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Original Research

Incidence and Trends of High Tibial Osteotomy and Unicompartmental Knee Arthroplasty Over the Past Decade: A Lost Art

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ABSTRACT

Background: After failed nonoperative treatment, unicompartmental osteoarthritis can be treated surgically by either unicompartmental knee arthroplasty (UKA) or high tibial osteotomy (HTO). The purpose of this retrospective study is to analyze utilization and demographic trends of UKA and HTO relative to total knee arthroplasty (TKA) over the past decade.
Methods: A retrospective review was conducted using the PearlDiver database. Patients that received a UKA or HTO were identified. Trend analyses of surgical procedure utilization were performed with the Mann-Kendall trend test. Demographic data and the rates of various comorbidities were also queried.
Results: A total of 103,465 UKAs, 2183 HTOs, and 1,413,425 TKAs, between 2010 and 2021 quarter 1, were analyzed. Trend analyses revealed that relative to TKA utilization, UKA utilization significantly increased ($P < .001$) while HTO utilization significantly decreased ($P < .001$). The compound annual growth rate of UKA utilization relative to TKA was +5.16% from 2010 to 2017 but was −10.61% from 2018 to 2021, while that of HTO relative to TKA was −9.69% from 2010 to 2021. Demographic analyses demonstrated the UKA cohort (63.1) was significantly older than the HTO cohort (46.5) ($P < .001$). Additionally, there were significantly more female patients who underwent UKA than HTO ($P < .001$).
Conclusions: The present study demonstrated that relative to TKA, UKA utilization increased from 2010 to 2017, with a subsequent decrease afterward, whereas HTO utilization decreased since 2010. Demographic differences exist between the 2 operations, with HTOs more commonly performed in younger male patients, and UKAs in older female patients.
Level of Evidence: Level III.

Introduction

Osteoarthritis (OA) of the knee represents a significant burden within the United States health-care system. Nationally, 14 million people have symptomatic OA of the knee, with more than half of them being younger than 65 years [1]. Total knee arthroplasty (TKA) is the most performed definitive surgical treatment for tricompartmental OA. However, single compartmental arthritis is encountered far more frequently than tricompartmental disease (50% vs 17%, respectively) [2]. In all cases of degenerative joint disease, including cases isolated to one compartment, nonoperative treatment is initially pursued to delay any surgical procedure. In cases where nonoperative management fails, surgical options for unicompartmental disease include high tibial osteotomy (HTO) and unicompartmental knee arthroplasty (UKA). While both procedures address unicompartmental arthritis, HTO and UKA utilize different biomechanical mechanisms to achieve pain relief. UKA replaces the weight-bearing surface of a single osteoarthritic compartment while maintaining native knee kinematics in the other compartments [3]. HTO alters joint surface alignment to correct an angular knee deformity that often results from unicompartmental arthritis. By restoring the normal coronal plane

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alignment of the knee, HTO offloads the arthritic compartment and seeks to preserve the affected intra-articular cartilage [4]. HTO is typically performed to correct a varus deformity with medial compartment OA [5].

With careful patient selection, HTO and UKA are both viable treatment options for unicompartmental arthritis, each with demonstrated advantages and disadvantages. Compared to HTO, UKA has been demonstrated to have fewer complications, such as infection, leg length discrepancy, deep vein thrombosis, peroneal palsy, less postoperative pain, and lower revision rates when defined as time to second surgery or conversion to TKA [6]. Advantages of HTO include greater postoperative range of motion, faster return to full-impact sports, preservation of bone stock, and better functional activity [7]. Additionally, specific indications for each procedure vary, such as younger patients with a good range of motion and no severe instability being preferable for an HTO, while older patients with a lower activity demand could be better suited for a UKA [8]. Recently, utilization of HTO and UKA has increased in other parts of the world. In Korea, from 2009 to 2013, HTO volume increased 210%, and UKA volume increased by 138%. During that same period, TKA growth was only 18% [9]. Similarly, in Japan, from 2007 to 2014, HTO and UKA became increasingly popular while TKA utilization decreased [10]. In the United States, during the 2000s, UKA utilization increased and HTO utilization decreased [11,12]. Despite the volume of literature on the trends in the 2000s, there is a paucity of literature on volume trends during the most recent decade.

In the present study, rates of UKA and HTO utilization relative to TKA utilization in the United States were compared to investigate the surgical procedure volume trends from 2010 to 2021 and the clinical demographics of patients undergoing each procedure. It was hypothesized that the number of UKAs performed per year relative to TKAs increased over the past decade while the number of HTOs per year relative to TKAs decreased. Based on previous trends, we anticipated a greater proportion of HTO patients would be younger males while UKA patients would be older females.

Material and methods

Patient information was queried from PearlDiver (PearlDiver Technologies, Colorado Springs, CO), a commercially available administrative claims database that contains deidentified patient data from the inpatient and outpatient settings. The database contains the medical records of patients across the United States from 2010 through the first quarter of 2021, which are collected by an independent data aggregator. This study utilized the "M151Ortho" data set within PearlDiver, which contains a random sample of 151 million patients. All health insurance payors are represented including commercial, private, and government plans. Researchers extract data using Current Procedural Technology (CPT) and International Classification of Diseases, Ninth and Tenth revision, (ICD-9 and ICD-10) diagnosis and procedural codes This study was granted institutional review board exemption because all data were deidentified and compliant with the Health Insurance Portability and Accountability Act.

A retrospective cohort design was used to compare the rates and trends of UKA and HTO, utilization relative to elective primary TKA utilization, from 2010 to the first quarter of 2021. Using CPT codes and ICD-9/ICD-10 procedural and diagnosis codes, patients undergoing UKA, HTO, and TKA on the same day as a knee OA diagnosis were identified. Using ICD-9/ICD-10 diagnosis codes, patients with a prior diagnosis of rheumatoid arthritis were excluded. Patients were excluded from the UKA cohort if they had a prior HTO. Patients were excluded from the TKA cohort if they had a fracture, knee infection, or antibiotic spacer removal on the same day as the TKA. The CPT and ICD-9/ICD-10 codes used to define the patient cohorts are given in Appendix A.1.

All cohorts were then filtered by individual year from 2010 to the first quarter of 2021. The number of patients in each cohort each year was used to generate line graphs illustrating utilization trends within this 11-year span. The 2 cohorts were then queried for demographic information including age, sex, body mass index (BMI), Elixhauser Comorbidity Index (ECI), and incidences of several specific comorbidities. Regional data were categorized using the United States Consensus Bureau classification of Northeast, South, West, and Midwest. Several comorbidities were queried for, including a history of diabetes, obesity, chronic heart failure, and chronic obstructive pulmonary disease.

Statistical analysis

Data analysis was performed using R statistical software (R project for Statistical Computing, Vienna, Austria) that is integrated into the PearlDiver software. An α level less than 0.05 was considered statistically significant for all analyses. Categorical variables, such as demographics, were compared using chi-square analysis, and a Welch's *t*-test was used to compare continuous variables including ECI and age.

Trends in utilization of UKA and HTO relative to TKA utilization from 2010 to 2021 were then analyzed using the Mann-Kendall trend test evaluating the 1-tailed null hypotheses that the volume of UKAs relative to TKAs increased over time and the volume of HTOs relative to TKAs decreased over time. Additionally, the compound annual growth rates (CAGRs) of HTO and UKA utilization relative to TKA utilization were calculated. Both the Mann-Kendall trend tests and CAGR calculations were performed using Microsoft Excel (Microsoft, Redmond, Washington).

Results

A total of 103,465 UKAs, 2183 HTOs, and 1,413,425 TKAs, between 2010 and 2021 quarter 1, were analyzed. The number of patients in each cohort within every independent year can be found in Table 1. Overall, utilization of UKA relative to TKA increased from 6.314% to 8.982% at its peak in 2017 but has subsequently decreased to 5.647% in quarter 1 of 2021 (Fig. 1). The utilization of HTOs relative to TKA decreased from 0.217% to 0.071%. Mann-Kendall analyses of the 2 cohorts demonstrated that relative to TKA, utilization of UKA significantly increased during the study period ($P < .001$), and HTO utilization significantly decreased ($P < .001$). Additionally, over the 2010 to 2021 timeframe, relative to TKA, the CAGR of UKA utilization was +5.16% from 2010 to 2017 but −10.61% from 2018 to 2021. While that for HTO was −9.69% from 2010 to 2021. Graphic analyses of these trends can be seen in Figure 2.

Table 1
UKA and HTO Utilization Relative to TKA Utilization Over the Past Decade.

Year	TKA	HTO	HTO/TKA	UKA	UKA/TKA
2010	119,177	259	0.217%	7525	6.314%
2011	112,361	244	0.217%	7096	6.315%
2012	114,756	267	0.233%	7417	6.463%
2013	123,659	241	0.195%	8578	6.937%
2014	122,339	233	0.190%	9880	8.076%
2015	115,132	194	0.169%	9908	8.606%
2016	116,440	191	0.164%	10,458	8.981%
2017	113,502	154	0.136%	10,195	8.982%
2018	127,224	131	0.103%	10,058	7.906%
2019	154,616	126	0.081%	10,670	6.901%
2020	140,593	105	0.075%	8652	6.154%
2021	53,626	38	0.071%	3028	5.647%

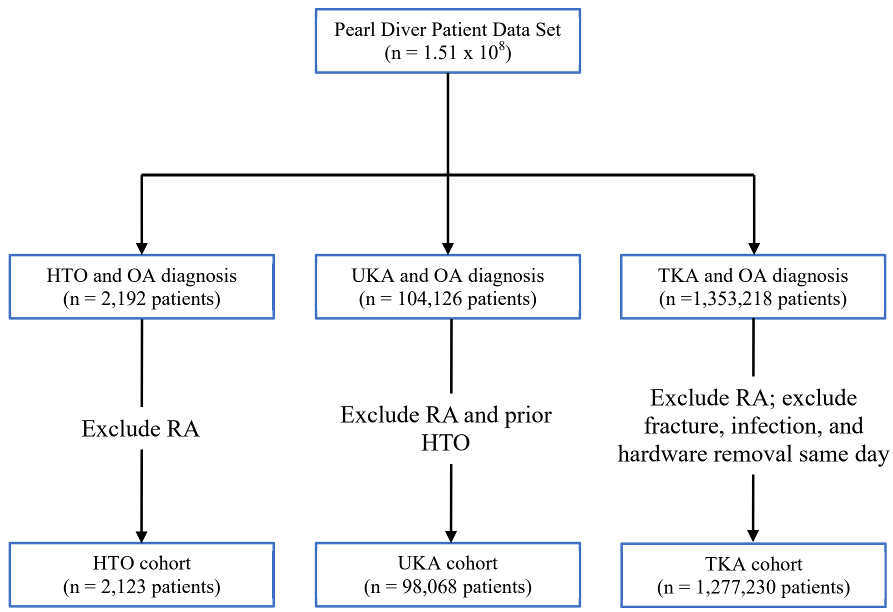

Figure 1. Process for identifying retrospective HTO, UKA, and TKA cohorts.

Descriptive statistics for patient demographics including sex, age, ECI, and comorbidities are located in Table 2. Notably, significantly more patients in the UKA cohort were female (52.9% vs 40.9%; $P < .001$) and had a greater mean age (63.1 vs 46.1 years; $P < .001$). Additionally, patients in the UKA cohort were more likely to be diagnosed with diabetes (39.7% vs 28.3%; $P < .001$), hypertension (78.5% vs 59.1%; $P < .001$), chronic obstructive pulmonary disease (29.3% vs 27.0%; $P = .02$), chronic kidney disease (14.9% vs 7.9%; $P < .001$), congestive heart failure (6.0% vs 4.0%; $P < .001$), and coronary artery disease (28.6% vs 14.1%; $P < .001$). In the HTO cohort, significantly more patients had obesity (48.7% vs 45.6%; $P = .004$). Additionally, there was a significant difference in ECI between the HTO (2.55) and UKA (3.48) cohorts ($P < .001$).

Discussion

The present study demonstrated significant differences in the demographics between the cohorts of patients undergoing UKA and HTO. HTO was more commonly performed in younger male patients, while UKA was more commonly performed in older female patients. The demographic attributes and differences found that the HTO and UKA cohorts are congruent with the evolving knowledge of outcomes for the 2 procedures. A 2019 study by Keenan et al. analyzing 111 opening-wedge HTO patients with a mean follow-up period of 12 years demonstrated female sex as an independent risk factor for failure (hazard ratio of 2.37; 95% confidence interval 1.06 − 5.33) [13]. Regarding sex-based differences in UKA, or rather lack thereof, a retrospective cohort study by Goh et al. including 128 UKA patients with a minimum follow-up period of 10 years demonstrated no clinical differences between male and female patients who underwent UKA [14]. In this context, it is unsurprising that we found a significantly greater proportion of female patients who underwent UKA (52.9%) vs HTO (40.9%) during the 2010 to 2021 timeframe ($P < .001$).

Another significant demographic difference identified by the present study was an increased rate of obesity in the HTO cohort (48.7%) compared to the UKA cohort (45.6%) ($P < .001$). Of note, this means a significantly higher proportion of HTO patients had a BMI

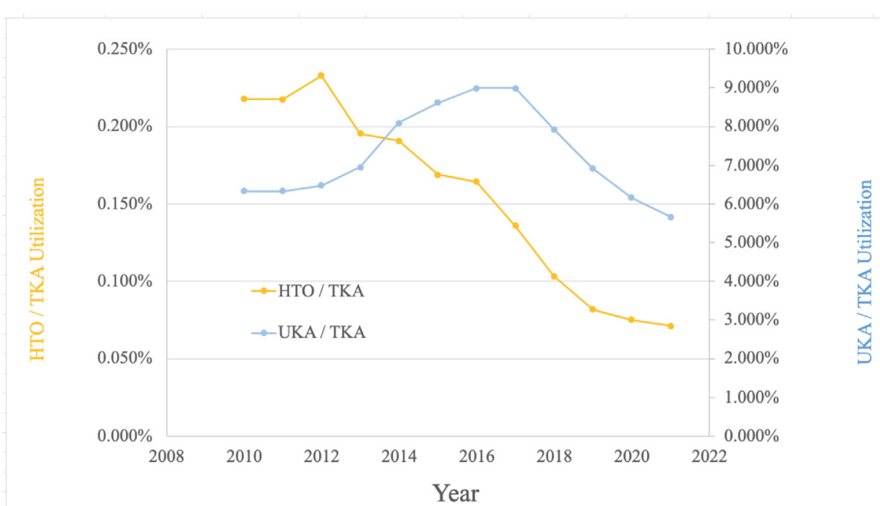

Figure 2. Trends in HTO and UKA utilization relative to TKA utilization over the past decade.

Table 2
Patient demographics of UKA and HTO cohorts.

Demographic variable	HTO, n = 2183		UKA, n = 103,465		*P* value
	n	%	n	%	
Age, mean +SD	46.5 ± 12.4	-	63.1 ± 9.9	-	**<.001**
Female	868	40.9	51,839	52.9	**<.001**
ECI	2.55	-	3.48	-	**<.001**
Obesity	1033	48.7	44,677	45.6	**.004**
Diabetes	600	28.3	38,906	39.7	**<.001**
Hypertension	1255	59.1	76,965	78.5	**<.001**
COPD	573	27.0	28,703	29.3	**.020**
Chronic kidney disease	168	7.9	14,622	14.9	**<.001**
Congestive heart failure	84	4.0	5876	6.0	**<.001**
Coronary artery disease	299	14.1	28,014	28.6	**<.001**

COPD, chronic obstructive pulmonary disease; SD, standard deviation.
Bolded *P* values indicate significant results.

over 30 and should not be extrapolated to imply that HTO patients necessarily had a higher average BMI. Although patients with obesity are not commonly considered ideal candidates for either procedure or arthroplasty in general, there is evidence, at least for HTO, that patients with obesity demonstrate similar benefits as those without obesity [12]. A 2021 prospective study by Herbst et al. including 120 patients with a minimum 6-year follow-up found that patients undergoing HTO with obesity achieved inferior clinical and functional midterm results compared to those without obesity [15]. However, the cohorts in that study demonstrated equivocal benefits in terms of patient-reported outcomes and failure rates in the long term [15].

The present study demonstrated a precipitous decrease in the volume of HTOs relative to TKAs within the observed database during the 2010s, comprising just 0.07% of surgical volume relative to all TKAs in 2021. By contrast, UKA volumes displayed modest growth initially during the past decade although utilization relative to TKA volume declined modestly since the peak in 2017. This study also demonstrated a CAGR of −1.01% for UKA utilization relative to TKA utilization and −9.69% for HTO from 2010 to 2021. From 2010 to 2017, however, a CAGR of +5.16% for UKA utilization relative to TKA utilization was observed, which can be considered a continuation of the trends described by Nwachuwku et al. [12]. This sustained utilization of UKA may in part be attributed to evolutionary changes of prosthetic implants over the past 2 decades and the increased adoption of robotic assistance in UKA [16]. Implant and postoperative lower-extremity malalignment have been cardinal sources of failure in UKA [17–19], and literature has demonstrated implant mal-alignment in 40%–60% of patients with manually performed UKA (>2% delta vs preoperative planning) [20,21]. Robot-assisted UKA, however, seeks to address the challenge of implant positioning and alignment of manually performed UKAs [22–24]. Naziri et al. demonstrated that utilization of robotic assistance in knee arthroplasty increased 500% from 2009 to 2013 (which included UKA) [25], with other studies demonstrating superior short-term survivorship and outcomes with robot-assisted UKAs [21,26–29].

A cost analysis performed by Konopka et al. demonstrated that the cost of HTO was $10,006 compared to $13,369 for a UKA [30]. Additionally, according to Medicare services, the doctor fee for a UKA is $1,182, while that for an HTO is $780 [31]. Furthermore, according to the Physician Fee Schedules published by the Centers for Medicare and Medicaid Services, physicians received 14.03 work relative value units for performing an HTO during the entirety of the study period, 2010 to 2021, during which time, utilization of the procedure decreased relative to TKA utilization. For a UKA, physicians received 16.38 work relative value units from 2010 through 2013, and then in 2014, that number rose to 17.48 where it has remained through 2021 [32]. This change in economic incentives may be reflected in both the rise in UKA utilization from 2013 to 2014 and the fall in HTO utilization.

Although the utilization of HTOs is declining, orthopedic surgeons must evaluate each patient's case to ensure they receive the most effective treatment. A 2020 retrospective review by Jacquet et al. demonstrated that compared to UKA, opening-wedge HTO offers a statistically significant quicker return to sports and previous professional activities with a higher rate of participation in impact activities (62% for HTO vs 28% for UKA) [33]. Furthermore, that study demonstrated superior sports-related functional scores at 2 years postoperatively compared to UKA [6,33–37]. A meta-analysis by Cao et al. comparing 267 HTO and UKA patients demonstrated that HTO yielded superior postoperative range of motion [33].

Limitations

An inherent limitation of an administrative claims database study is the accuracy of the findings, which relies on the appropriate selection of ICD and CPT codes in the database and is subject to human error. This margin of error is mitigated by the large number of patients in this study (UKA n = 103,645; HTO n = 2183). To both mitigate the margin of error and capture as many patients as possible, ICD-9 and ICD-10 and CPT codes were used to query patients both before and after 2015, which may have led to discrepancies in the terminology. To address these differences, a code translator following the Center for Medicare and Medicaid Services general equivalence mapping was used. This is a validated and universally accepted methodology to identify corresponding ICD-9 and ICD-10 codes. The utilization of both ICD and CPT codes may have also affected the results as ICD-10 procedural codes are used in inpatient facilities, while CPT codes are used when coding for physicians or outpatient facilities. This limitation was accepted as maximizing the number of patients captured within each cohort would have a greater effect on the significance of the results. Additionally, clinical data such as race, patient outcome scores, blood loss, prior surgery to UKA or HTO, and radiographic images could not be queried from the database. This study is limited to the identification of demographics, comorbidities, and the number of patients undergoing the procedure through the binary presence or absence of the factor. It is also possible that other confounders may have influenced the results of this study; however, this study focused on the trends in UKA and HTO use over a 10-year period, which would mitigate small discrepancies within a single year. Figure 1 also represents a small number of patients with TKA and a diagnosis of OA, smaller than our total TKA patient cohort, which could reflect a lack of appropriate coding for OA in some patients.

Additionally, the 2021 data are incomplete, as the database only includes data from the first quartile of that year.

Conclusions

The present study demonstrated utilization of UKA significantly increased from 2010 to 2021 whereas HTO utilization significantly decreased. Additionally, demographic differences exist between HTO and UKA, with HTO more commonly performed in younger male patients and UKA more commonly performed in older female patients. Although HTO is a highly successful treatment option for young, active patients with unicompartmental arthritis, it is becoming a lost art in orthopaedics.

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101121.

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Appendix: PearlDiver Codes

Appendix A.1
Codes used to define inclusion/exclusion criteria and other demographic and clinical variables.

Criteria	Code(s)
Inclusion criteria	
Knee arthritis	ICD-9-D-71516, ICD-9-D-71526, ICD-9-D-71536, ICD-9-D-71596, ICD-10-D-M170, ICD-10-D-M1710, ICD-10-D-M1711, ICD-10-D-M1712, ICD-10-D-M172, ICD-10-D-M1730, ICD-10-D-M1731, ICD-10-D-M1732, ICD-10-D-M174, ICD-10-D-M175, ICD-10-D-M179
Unicompartmental knee arthroplasty	CPT-27446, ICD-10-P-0SRC0L9, ICD-10-P-0SRC0LA, ICD-10-P-0SRC0LZ, ICD-10-P-0SRC0M9, ICD-10-P-0SRC0MA, ICD-10-P-0SRC0MZ, ICD-10-P-0SRD0L9, ICD-10-P-0SRD0LA, ICD-10-P-0SRD0LZ, ICD-10-P-0SRD0M9, ICD-10-P-0SRD0MA, ICD-10-P-0SRD0MZ
High tibial osteotomy	CPT-27457, CPT-27705, CPT-27709, ICD-9-P-7727, ICD-10-P-0Q8G0ZZ, ICD-10-P-0Q8G3ZZ, ICD-10-P-0Q8G4ZZ, ICD-10-P-0Q8H0ZZ, ICD-10-P-0Q8H3ZZ, ICD-10-P-0Q8H4ZZ
Total knee arthroplasty	CPT-27447
Exclusion criteria	
Knee fracture	ICD-9-D-82100, ICD-9-D-82110, ICD-9-D-82120, ICD-9-D-82123, ICD-9-D-82129, ICD-9-D-82130, ICD-9-D-82132, ICD-9-D-82133, ICD-9-D-82139, ICD-9-D-73316, ICD-9-D-73393, ICD-9-D-82300, ICD-9-D-82302, ICD-9-D-82310, ICD-9-D-82312, ICD-9-D-82380, ICD-9-D-82382, ICD-9-D-82390, ICD-9-D-82392, ICD-10-D-M84453A, ICD-10-D-M84453A, ICD-10-D-M84453A, ICD-10-D-M84453A, ICD-10-D-M84453A, ICD-10-D-S7290XC, ICD-10-D-S72409A, ICD-10-D-S72453A, ICD-10-D-S72456A, ICD-10-D-S72499A, ICD-10-D-S72409B, ICD-10-D-S72453B, ICD-10-D-M84469A, ICD-10-D-M84369A, ICD-10-D-S82109A, ICD-10-D-S82101A, ICD-10-D-S82831A, ICD-10-D-S82102A, ICD-10-D-S82832A, ICD-10-D-S82109B, ICD-10-D-S82109C, ICD-10-D-S82101B, ICD-10-D-S82831B, ICD-10-D-S82102B, ICD-10-D-S82832B, ICD-10-D-S82201A, ICD-10-D-S82401A, ICD-10-D-S82202A, ICD-10-D-S82402A, ICD-10-D-S82201B, ICD-10-D-S82201C, ICD-10-D-S82401B, ICD-10-D-S82202B, ICD-10-D-S82402B
Knee infection	ICD-9-D-99666, ICD-10-D-M01X61, ICD-10-D-M01X62, ICD-10-D-M01X69, ICD-10-D-T8453XA, ICD-10-D-T8453XD, ICD-10-D-T8453XS, ICD-10-D-T8454XA, ICD-10-D-T8454XD, ICD-10-D-T8454XS
Antibiotic spacer removal	CPT-11982, ICD-9-P-8457, ICD-10-P-0SPC08Z, ICD-10-P-0SPC0EZ, ICD-10-P-0SPD08Z, ICD-10-P-0SPD0EZ
Rheumatoid arthritis	ICD-9-D-7140, ICD-9-D-7142, ICD-10-D-M0520:ICD-10-D-M061