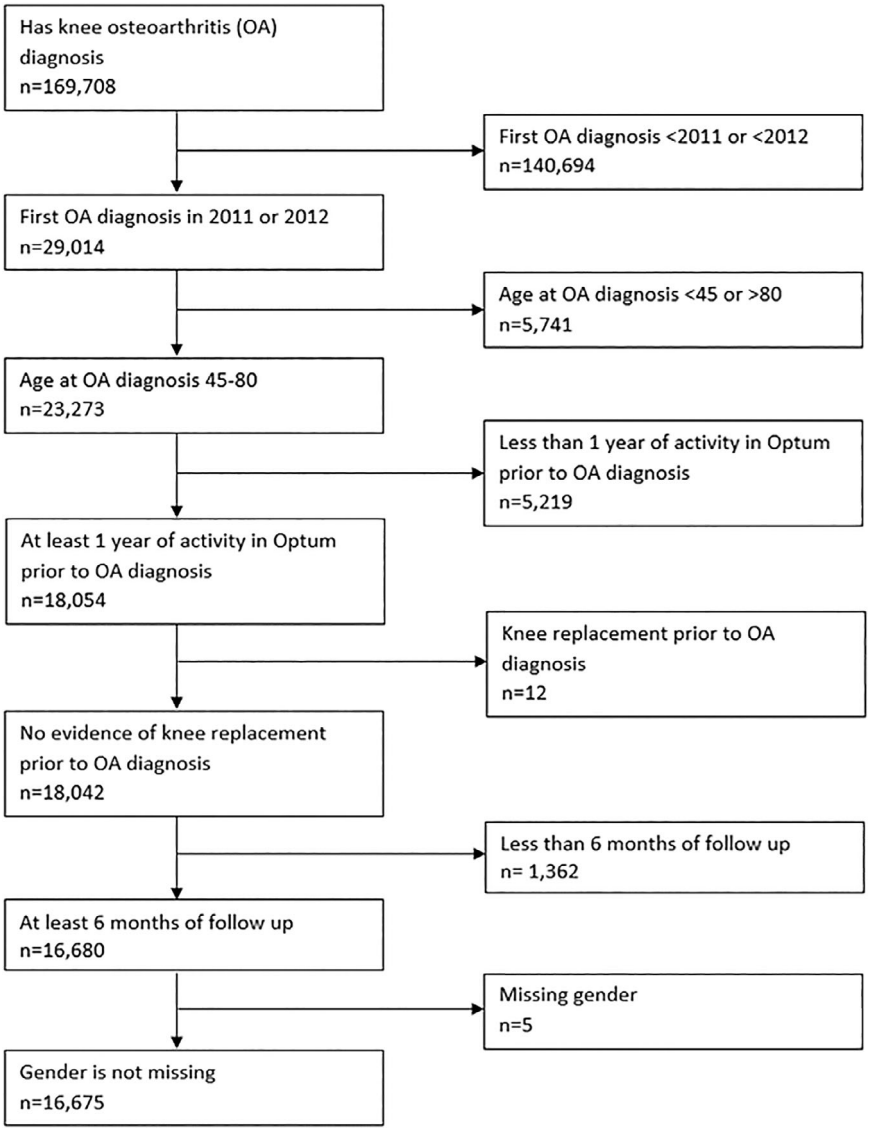

Figure 1. Flow of inclusion.

defined by the presence of ICD-9 or ICD-10 codes for depression or anxiety on two or more outpatient visits within the same 12 months or at least one inpatient visit. This algorithm has shown to have excellent agreement with manual chart abstraction and self-report (22,23). Comorbidity index, depression, anxiety, and obesity (body mass index >30 or ICD code for obesity) were treated as time-varying covariates. These variables were assessed at the end of each 6-month interval, so any condition present any time prior to the end of the 6-month interval was counted. Once a condition was coded as positive, patients were classified as having that condition for the remainder of follow-up.

Analytic approach. Bivariate, unadjusted associations with KA were assessed for the sum OASI and all covariates using χ^2 tests for categorical variables and independent sample *t*-tests for continuous variables. Extended Cox proportional hazards models were used to examine the association between time-varying severity index and KA after adjusting for relevant demographic and time-varying covariates via Andersen–Gill methods (24). The proportional hazard assumption was tested and held true for all models. All analyses were conducted with SAS version 9.4 (SAS Institute, Inc.) at $\alpha = 0.05$. The example code for this analysis is available in the Supplementary Materials.

Human subjects' protection. The Saint Louis University Institutional Review Board approved the research as a non–human subjects study because this was a retrospective cohort study of anonymized medical record and claims data. Investigators only had access to anonymized data.

RESULTS

As shown in Table 1, patients in this cohort were most commonly aged 65 or older (44.8%), White (82.9%), and female

Table 1. Cohort characteristics by knee replacement status (N = 16,675)

	Total (N = 16,675)	KA (n = 2119)	No KA (n = 14,556)	*P*
Age at diagnosis				<0.0001
45-54	3552 (21.3%)	378 (17.8%)	3174 (21.8%)	
55-64	5656 (33.9%)	778 (36.7%)	4878 (33.5%)	
65 and older	7467 (44.8%)	963 (45.4%)	6504 (44.7%)	
Race				<0.0001
African American	1781 (10.7%)	149 (7%)	1632 (11.2%)	
White	13,821 (82.9%)	1854 (87.5%)	11,967 (82.2%)	
Other or unknown	1073 (6.4%)	116 (5.5%)	957 (6.6%)	
Sex				0.0448
Female	10,524 (63.1%)	1379 (65.1%)	9145 (62.8%)	
Male	6151 (36.9%)	740 (34.9%)	5411 (37.2%)	
Region				<0.0001
Midwest	8676 (52%)	1272 (60%)	7404 (50.9%)	
Northeast	1530 (9.2%)	150 (7.1%)	1380 (9.5%)	
Other or unknown	405 (2.4%)	51 (2.4%)	354 (2.4%)	
South	4273 (25.6%)	423 (20%)	3850 (26.4%)	
West	1791 (10.7%)	223 (10.5%)	1568 (10.8%)	
Status at end of follow-up				
Depression	1326 (8%)	148 (7%)	1178 (8.1%)	0.0781
Anxiety	951 (5.7%)	103 (4.9%)	848 (5.8%)	0.0735
Obesity	12,148 (72.9%)	1620 (76.5%)	10,528 (72.3%)	<0.0001
Comorbidity index (mean, SD)	3.2 (3.3)	2.1 (2.4)	3.4 (3.4)	<0.0001
X-ray	10,450 (62.7%)	1957 (92.4%)	8493 (58.3%)	<0.0001
Advanced imaging	2914 (17.5%)	500 (23.6%)	2414 (16.6%)	<0.0001
Injection	7682 (46.1%)	1588 (74.9%)	6094 (41.9%)	<0.0001
NSAID	8832 (53%)	1109 (52.3%)	7723 (53.1%)	0.5343
Opioid	10,677 (64%)	1338 (63.1%)	9339 (64.2%)	0.3625
Physical therapy	7026 (42.1%)	981 (46.3%)	6045 (41.5%)	0.0001
Number of therapies received, mean, SD	2.9 (1.5)	3.5 (1.3)	2.8 (1.5)	0.0001

Abbreviations: KA, knee arthroplasty; NSAID, nonsteroidal anti-inflammatory drugs.

(63.1%). The majority of patients were from the Midwest and Southern regions of the United States. Of the OA interventions received, opioid prescription was the most prevalent by the end of follow-up (64.0%) followed closely by x-ray (62.7%) and NSAID prescription (53.0%).

When comparing patients who received KA to patients who did not, numerous significant differences were observed. Those receiving KA were significantly older ($P < 0.0001$), more likely to be White ($P < 0.0001$), and more likely to be female ($P = 0.0448$). A significantly higher percentage of KA patients then non-KA patients ($P < 0.0001$) were in the Midwest. Depression and anxiety were not significantly associated with KA. Significantly higher mean comorbidity index scores ($P < 0.0001$) were observed in those who had KA compared to those without KA. Among the OA therapies received by the end of follow-up, x-ray, advanced imaging, injection, and physical therapy were all significantly ($P < 0.0001$) associated with KA, but not NSAID and opioid prescriptions. Patients who received KA had significantly more therapies received in follow-up compared to those who did not receive KA (3.5 vs 2.8, $P < 0.0001$).

Unadjusted and adjusted results of survival models for simple count OASI are shown in Table 2. Median follow-up time was 72 months (interquartile range = 48-84). Before adjusting for any covariates, each additional therapy received resulted in 78% higher likelihood of KA (hazard ratio [HR 1.78; 95% confidence interval [CI]: 1.73-1.83). After adjusting for relevant covariates, this association increased slightly. In the fully adjusted model, each

Table 2. Unadjusted and adjusted extended Cox models using sum index score for hazard of KA

	Unadjusted HR (95% CI)	Adjusted HR (95% CI)
Number of different therapies and/or imaging	1.78 (1.73-1.83)	1.80 (1.75-1.86)
Age: 55-64 vs 45-54		1.43 (1.26-1.61)
Age: ≥65 vs 45-54		1.63 (1.44-1.85)
Comorbidity index		0.93 (0.91-0.95)
Race: African American vs White		0.66 (0.56-0.78)
Race: other or unknown vs White		1.14 (0.94-1.38)
Sex: female vs male		0.98 (0.89-1.07)
Region: Northeast vs Midwest		0.90 (0.76-1.07)
Region: other or unknown vs Midwest		1.18 (0.89-1.56)
Region: South vs Midwest		0.84 (0.75-0.94)
Region: West vs Midwest		1.06 (0.92-1.22)
Depression		0.85 (0.71-1.02)
Anxiety		0.85 (0.69-1.05)
Obesity		1.35 (1.22-1.50)

Abbreviations: CI, confidence interval; HR, hazard ratio; KA, knee arthroplasty.

Table 3. PCA scores

Severity index component	Standardized scoring coefficient
X-ray	0.41080
Advanced imaging	0.31852
Injection	0.29350
NSAID	0.32189
Opioid	0.38638
Physical therapy	0.32154

Abbreviations: NSAID, nonsteroidal anti-inflammatory drug; PCA, principal components analysis.

additional therapy received was associated with 80% higher likelihood of KA (HR 1.80; 95% CI: 1.75-1.86). The adjusted model also showed that African American patients were significantly less likely to receive KA compared to White patients (HR 0.66; 95% CI: 0.56-0.78), a higher comorbidity index was associated with lower likelihood of KA (HR 0.93; 95% CI: 0.91-0.95), and older compared to younger age was associated with higher likelihood of KA. Obesity was also significantly associated with increased likelihood of KA (HR 1.35; 95% CI: 1.22-1.50)

Secondary analyses examined the association of a PCA index (PCI) rather than a sum index in the fully adjusted model. Table 3 depicts the standardized scoring coefficients for the six components of the PCA derived OASI, which were very similar to one another, ranging from 0.41080 for x-ray to 0.29350 for injection.

Table 4 shows the results of the survival analysis incorporating the PCI-derived OASI. Results showed that after controlling for demographics and time-varying covariates, the PCI had a similar association with KA as the sum index score. With every unit increase in the PCI, the risk of KA increased by 91% (HR 1.91; 95% CI: 1.85-1.98).

Table 4. Unadjusted and adjusted survival analysis results for PCI showing hazard of KA

	Unadjusted HR (95% CI)	Adjusted HR (95% CI)
Severity factor	1.88 (1.82-1.95)	1.91 (1.85-1.98)
Age: 55-64 vs 45-54		1.43 (1.27-1.62)
Age: ≥65 vs 45-54		1.64 (1.45-1.85)
Comorbidity index		0.93 (0.91-0.95)
Race: African American vs White		0.66 (0.56-0.78)
Race: Other or unknown vs White		1.13 (0.93-1.37)
Sex: female vs male		0.99 (0.9-1.08)
Region: Northeast vs Midwest		0.89 (0.75-1.05)
Region: other or unknown vs Midwest		1.17 (0.88-1.55)
Region: South vs Midwest		0.84 (0.75-0.94)
Region West vs Midwest		1.05 (0.91-1.21)
Depression		0.85 (0.71-1.02)
Anxiety		0.85 (0.69-1.05)
Obesity		1.38 (1.24-1.53)

Abbreviations: CI, confidence interval; HR, hazard ratio; KA, knee arthroplasty; PCI, principal components analysis index.

DISCUSSION

In this retrospective cohort study using administrative EHR data, an OASI using a simple sum of the number of types of therapies or imaging received performed well in predicting KA. An index created from PCA, in which an index score is the weighted linear combination of components, performed similarly to a simple count.

Our findings using a simple count-based index are in contrast to those found by Ting et al, (11) who developed an administrative index to measure rheumatoid arthritis severity. The Claims-Based Index of Rheumatoid Arthritis Severity used not only demographics but also multiple measures of inflammatory markers, whereas our index focuses on treatment and imaging only. These laboratory tests are generally irrelevant to knee OA treatment, because most treatment decisions are based on clinical severity, rather than laboratory tests (25). Further, rheumatoid arthritis can have a variable course influenced by inflammatory mediators, whereas knee OA is reliably slow and steady (6,26).

Clinicians and researchers may find the OASI useful for a multitude of purposes. The elements of the OASI represent the typical treatments and imaging offered to patients with knee OA during the course of their disease. Accrual of the elements of this index, and thus increased severity, may help give clinicians and patients a quantification of the therapies that have been exhausted prior to considering KA, therefore, enabling shared decision-making. This OASI may serve as a simple tool or checklist to ensure patients have, indeed, tried most conservative therapies and could be considered for surgery in the context of their overall clinical picture. For researchers, the OASI can be used as a control variable in studies of other factors associated with time to KA, such as the social determinants of health. Vetting hypotheses via EHR data will allow for wise investment in prospective cohort studies or interventions to improve knee OA outcomes.

This study has multiple strengths, including long follow-up time, reliable data on treatment events, and ability to adjust for multiple confounders. There are several limitations. The use of EHR data for this study does limit the available variables and did not allow for measurement of treatment that may have occurred outside of the Optum data. However, missing clinic encounters should be random and would not bias our analyses. Additionally, we chose to use binary yes or no for each element of the OASI, which leaves much of the detail regarding specific treatment, duration, and dose unexplored. We argue, however, that for ease of use in administrative data sets, this binary classification appears to suffice. Attempting to quantify each instance of medication, dose, and duration, for example, would have unnecessarily complicated the OASI and essentially excluded its use in administrative data sets because this would be beyond the capabilities of most EHR data without chart review. Thus, the purpose of the OASI would be undermined. Findings using the OASI may serve as justification in investment to complete further studies.

Our data set did not include enough pain score data to allow for inclusion as a variable. Pain scores are an important driver of KA (6). Although they are not drivers of KA, we did not have clinical severity scores, such as WOMAC or KOOS. Future studies should compare the agreement between the OASI and WOMAC and KOOS because construct validity is not currently possible without these available. Future studies will use data set that include use of treatments and imaging, and not just orders. Further, this sample was mostly White, which may limit its generalizability to other populations.

This knee OASI can be computed in most administrative medical record data and medical claims databases and demonstrates face validity in its association with KA. The OASI can be used to explore trajectories of knee OA in a cost-effective manner and develop hypotheses to justify prospective cohort studies.

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AUTHOR CONTRIBUTIONS

All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be published. Dr. Gebauer had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study conception and design. Gebauer, Chrusciel, Salas, Neme, Callahan, Scherrer.

Acquisition of data. Scherrer.

Analysis and interpretation of data. Gebauer, Chrusciel, Salas, Neme, Callahan, Scherrer.

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