Geographic Variation in Knee Replacement Surgery:

Provider or Population Driven?

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Abstract

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(Under the direction of Thomas Ricketts)

In recent years there has been rapid growth in the use of total knee arthroplasty (TKA). This study examines longitudinal and geographic trends for TKA in North Carolina between 2000 and 2009. Data are drawn from the North Carolina Discharge databases, linked to external datasets and analyzed by provider, facility, and county. Discharges with an ICD-9 procedure code for TKA (81.54) are included in the analyses.

Between 2000 and 2009, TKA utilization doubled in North Carolina, increasing from 96 to 196 procedures per 100,000 persons. Utilization of TKA increased more rapidly for people under 65 compared with those over 65, and the proportion of procedures billed to Medicare decreased from 66% to 57%. The number of TKA procedures performed in low-volume hospitals declined by nearly 40%, while the volume in high-volume facilities tripled. The number of orthopedic surgeons performing TKA remained relatively constant over time, on average 378 physicians per year, but the average provider volume of TKA procedures more than doubled. Between 2000 and 2009, the number of orthopedic surgeons performing between 50 and 99 TKAs per year more than quadrupled, and the number performing more than 100 increased by a factor of seven. By 2009, approximately 70% of all discharges were performed by surgeons with annual volume of at least 50 procedures.

Multivariate spatial regression analysis of TKA utilization in 2008 found that the most significant predictors of county TKA utilization were supply related. County supply of primary care providers per 100,000 persons, the presence of a hospital with high-volume of TKA, the number of skilled nursing facilities, and number of hospital beds were all statistically significant predictors of use. The county rate of uninsurance, admission rate for marker conditions, and the spatial parameter representing TKA utilization for neighboring counties were also statistically significant factors.

Substantial growth in utilization and expenditures for TKA between 2000-2009 has motivated payers to consider new reimbursement policies which promote efficiency and require strong networks between providers and institutions, which could affect future access to the procedure. It is unclear whether the increasing volume of procedures among a relatively stable supply of providers and hospitals is sustainable or if new providers and institutions will be necessary to meet future demand.

For Porter

So that I may provide every possible opportunity for you.

And to show you that anything is possible if you work hard and don't give up.

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The road that led me to this achievement was marked by a few bumps, dead ends, pleasant diversions, detours, and a big hill at the end. But I made it to the end and my journey was greatly enriched by taking the scenic route. I credit my compass, my crew, my cheerleaders, and my stubbornness for getting me here.

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List of Abbreviations

ACGME	The Accreditation Council for Graduate Medical Education
AHRQ	Agency for Healthcare Research and Quality
AIC	Akaike Information Criterion
ARF	Area Resource File
BLS	Bureau of Labor Statistics
BMI	Body Mass Index
BRFSS	Behavioral Risk Factor Surveillance Survey
B-P	Breusch-Pagan Test
CDC	Centers for Disease Control and Prevention
CMS	Centers for Medicare and Medicaid Services
CPI	Consumer Price Index
CPS	Current Population Survey
DHSR	Division of Healthcare Services Regulation
DRG	Diagnosis Related Group
FE	Fixed Effects Regression
FIPS	Federal Information Processing System
HCUP	Healthcare Cost and Utilization Project
HRQoL	Healthcare Related Quality of Life
HRR	Hospital Referral Region
ICD-9	International Classification of Diseases, Version 9

J-B	Jarque-Bera Test
KA	Knee Arthroplasty
KOA	Knee Osteoarthritis
LISA	Local Indicators of Spatial Autocorrelation
LM	Lagrange Multiplier Test
MDC	Major Diagnostic Category
MIS	Minimally Invasive Surgery
NCHPDS	North Carolina Health Professions Data System
NCIOM	North Carolina Institute of Medicine
NHANES	National Health and Nutrition Examination Survey
NCOSMB	North Carolina Office of State Budget and Management
NIS	Nationwide Inpatient Sample (Discharge Data)
NPI	National Provider Identification
OA	Osteoarthritis
OLS	Ordinary Least Squares Regression
PCI	Per Capita Income
PCP	Primary Care Provider
PPACA	Patient Protection and Affordable Care Act
SNF	Skilled Nursing Facility
TKA	Total Knee Arthroplasty
UKA	Unicompartmental Knee Arthroplasty
UPIN	Uniform Provider Identification Number

1. Introduction

1.1. Background

In recent years, there has been a sharp increase in the volume of orthopedic surgical procedures in the United States, particularly joint replacement. Between 1997 and 2005, hospitalizations involving musculoskeletal procedures increased by nearly 24%[1], far outpacing population growth of 11% during the same 9-year period[1]. Hospitalization for one of the most common orthopedic procedures, knee arthroplasty, increased by 69% between 1997 and 2005[1], and growth in demand for this procedure is expected to continue and accelerate over the next two decades. Why utilization of this procedure has changed so dramatically is unclear. Since neither the technology nor technique for knee arthroplasty has changed substantially in recent years, most explanations of the increase tend to focus on changes in the patient population, their lifestyles and health behaviors, and the practice patterns of providers performing the surgery. This study examines longitudinal and geographic trends in knee arthroplasty in North Carolina between 2000 and 2009 and describes patterns of the utilization at the patient and provider level, identifying factors that are associated with the increase in utilization.

The study approach is driven by literature on geographic variation in health care utilization, especially the work by Wennberg and associates at Dartmouth since the 1970s.[2-10] In a landmark study of healthcare utilization in Vermont, Wennberg et al. found hospitalization

[1] http://www.census.gov/popest/archives/

rates for specific diagnoses and procedures that were ten times as high in some hospital service areas as in others. [5] The unexplained variation in utilization, according to Wennberg, is evidence of differences in physicians' beliefs regarding the most efficacious treatments and consumer preferences for conditions with multiple treatment options. Interest in regional variation among otherwise similar places remains prominent in health services research and in debates about reducing healthcare costs. Of significant concern is whether the variation may be indicative of under- or over-utilization. This study examines variation in knee arthroplasty rates as a function of population characteristics and local healthcare resources, using North Carolina counties as the unit of analysis.

<u>1.1.1. Knee Arthroplasty</u>

The normal knee joint is made up of three compartments or bone surfaces, the lateral, medial, and patellofemoral, which function together as a complex hinge and allow the leg to extend, flex, rotate, and glide. Trauma or disease may erode cartilage in one or more compartment and lead to inflammation and pain.[11] Knee arthroplasty is a surgical procedure in which the diseased or damaged knee joint tissue is resurfaced and an artificial knee joint is implanted (Figures 1 and 2). Surgery may involve some or all of the three knee bone surfaces. The most common indications for knee arthroplasty include severe osteoarthritis of the knee and traumatic joint damage; other diseases for which joint replacement may be recommended include rheumatoid arthritis, cancer, or congenital deformity.

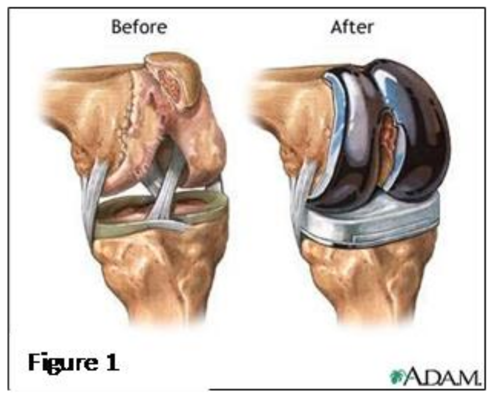


Figure 1

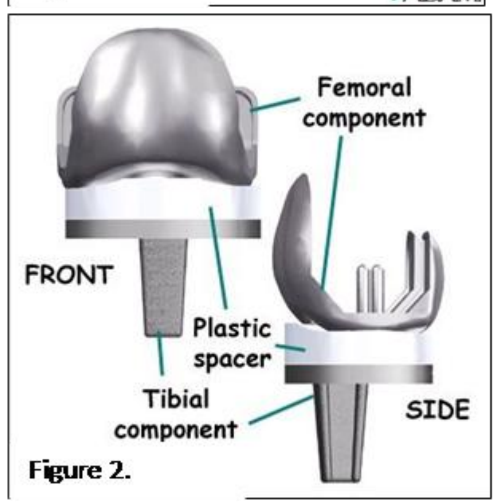


Figure 2.

Osteoarthritis (OA) is a degenerative disease which affects joint cartilage and underlying bones, and the condition is often marked by inflammation, pain, stiffness and, occasionally, muscle atrophy. It is the most common form of arthritis and the CDC estimates that approximately 26.9 million adults in the U.S. are currently affected by the disease[2]. A study by Hootman predicts prevalence of arthritis and rheumatic conditions will be 67 million (25% of the population) by 2030.[12] Idiopathic OA and other types such as rheumatoid or posttraumatic OA have distinctly different disease pathways and causes; however, little information is available distinguishing the prevalence of each type. A study of the disease in Iowa estimated that approximately 12% of osteoarthritis cases are posttraumatic OA.[13] Risk factors for these different types of OA vary, but most research tends to focus on the risk factors associated with idiopathic OA.

A study by Hawker et al. estimated that 93.4% of all Medicare patients receiving knee replacements between 1985 and 1989 had a primary diagnosis of osteoarthritis,[14] and other studies indicate that knee arthroplasty may be more successful for degenerative conditions than traumatic injury.[15] Knee osteoarthritis is caused by gradual loss of cartilage between the bones of the knee joint. Primary osteoarthritis is generally associated with aging, a process during which an increase in the water content of the cartilage gradually causes the protein composition to change such that the cartilage cracks and flakes. Secondary osteoarthritis is characterized by an underlying condition such as injury or obesity. Obesity causes osteoarthritis by eroding the cartilage through excessive mechanical stress; metabolic processes such as diabetes, hypertension, and high levels of dietary fat may also have a biological effect which degrades cartilage, though the evidence on this association is weak and sparse.[16, 17] Osteoarthritis acts to degrade the normal

[2] http://www.cdc.gov/arthritis/arthritis/osteoarthritis.htm

cushion of cartilage between bones, leaving friction between bones unmitigated and leading to inflammation and pain. Prosthetic implants, via knee arthroplasty, act as a substitute cushion for the damaged cartilage, thereby eliminating pain and restoring range of motion.

Knee arthroplasty techniques were adapted from those developed for hip arthroplasty in the 1960s by John Charnley, and the first generation of knee total condylar prostheses was introduced in 1972 by Insall and colleagues.[11] Today, there are multiple designs and manufacturers of prosthetic knees, and the procedure is one of the most common orthopedic procedures performed in the U.S. The procedure requires anesthesia and is increasingly being performed with minimally invasive techniques, described in more detail below. Prostheses can be implanted using cemented or cementless fixation techniques, the choice of which may affect the lifespan of the procedure.[18] Implant survivorship also varies according to patient characteristics and prosthesis. Overall, evidence points to a finite lifespan of prosthetic components and high likelihood of revision surgery due to aseptic loosening. Aseptic loosening is the shedding of microscopic particles from the polyethylene surface; it occurs as a result of the biological impact of wear on the polyethylene surfaces, which can be accelerated by mechanical demand, sterilization method, prosthesis size, and joint congruity.[3] Literature indicates standard open arthroplasty results in 90% prosthesis survivorship at 10 to 15 years.[11, 18-21] NIH consensus statements suggest failure rates of approximately 1% per year at 20 years post surgery.[22]

Over the past three decades, advances in the procedure have been made in the development of alternative prosthetic materials such as titanium, improvements in and better adherence to sterilization procedures, and innovations in the cementing process and materials.[11, 23] In particular, much focus has been centered on improving the durability of ultra-high molecular weight polyethylene, the most common material used as a bearing surface, to delay prosthetic failure due to aseptic loosening.[19, 24] Aseptic loosening is the primary cause of most revision surgeries.

Minimally invasive surgical (MIS) techniques, characterized by an 8-12 centimeter incision, are perhaps the most profound recent surgical innovation for knee arthroplasty. [21, 25] Introduced in the 1990s, the technique is appealing to both patients and doctors because MIS is believed to cause less damage to the extensor mechanism, shorten operative and recovery time, reduce pain, and improve post-operative healing.[21] However, some critics believe that the limited visualization may compromise component placement and consequently shorten the survivorship of the prosthesis.[26]

A number of factors are considered when assessing a patient's candidacy for knee arthroplasty, including age, comorbidities, and the stage and anatomy of disease or joint damage. The main contraindication for the procedure is an active local or systemic infection; other factors that may disqualify a patient for the procedure include poor vascular circulation, neurological disease, or previous history of septic arthritis.[11, 19, 22] Patients with moderate osteoarthritis may be appropriate candidates for less invasive therapies such as arthroscopy and osteotomy; however, the benefit of these other procedures depends on the severity and site of the osteoarthritis.[27] Further, some evidence suggests that these procedures may have limited benefit or, in fact, be harmful to the joint and lead to complicated subsequent procedures including total knee arthroplasty.[28-30]

The most recent report on utilization of hospital care for musculoskeletal conditions published by AHRQ report showed a 69% increase in inpatient discharges with one of fourteen procedures classified as knee arthroplasty between 1995 and 2005 in the United States.[1] More recent unpublished data, obtained via HCUP-net, shows additional growth between 2005 and 2007 of nearly 9%. In 2007, there were 605,176 discharges in the United States involving a knee arthroplasty, making the overall incidence rate 200 per 100,000 persons (Figure 3).

Figure 3. U.S. Hospitalizations in 2007

	Knee arthroplasty	All hospital stays
Number of hospital stays (% of all stays)	605,176 (1.5%)	39,541,948 (100%)
Mean length of stay	3.6 days	4.6 days
Mean hospital cost	$14,777	$8,692
Aggregate costs (% of total national cost)	$8.946 billion (2.6%)	$343.9 billion (100%)

Number of hospital stays based on all-listed procedures; knee arthroplasty discharges based primary ICD-9 procedure code of 80-84, 81.54 or 81.55
Source: HCUPnet, Accessed 1/25/2010 at http://hcupnet.ahrq.gov/HCUPnet.jsp?Id=1C31F07F275640C3&Form=SelDB&JS=Y&Action=%3E%3ENext%3E%3E&_DB=NIS07
Data Source: AHRQ, Center for Delivery, Organization, and Markets, Healthcare Cost and Utilization project, Nationwide Inpatient Sample, 2007.

1.1.2. Clinical Effectiveness of Knee Arthroplasty

Knee arthroplasty is widely accepted as a procedure to treat degenerated knees with favorable long-term results and low rates of complications and mortality. While complete rehabilitation may take up to 18 months, postoperative functional improvements and pain reduction are evident in a shorter time period for a large proportion of patients.[21] Twenty years of research show substantial overall improvements in functional status, health-related quality of life, and pain alleviation; the NIH consensus statement estimates 85 percent of patients are satisfied with results from knee arthroplasty.[22] A recent case-control study by Hawker et al. found that Canadian patients with osteoarthritis who had joint arthroplasty, compared with those who did not have the procedure, experienced significant reductions in pain, disability, associated arthritis-attributable health care costs, and stable general health status.[31] However, the vast majority of literature on knee arthroplasty outcomes shows that clinical effectiveness varies according to patient demographics, health-related factors, and surgical factors.[19] In addition to functional improvements resulting from knee arthroplasty, the rate of complications is very low; overall, mortality estimates range from 0.3% to 0.7%, with some variation by demographic group.[22, 32-34]

Multiple studies have found that the long-term benefit and implant durability are greater in older patients, perhaps because of lower levels of postoperative physical activity.[35-38] Richmond notes that "high-impact activities are deleterious after joint replacement arthroplasty and may lead to precocious failure of the implant through wear of the polyethylene and potential loosening of the prosthesis."[27]   On the other hand, risk of mortality and surgical complications have been shown to increase with age following knee arthroplasty, likely due to more preoperative comorbidities.[39-41]

Similarly, the long-term benefit of a knee prosthesis is lower [36] and risk of mortality [40] or surgical complication [41] is slightly higher for men than for women undergoing knee arthroplasty. In a study of more than four million discharges between 1990 and 2004, Memtsoudis et al. found men had 10% higher risk of mortality and higher risk of surgical complications associated with knee arthroplasty, including cardiac complication and pulmonary embolism, than did women.[41]

Although the evidence is mixed, obesity is generally believed to have a negative effect on outcomes for knee arthroplasty. While surgery can be successful in obese patients, surgical complications are greater and postoperative healing and improvements are worse due to aseptic loosening from mechanical stress.[36, 42-45] Thus, while obesity is a strong risk factor for osteoarthritis, knee arthroplasty without weight reduction may have less benefit than for non-obese patients.

Several studies have shown that complication rates for knee arthroplasty are inversely related to hospital and surgeon knee arthroplasty volume; facilities and/or providers performing a few knee arthroplasties have worse outcomes. [40, 46-49] Similarly, a recent study by Cram showed that the incidence of surgical complications was lower in orthopedic specialty hospitals versus general hospitals.[50] Medicare patients undergoing total knee or hip replacement in orthopedic specialty hospitals had approximately 62% of the risk of complication or death observed in general hospitals.

1.1.3. Cost-Effectiveness of Knee Arthroplasty

Knee arthroplasty is also regarded as a cost-effective therapy for improving mobility and improving quality of life for patients, compared with no surgical intervention. Studies have shown that knee arthroplasty produces significant improvements in well-being at modest costs, though results can be difficult to interpret, due to the computational methods.[51-53] Using Medicare data, Lavernia et al estimate that knee arthroplasty costs at approximately $6,500 per "well-year".[53] Alternately, a Finnish study by Rissanen et al. estimated the cost-effectiveness of inpatient knee arthroplasty by calculating the medical expenditures associated with every one-unit increase in the 15D, a 15-dimension score for health-related quality of life (HRQoL); for patients under 60 or over 70 years old, a one-unit improvement in HRQoL was associated with $1,400 (US 1997) and $3,776 (US 1997) respectively.[52] Debate continues over whether unicompartmental knee arthroplasty (UKA) is more cost-effective than total knee arthroplasty; most recently, Slover et al. found the treatments essentially equivalent in cost-effectiveness and cost-benefit analyses, while SooHoo et al. found circumstances under which UKA is favored.[40, 54] While most studies of the cost-effectiveness for joint arthroplasty consider direct costs of primary knee arthroplasty relative to health status improvements, most ignore indirect costs such as postoperative reductions in healthcare expenditures as well as the cost of revision arthroplasty. However, a study by

Hawker et al. examined osteoarthritis-related health care expenditures among patients who did and did not receive joint replacement and found a statistically significant reduction in costs for patients who had surgery.[31] Revision arthroplasty, which is more costly due to higher incidence of complications, such as infection, and requires longer length of hospital stay, is not considered in most cost analyses. The costs of revision surgery is estimated conservatively at $36,848 (2006).[55] Several studies [55-59] suggest that the direct costs of revision knee arthroplasty are not fully reimbursed in all facilities and that the estimates of costs may therefore be skewed to the low end.

1.2. Study Purpose and Specific Aims

This dissertation explores the influence of population and provider characteristics on the geographic variation of knee replacement utilization in North Carolina between 2000 and 2009. The theoretical motivation for the study follows Wennberg's observations of regional variation, incorporating some elements of classic sociological theory including Andersen's Behavioral Model of Healthcare Utilization [60, 61], and economic theory which emphasizes the effect of providers and capacity on utilization. The study takes a multidisciplinary approach to examining use of a specific elective surgical procedure. A secondary goal of the study is to describe how the characteristics of patients, providers, and institutions for knee arthroplasty have changed over time in North Carolina. Specifically, this dissertation's four research questions include three essentially descriptive queries and one analytic question:

Given the overall increase in the volume of knee replacements in North Carolina between 2000-2009:

1. Have there been changes in the characteristics of patients receiving knee replacement surgery during the study period?
2. Have there been changes in the supply, distribution, and scope of practice of orthopedic surgeons in North Carolina during the study period?
3. Have there been changes in the institutions that provide orthopedic surgical service, particularly knee arthroplasty, during the study period?
4. What factors are associated with higher or lower utilization of knee arthroplasty in North Carolina counties? Does the variation exist because of the ecological factors suggested by Andersen or does it reflect a variation in inputs as suggested by Wennberg?

1.3. Relevance

The Agency for Healthcare Research and Quality (AHRQ) estimates that hospitalizations involving musculoskeletal procedures are longer and more expensive than other inpatient stays and represent a significant portion of the total cost of hospital care in the U.S.[1] Discharges involving a knee arthroplasty account for 2.6% of total national spending for hospital care in 2007, which is out of proportion to the 1.5% of discharges they represent (Figure 3). Hospitalizations with a knee arthroplasty accounted for nearly $9 billion dollars (payments for all inpatient services) in 2007 and projections suggest that utilization of the procedure will increase by more than 600 percent by 2030 [62, 63]. As the volume of high-cost procedures such as knee replacement surgery increases, so too does the economic burden to society and the publicly supported medical care financing system given that Medicare is the primary payer for knee arthroplasty in the U.S. Understanding the causes of the increasing procedure rate is important in developing strategies to both anticipate and control spending growth and ensure an adequate workforce to meet future demand.

Investigating the factors associated with geographic variation in utilization of knee arthroplasty allows us to answer the question about whether particular areas may be under- or over-utilizing care, and to develop workforce distribution strategies.

Information regarding the epidemiology and utilization trends for knee replacement can be useful to help us know if knee arthroplasty can be prevented through modifiable risk factors, including obesity, joint injury and occupational risk. Public health policies or programs may be designed to increase participation in physical activity, improve nutrition, or focus occupational therapy in order to reduce the incidence of knee osteoarthritis and joint injury which lead to knee arthroplasty. Such interventions have potential to reduce the considerable and growing economic burden of knee arthroplasty by preventing the underlying diseases.[64, 65]

Further, the increasing utilization of knee arthroplasty procedures poses important challenges for workforce planning and reimbursement policies. The current and projected trend of knee replacement surgery is expected to result in a significant imbalance between demand for services and availability of orthopedic surgeons over the next 10 to 20 years, according to national analyses. Iorio et al. estimate that nationally, the orthopedic surgical workforce will increase by only 2% between 2000 and 2020, while demand for services will increase by 23%.[66] The number of primary total knee arthroplasties is conservatively estimated to increase from 549,867 in 2005 to 758,895 in 2020; other estimates for future use of knee replacement are significantly higher.[67] Identifying the locales and providers associated with potential under- and over-utilization allows policymakers the opportunity to intervene via workforce redistribution and preferential reimbursement policy.

From a public health, economic, and health planning perspective, understanding the patterns of medical care utilization and its causes are important goals. Such information permits appropriate allocation and distribution of resources such as healthcare workers, reimbursement rates, technology, and physical capacity or infrastructure. Further, it provides policymakers and health planners with insights to prevent illness, improve medical outcomes, and promote efficient use of limited resources. The projected imbalance between demand and capacity requires a focus on either increasing provider supply through training expansions or reducing demand for services by focusing on preventing severe knee osteoarthritis in the population. The Accreditation Council for Graduate Medical Education (ACGME) accredited positions in orthopedic surgery recently expanded by approximately 9.3%; however, more positions may be necessary to meet future demand if current projections of demand for orthopedic procedures are accurate [67]. Further, alternative workforce strategies may be necessary to address the shortage in the short-term, as training delays the entry of these new providers into the workforce.

Previous studies have examined risk factors for knee arthroplasty and documented an increase; however, few studies have empirically explored the determinants driving demand and none have studied the trends in North Carolina, a state whose population characteristics are much like the rest of the U.S. population. Literature on other types of medical care utilization provides useful theories to test in the case of knee arthroplasty rates, including a prominent theory that posits that medical care providers “induce” demand for their services.[68-73] This study blends an epidemiological approach with sociological theory about risk factors and correlates of utilization with economic theory about provider influence, examining some of the traditionally unexplained variation in utilization of a procedure which accounts for a substantial amount of national medical expenditures. As such, the study contributes to the academic knowledge about medical care utilization and small area variation, but also offers evidence for the purpose of policy development around disease prevention and healthcare workforce planning.

1.4. Conceptual Framework

Regional variation is a phenomenon in which neighboring geographic areas exhibit very different utilization rates for healthcare services [5]. Over the past three decades, studies of regional variation have identified conditions and procedures for which there are significant differences in the rate of hospitalization among communities that are otherwise similar with respect to population characteristics. Knee replacement surgery is among those procedures that have shown high variability in utilization across space and time, but little evidence exists to explain the variation. [4, 74] The theoretical and methodological motivation for this dissertation is derived from this body of work on regional variation in healthcare utilization, much of it led by Wennberg and colleagues at Dartmouth.

In fact, studies of regional variation have generally ignored the influence of community and population characteristics on utilization, and attributed the variation to the treatment choices of physicians. While most health services researchers acknowledge that provider decisions contribute to variation in patterns of healthcare use, a common criticism of these studies is that they fail to empirically demonstrate the relationship. A major objective of this study is to incorporate additional explanatory variables into a model of utilization for knee arthroplasty, including population and local provider characteristics. This study takes a multidisciplinary approach in identifying the determinants of utilization for knee arthroplasty based on classic models of medical care use (Figure 5). Figure 5 represents the distillation of several theoretical structures used to guide the analysis. The classic sociological Behavioral Model of Healthcare Utilization, by Andersen and Newman, and the economic theory of provider-induced demand are drawn upon to help build the analytical model.

1.5. Regional Variation

With its findings of significant variation in the rates of tonsillectomies, appendectomies, cholecystectomies, hysterectomies, and other surgical procedures, Wennberg and Gittlesohn's 1973 study of small area variation in Vermont ignited a strong and lasting interest in studying geographic variation of healthcare utilization.[5] Numerous studies by Wennberg and others have followed over the past four decades, showing similar patterns of variation in other states and regions, and between countries [4, 74-81]. Various theories arise from these studies over what causes the variation, most prominently Wennberg's belief that there is inconsistency in medical decision making over and above the variation in need. Other factors that have been shown to be associated with variation in utilization include local healthcare resources such as hospital beds or outpatient surgery centers, [6, 78] and physician supply, [68, 69] discussed in greater detail in the following section. Other studies emphasize the need to estimate the effect of socioeconomic population characteristics such as education, poverty, income, unemployment, and others.[75, 82-85] These studies are the foundation for this dissertation's methodological approach of knee arthroplasty utilization in North Carolina, which focuses on the effect of population and provider variables which have been omitted in previous studies of the procedure.

1.6. Healthcare Supply and Surgeon-Induced Demand

Physicians and healthcare providers have a complicated influence on patient utilization of medical services. A physician's responsibility to assess illness and then treat or refer patients for care creates a dual role as both supplier of services and agent for the patient,[69, 72, 86] which may consequently create a shift in the demand for services. Generally, it is believed that physician influence on demand shifts the demand curve outward (from D_1 to D_2 in Figure 4) increasing utilization so as to optimize the physicians' preferred level of services and related income. In markets with high provider to population ratios, the demand shift may be inward so as to contract utilization and associated physician workload. However, in the case of surgical services, demand is rarely expected to be suppressed because most markets are thought to have excess capacity among practicing surgeons.[69] This theory is commonly called supplier-induced demand, and it posits that the utilization of healthcare services is inflated due to the economic motivations of providers.

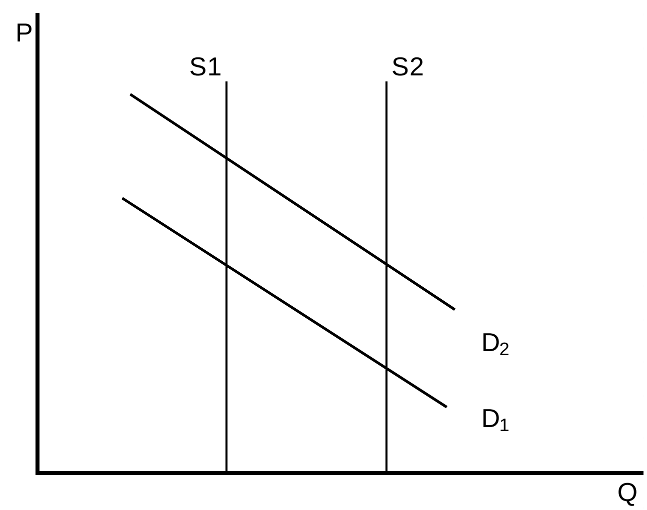


Figure 4. Demand Shifting

In his seminal 1978 study of surgeon-induced demand, Victor Fuchs estimated a 3% increase in surgical volume associated with a ten percent increase in the surgeon to population ratio[69]. Cromwell and Mitchell subsequently found a positive, though weaker, relationship between utilization and surgeon density, especially for elective procedures.[68]

Like Cromwell and Mitchell, more recent studies have found evidence that provider-induced demand is greatest for services that are more discretionary, such as elective surgery and diagnostic procedures.[73, 87-90]

Other classic studies of provider-induced demand focus on the relationship between provider density and income, [70, 71] finding evidence of a positive relationship between the two. That is, output per provider in areas with greater physician density is higher as physicians seek to increase their income. Using an alternative approach to estimate induced demand, two other studies [72, 91] compared utilization rates of the general population with that of physicians and their spouses. Both discovered higher rates of healthcare utilization among the more informed population, lending support to the theory of provider-induced demand.

"The mechanisms by which physicians are hypothesized to be able to increase both fees and volume of services in the presence of an increasing manpower supply vary, but taken together they represent a belief in the theory of demand inducement."[73] Still, non-believers are plentiful. Many of the classic studies, especially those by Fuchs and Cromwell and Mitchell, have been criticized for methodological limitations including omitted variable bias and inconsistency in the construction of variables for geographic areas – particularly related to utilization rates using sample data.[73, 92, 93] Perhaps the greatest criticism of the theory is that conclusions of induced demand rely on the lack of other explanations; unobserved variable bias and potentially erroneous causal inference concern economists who prefer to believe that market forces function normally for healthcare services. Specifically, the omission of information about insurance from the models is of great concern. To an extent, some of the later studies, including those by Wilensky and Rice, addressed these concerns and still found evidence of provider-induced demand.[73, 87, 88]

More recently, a study by Lu et al. measured the influence of new orthopedic surgery programs on increasing Medicare utilization of lower extremity arthroplasty, finding no evidence of an association and therefore concluding there was no provider-induced demand. However, the methodological approach of this study included many opportunities for bias including the composition of comparison groups, construction of independent variables, and choice of level of analysis [94]. This dissertation draws upon the methodological improvements of these studies in examining the relationship between utilization of knee replacement surgery and provider supply.

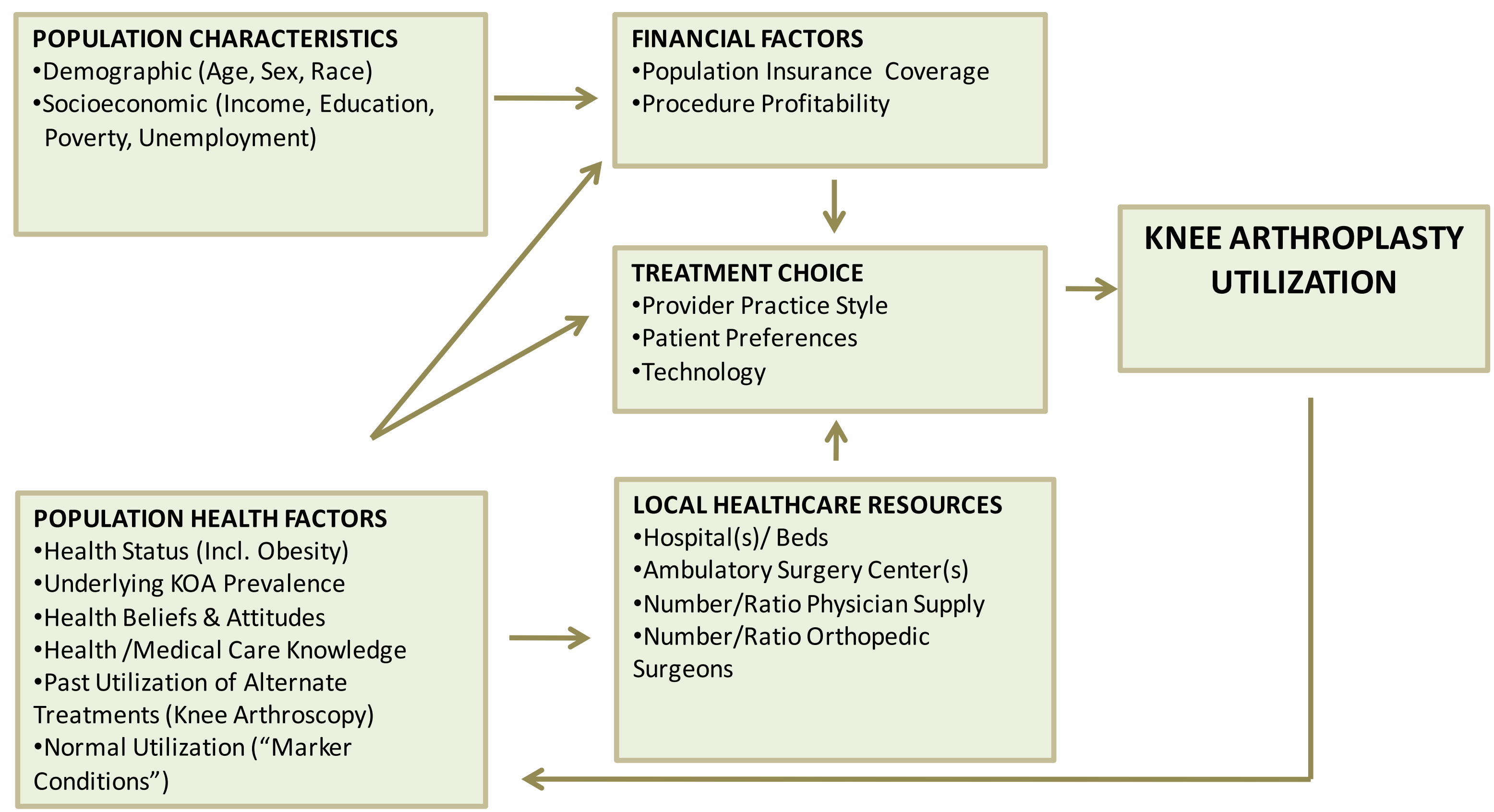
Despite criticism, the plausibility of provider-induced demand offers continuing appeal for researchers interested in explaining geographic variation in healthcare utilization. Improving upon past methodologies and using new datasets, the theory remains a prominent framework for explaining a portion of healthcare utilization. While acknowledging disagreements and challenges, Green notes that "looking for the effects of availability on the utilization of medical resources is similar to tracking the abominable snowman. The evidence is fragmentary, and though the search is exciting and fraught with danger, no one is quite sure what to do were the beast ever confronted face to face." [95]

In pursuit of an estimate of surgeon-induced demand, it is important to reiterate that a finding of its existence does not necessarily imply that there is unnecessary care. In fact, both empirical evidence and anecdotes suggest that some beneficial treatments, such as knee replacement, may actually be underutilized for certain populations.[50, 96] While findings from the Dartmouth group on small-area variation are interpreted to suggest waste and inappropriate care, there is limited justification for such conclusions. Dr. Schlicke's 1978 comments that "much has been made of the fact that Americans have twice as many operations as people in England and Wales but no one is sure whether this means too many in one country or too few in the other" are important to consider.[97] More recently, research has suggested that unwarranted geographic variation is less extensive than believed and that some research concluding inefficiency related to regional variation may be based on flawed methods.[98] However, estimating the various influences on healthcare utilization provides a more clear understanding of the policy levers available to achieve the optimal level of care.

1.7. Andersen's Behavioral Model of Healthcare Utilization

A much cited classic theoretical model of healthcare utilization from the 1960s is that of Ronald Andersen called the Behavioral Model of Healthcare Utilization. This framework depicts the use of medical care as a function of individual, societal, and institutional factors. An important improvement on the original model was published in 1973 by Andersen and Newman,[61] in which they further explain utilization as dependent on the type of health service in question. That is, the relative influence of factors such as age, education, income, and others will vary in predicting utilization of therapeutic treatments, such as knee arthroplasty, in the present context, versus preventive, diagnostic, or custodial care. In their model, utilization of secondary care, which returns an individual to the state of functioning prior to the illness or injury, depends in part on the nature and structure of local healthcare resources and community characteristics. This dissertation incorporates characteristics of the county's population, focusing specifically on the effect of the local physician and orthopedic surgeon supply and hospital capacity on the utilization of inpatient knee replacement surgeries over time.

FIGURE 5. DETERMINANTS OF POPULATION UTILIZATION RATES FOR KNEE ARTHROPLASTY



2. Literature Review

2.1. Overview of Literature Review

Literature on knee replacement surgery provides some insight to longitudinal trends in utilization by identifying the main individual risk factors for disease that leads to knee arthroplasty. Studies have identified variation in the use of knee arthroplasty; however, few have examined the correlates of utilization at a population level, and the potential association with characteristics of the local healthcare market has been virtually ignored. This chapter summarizes what is known about knee arthroplasty utilization through published literature.

2.2. Utilization Trends and Demographic Profile of Patients

Changes in the rate of knee replacement surgery in the United States have been well documented since the 1980s. Data have consistently shown an increase in knee replacement surgery, though the magnitude of growth varies according to the study population, geographic area, and time period studied. A common conclusion is that growth in knee arthroplasty has been steadily if not rapidly increasing and that the increase is disproportionate to overall utilization of healthcare services or other surgical procedures.

One of the earliest studies of knee replacement trends by Katz [99] et al. found the rate of knee replacement surgery among Medicare beneficiaries surgery doubled over a five year period between 1985 and 1990. An analysis of the National Hospital Discharge Survey (NHDS) by Kurtz[100] showed a threefold increase in knee replacement surgery throughout the 1990s and early 2000s. More recent studies expand the scope of examination to include other payers through Healthcare Cost and Utilization Project (HCUP) discharge databases, which show more modest though still substantial increases in the general population. Using HCUP Nationwide Inpatient Sample (NIS) discharge data, Kim et al. [62] found a 50% increase in knee replacement surgery between 1997 and 2004. Similarly, Merrill [1] found an increase of 69% in the procedure in the U.S between 1997 and 2005 using NIS. By 2005, more than 555,800 inpatient knee replacements had been performed, which corresponds to a utilization rate of 187.5 procedures per 100,000 persons, using U.S. Census Bureau population estimates. Compared to other surgical procedures, growth in knee replacement is the second fastest growing reason for hospitalization for orthopedic treatment in 2005.[101] Future growth in the procedure rate for knee arthroplasty is estimated to be 673% by 2030.[102]

Regional and state analyses have also found similar patterns of growth in knee replacement surgery during the same timeframe. Mehrotra et al. [103] found the age-adjusted rate of knee replacement in Wisconsin, using the state’s inpatient discharge data, increased by 81.5% for persons older than 44 between 1990 and 2000. Data from a large prepaid health plan in Southern California show incidence rates for knee replacement increasing by approximately 5% annually between 1995 and 2004.[32]

Comparison of knee arthroplasty rates in the U.S. to other developed countries is difficult because of differences in data, study populations, estimates of “at risk” populations, methodology of case selection in analyses, and time periods of analysis. Despite these difficulties, several foreign studies have yielded relevant findings and provide a context for interpreting utilization rates within the U.S.   For example, studies of the Swedish Knee Arthroplasty Register indicate a five-fold increase in utilization rates between the 1980s and 1990s, mostly in the population over 65 years old. [104] Still, the utilization rate in Sweden was 63 per 100,000 persons in 1996-1997, which is approximately half the rate in the U.S. for 1997 according to data from AHRQ (Figure 3). Australia's utilization for knee arthroplasty was 76.8 per 100,000 persons in 1998, and the volume of knee arthroplasty cases increased by 42.8% between 1994-1998[105] Similarly, the total volume of knee replacements more than doubled in England during the 1990s, to an incidence rate of 70.7 per 100,000 women and 62.1 per 100,000 men in 2000.[106]   These studies demonstrate that utilization of knee arthroplasty is increasing rapidly outside of the United States, but that our rate of use is still much higher than in other countries.

2.3. Risk Factors for Knee Arthroplasty

The literature on knee arthroplasty includes many studies which examine variation in utilization of the procedure by patient characteristics, most notably age, gender, race, and health status characteristics including obesity. A recent meta-analysis of risk factors for onset of knee osteoarthritis in older adults identifies additional modifiable risk factors including previous knee injury, smoking, occupational activities, and physical activity [107]. For many patient characteristics, there appears to be a difference in utilization despite similarity in the prevalence of underlying clinical causes.

The most straightforward characteristic associated with knee arthroplasty risk is age, which predictably is positively associated with higher utilization rates and risk of knee arthroplasty. Evidence identifying the most at-risk age group is mixed, though generally points to 65 years old, the age when elevated risk begins. Examining utilization among only the Medicare population, Mahomed et al.[33] found the highest rates of knee arthroplasty in the 75-79 year old age group and lowest among those over 90 years. Similarly, Katz et al.[99] found a higher risk of knee replacement associated with the age group including 70-84 among Medicare enrollees, with reduced risk after 85 years of age. Dixon's study in the U.K. also found that being between the ages of 70-74 was one of the strongest predictors of having a knee arthroplasty.[106] Kurtz found knee arthroplasty utilization higher in the age group 65-74 than in 45-64, but discovered that the largest increase in utilization between 1990-2002 was for those under 65 years.[100]

This finding has been corroborated by other work, including a study by Jain which found that though most knee arthroplasties were performed on older patients and most of the increase in the study period was for older age groups, there was a "rapid increase in knee arthroplasty rates among younger populations (40-49 and 50-59) between 1990-2000".[108] Using NIS data, Kim found that the rate of increase in knee arthroplasty among persons age 45-64 was 83% compared with 38% in the 65-84 year old group.[62] In Wisconsin, Mehrotra observed a decline in the average age of knee replacement during the 1990s by more than ten years, from 79.6 to 68.5 years, and found that the youngest age group (45-49 years) experienced the greatest increase in knee replacements.[103] Khatod also found that the greatest rates of increase for knee arthroplasty utilization were among individuals younger than 65 in Southern California.[32] Abroad, utilization of knee arthroplasty among younger patients is also increasing at a similarly rapid rate. A recent study of the Swedish Knee Arthroplasty Register found the rate of total knee replacement surgery in patients younger than 55 increased fivefold between 1998 and 2007, and between 2002 and 2007 Australia reported a 40% increase in utilization for patients under 55 [109, 110].

Throughout the literature, women are found to account for a disproportionate share of knee replacement surgeries. Between 1990-2000, Jain found that women accounted for approximately 63% of knee arthroplasties in the U.S. according to the National Inpatient Survey discharge data.[108] Also using NIS data but for a later time period, 1997-2004, Kim found that between 57% to 64% of knee replacements were for women.[62] Analyses of single states or regions have found consistent patterns. Mehrotra found that women accounted for approximately 60% of all knee replacement discharges in Wisconsin between 1990-2000.[103] In Southern California, women accounted for 61% of knee replacements between 1995-2004.[32] Within the Medicare population, Katz found that knee replacements were twice as likely for women as for men.[99] A separate study of Medicare data by Mahomed found nearly two-thirds of all primary knee replacements were for females[33]. Procedure rates among women in every race group were higher in Skinner's study using Medicare data, though the disparity between men and women was most pronounced among minorities.[111]

Several studies have investigated factors underlying the disproportionate utilization of knee arthroplasty among women. A population-based study by Hawker found that, among patients with identified knee osteoarthritis, knee replacement was underutilized for both genders, but was recommended significantly less often for women than for men.[112] The potential need for arthroplasty, determined by scored responses to health assessments and radiographic examination, was found to be three times as great for women as men. Further, the study showed that women were less likely to have discussed arthroplasty with their physician, suggesting the possibility of gender differences in clinical recommendations for knee arthroplasty. The latter issue was further examined in Borkhoff's study of 71 physicians' clinical decision making, which also identified underutilization of knee replacement among women.[113] Among gender-matched patients with identical clinical presentation and similar socioeconomic backgrounds, male patients were twice as likely be recommended for knee arthroplasty.

Minorities have also been found to have a lower likelihood of undergoing a knee replacement.[33, 99, 108, 111, 114-116] In a study of Medicare enrollees, Katz estimated the odds of having knee arthroplasty were 1.5 times higher for whites than for blacks.[99] Similarly, Mahomed found the risk ratio for knee arthroplasty among black Medicare enrollees was 0.73 as compared to whites [33] and a study of veterans by Jones had a nearly identical finding of lower odds among blacks.[115] Also consistent with these findings, Wilson calculated a lower likelihood of having knee arthroplasty among blacks, which persisted after controlling for insurance status, economic status, and age. Skinner's analysis of Medicare beneficiaries also found that knee arthroplasty was more common among whites than other groups;[111] blacks had the lowest rate of utilization among the three groups (whites, blacks, Hispanics) for both women and men. This study, however, showed that racial variation in utilization was more pronounced among men than women. In 29/30 Hospital Referral Regions (HRRs)[3], rates of knee arthroplasty were significantly lower for black men than White or Hispanic men; however, rates for white women were only significantly higher in 15/30 HRRs than for black or Hispanic women. A recent study by Steel analyzed data from the Health and Retirement Study, finding, among other factors, that being black is associated with lower likelihood of receiving joint replacement surgery among people deemed potentially in need of one; this analysis stands apart from many in that the denominator for incidence is the population with osteoarthritis.[117]

The potential causes of ethnic or racial variation in utilization of knee arthroplasty are many; however several recent studies show evidence of differences in knowledge, attitudes,

[3] Hospital referral regions are geographic areas, originally created for the Dartmouth Atlas, to represent the prevalent patterns of hospital use by residents.

preferences, and familiarity about the procedure. A survey by Ibrahim of 600 veterans in the late 1990s revealed race-related differences in familiarity or knowledge about knee replacement.[118] Similarly, a small study by Suarez-Almazor in a Houston, TX outpatient clinic found that minority patients with knee osteoarthritis were less familiar with the surgical treatment option of knee arthroplasty and less likely to have considered having one, even after controlling for severity of osteoarthritis.[119] Chang also conducted focus groups, observing that blacks were more likely to have concerns about their candidacy for knee arthroplasty and the overall clinical decision making process, signaling physician mistrust.[120] A less conclusive focus group study found that participants of different racial or ethnic backgrounds had dissimilar perspectives on pain and limitations associated with knee osteoarthritis, trust in their providers, and concerns about cost; however, authors stopped short of concluding patterns existed on the basis of race or ethnicity.[121] Most recently, Hausmann et al. found that blacks were less likely to receive a physician recommendation for joint replacement in the VA system, however, the disparity diminished when patient preferences regarding the procedure were incorporated [122]. This study suggests that patient preferences may have more influence on observed disparities in utilization of knee arthroplasty than previously thought.

Because it is considered a modifiable risk factor, obesity is perhaps the most studied variable related to osteoarthritis. Large population-based studies in the U.S., Sweden, Iceland, Canada, and Australia have consistently demonstrated a positive association between obesity and knee osteoarthritis using various measures of body mass. Early studies typically focused on weight or body mass index (BMI), while more recent studies have employed alternative measures such as adipose body composition, waist-to-hip ratio, body fat percentage, and waist circumference.

Several of the earliest studies of the connection between obesity and knee osteoarthritis were conducted by Felson and colleagues in the late 1980s.[123] These studies found a positive association between weight and knee osteoarthritis, which is stronger among women. Data from the Framingham study of cardiovascular disease demonstrated similar findings of an association between obesity and risk of osteoarthritis using weight level; the risk was higher for women. [123] Using National Health and Nutrition Examination Survey (NHANES) data, Anderson and Felson found that obese women had four times the risk of osteoarthritis of women with BMI under 25, while BMI greater than 30 was associated with a relative risk of 4.8 compared with men who were neither obese nor overweight.[123] Also using NHES, Dillon et al. examined the correlates of osteoarthritis, finding strong associations between radiographic knee osteoarthritis and obesity (BMI greater than or equal to 30); other significant factors included being over 70 years old, female, and black.[124] A study by Davis in the late 1980s found evidence in examining NHANES data to suggest that the differential prevalence of obesity in men and women contributes to the differences in osteoarthritis of the knee between men and women.[125] A recent study by Niu of 2,623 subjects in Iowa and Alabama found a positive association between BMI and incident knee osteoarthritis.[126]

Several small case-control studies have also identified an association between knee osteoarthritis and obesity. In Wendelboe's 2003 case-control study in a Utah hospital, BMI and knee arthroplasty had a strong association; in both women and men the odds ratio for knee replacement increased with weight in all but two weight categories for women.[127] In a different case-control study of women, Oliveria, Felson, and colleagues found that women in the highest weight category were ten times more likely to develop knee osteoarthritis than women in the lowest weight class.[128]

Numerous foreign studies have found similar associations between knee osteoarthritis and obesity. In Iceland, Franklin[129] found positive associations between high BMI and knee osteoarthritis, as did numerous studies in the U.K.,[130-133] Germany,[134] and the Netherlands.[135] The strongest association between obesity and knee replacement was observed in a recent study by Liu, where middle-aged women in the heaviest group had more than ten times the relative risk of knee replacement as those in the lightest weight group; these results did not vary significantly when controlling for confounding factors.[131] A more modest four-fold increase in risk for knee osteoarthritis was observed in Manek's 2003 study of twins in the U.K, which persisted after controlling for genetic factors.[133] Spector found that the risk of knee osteoarthritis increased by 6.5% for every five kilogram increase in weight [132] Sturmer found that the association between weight and knee osteoarthritis was stronger after controlling for confounding factors such as smoking and age; the study's findings of no association with osteoarthritis of other joints offer evidence to refute a potential metabolic process in favor of mechanical joint stress.[134] Reijman's Rotterdam study found similar evidence of an association between obesity and knee but not hip osteoarthritis.[135]

A number of studies have examined the strength of various anthropometric measures in relation to osteoarthritis risk. Abbate's study of women in Johnston County, NC, found that all obesity measures were associated with knee osteoarthritis, but that BMI was the strongest predictor.[57] Two other foreign studies also assessed similar obesity measures, similarly finding that BMI showed the strongest association, along with body weight in Wang's study.[136, 137]   Collectively, these studies establish a compelling connection between obesity and knee osteoarthritis at the individual level; however, no studies to date have examined the relationship at a population level.

2.4. Geographic Variation and Induced Demand for Knee Replacement Surgery

The importance of examining area variation in healthcare utilization, particularly for elective surgical interventions like knee replacement, has been frequently and contentiously discussed in the context of cost containment and appropriate provision of care. Although high use does not necessarily mean inappropriate use, the variation between adjacent or similar areas is of considerable interest in the quest to attain the optimum and most efficient level of care.

The geographic variation of a number of surgical procedures, such as CABG, tonsillectomy, and appendectomy, has been studied extensively by Dartmouth Atlas researchers and others. Yet, only a handful of studies have examined geographic variation in utilization for knee arthroplasty, one of the most common orthopedic surgical procedures in the U.S.; only a few of those take a multivariate approach to explaining the variation.

One of the most relevant studies for this dissertation was conducted by Zhou et al. and published 1996.[138] In this study authors conducted a two-stage regression analysis using hierarchical data, including Medicare claims data, to model variation in knee replacement rates nationally and within healthcare regions. Findings suggested that income, poverty, and total and orthopedic provider supply are all strongly associated with lower knee revision procedure rates, while hospital beds had a positive association. Rural areas also had higher rates of knee replacement than urban; this finding is consistent with other studies and is likely due to a higher prevalence of osteoarthritis among the areas' large elderly populations.[139] Another study of regional variation in knee arthroplasty in the U.S. using 1988 Medicare data by Peterson et al., found low correlation between states' knee replacement procedure rates and per capita surgeon supply but a strong inverse relationship with population density.[140] Also using Medicare data, Skinner found evidence of patient differences between HRRs that explained part of the variation observed in knee arthroplasty utilization among racial groups including all Hispanics and black women.[111] While these studies offer insight for examining regional variation in knee arthroplasty, they do not make use of spatial epidemiological techniques to assess the geography of variation. Furthermore, the results do not explain substantial increases in utilization observed in recent years as these studies preceded observed growth.

Foreign studies of geographic variation in knee arthroplasty have also yielded important results. A comparison of two regions in Canada by Hawker found high utilization of knee arthroplasty in areas with lower potential need (measured as underlying illness) and willingness to have the procedure.[96] A small study involving medical record auditing in high and low joint arthroplasty areas in Ontario by van Walraven examined whether geographic variation of utilization was explained by inappropriate provision of surgery through medical chart review. [141] Results detected no difference in the provision of inappropriate surgical care in high rate versus low rate areas. Although this study is limited by the number of cases reviewed, and suffers poor generalizeability for the U.S. because of differences between the two countries' population access to care, its value is in directly examining the issue most small-area variation studies strive to examine through proxies: inappropriate care.

2.5. Physician Practice Style in Knee Arthroplasty

Knee replacement surgery is one among several treatments for osteoarthritis of the knee. Other options include arthroscopy, osteotomy, and unicompartmental arthroplasty, or joint spacers – all of which are considered less invasive. The variation in physician recommendations for each type of treatment for knee osteoarthritis has not been studied in the U.S. However, a few Canadian studies have studied this component of regional variation.[141-144] Wright's 1999 study of area variation in knee replacement surgery is particularly relevant to this proposed analysis despite the fact that it analyzes Canadian trends and data.[145] Examining county-level knee arthroplasty procedures in Ontario, Wright examined the relationship between knee replacement rates and physician and population characteristics, including provider's enthusiasm for the procedure. The study found several variables to be strong predictors of county knee arthroplasty rates including two age groups (equal to or greater than 75 years and 60-64 years) and the local orthopedic surgeons' likelihood to operate.

3. Research Design

3.1. Overview of Methods

To study longitudinal and geographic trends in the utilization of knee replacement surgery, this dissertation analyzes North Carolina inpatient discharge data between 2000 and 2009, employing spatial regression techniques to identify provider and population characteristics associated with variation in use of knee replacement surgery in North Carolina counties. Descriptive analyses are conducted first, to provide a broad understanding of the trends in patient characteristics for knee arthroplasty discharges, as well as a profile of the physicians and institutions performing knee arthroplasty. Knee arthroplasty discharges were then aggregated by county to produce age-adjusted knee arthroplasty utilization rates for multivariate analyses. County aggregated data were merged with other datasets describing population characteristics and healthcare resources for each year between 2000 and 2009. Ordinary Least Squares (OLS) and spatial lag regression techniques, were then used to estimate the effect of county-level socio-demographic characteristics on utilization rates among North Carolina counties. Data availability and constraints of spatial regression methodology necessitated cross sectional analysis, using 2008 data, for the main multivariate analysis of utilization rates. To explore longitudinal variation in utilization of TKA, regression techniques were also used to analyze of the change in knee arthroplasty utilization between 2004-2008 as a function of change in covariates during the same period.

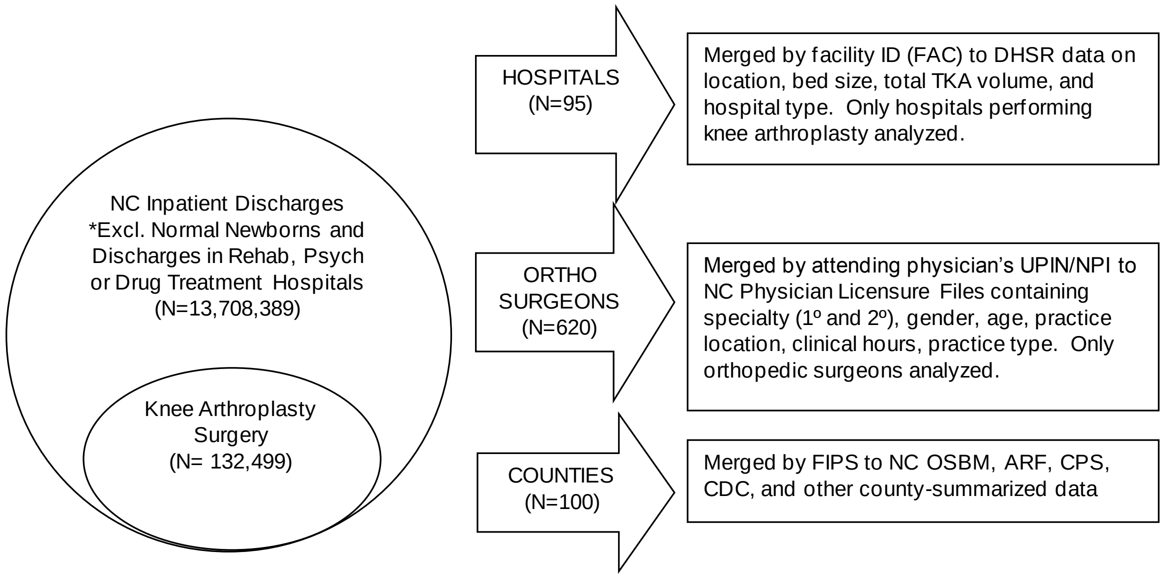
3.2. Sample and Data File Structure

Inpatient discharges with an ICD-9 procedure code for total knee arthroplasty, *81.54*, were extracted from the NC Inpatient Discharge database for the years 2000-2009[4]. Discharges were excluded if the institution was a psychiatric, rehabilitation or drug treatment facility and if the record contained an ICD-9 code for a known contraindication, V64.x patient refusal or other contraindication, among any of the diagnosis codes. A total of 1,649 discharges were excluded according to these criteria, leaving a total of 132,499 discharges with a knee arthroplasty procedure during the period Jan 1 2000 through December 31 2009. These discharges were summarized and extracted, creating four separate datasets for analysis: 1) a discharge-level file for examination of patient characteristics and the medical encounter; 2) a provider-level file, whereby the annual number of knee arthroplasty discharges are summarized for each orthopedic surgeon for analysis of trends in the physicians performing knee arthroplasty; 3) a hospital-level file, whereby the annual number of knee arthroplasty discharges are summarized for each hospital and analyzed for trends in the institutions where knee arthroplasties are performed; and 4) a county-level file, whereby an age-adjusted rate of knee arthroplasty utilization is calculated using patient residence for every North Carolina county, for multivariate and spatial analysis of factors associated with variation in utilization of the procedure. Production of these files was facilitated by the availability of key variables in the discharge record including the facility ID, the attending physician ID (which was either a national provider identification number (NPI) or a Uniform Provider Identification Number (UPIN)), and Federal Information Processing Standard (FIPS) county code of the patient's residence. These variables allowed linkage to external data, including hospital data from the NC Division of Healthcare Services Regulation using

[4] North Carolina Inpatient Discharge databases acquired from Cecil G. Sheps Center for Health Services Research at the University of North Carolina at Chapel Hill. http://www.shepscenter.unc.edu/research_programs/hosp_discharge/

the facility ID, the NC Physician Licensure Data using the attending physician ID, and various sources of county data using the patient's FIPS county code as detailed in Figure 6.

Figure 6. Sample and File Structure



Acronyms: DHSR=Division of Healthcare Services Regulation; CMS=Centers for Medicare and Medicaid Services; UPIN=Uniform Provider Identification Number; NPI=National Provider Identification; FIPS=Federal Information Processing System; NC OSMB = North Carolina Office of State Budget and Management; ARF=Area Resource File; CPS=Current Population Survey; CDC=Centers for Disease Control

Because the physician licensure files, maintained by the Cecil G. Sheps Center for Health Services Research under contract with the North Carolina Medical Board, do not currently contain UPINs or NPIs, linking the discharges to provider data required the construction of a crosswalk file. The crosswalk file was constructed by manually searching for two online national provider databases using the UPINs and NPIs contained in the discharge record for knee arthroplasty cases.[5,6] Successful searches in these databases returned the full name, current and historical UPINs and NPIs, primary specialty, current practice location, and state license numbers for the provider. Using the name and, when available, North Carolina state license number, a search was then performed in the North Carolina licensure data files to verify the information and confirm a match. Erroneous entry of provider IDs on the

5 The National Provider Indntifier Database NPI Registry Search: www.hmedata.com/npi.asp
6 Nebo Systems eCare Online NPI and UPIN Search: www.ecare.com /

discharges prevented identification of some physicians, as detailed later in this chapter.

3.3. Unit of Analysis and Geography

The main geographic unit of analysis for this dissertation is the county. Although county boundaries may not necessarily affect preferences in how a population uses healthcare services, counties are a conventional unit of analysis in health services research and planning because of the availability of county aggregated data and the convenience of distributing resources to an organized government. In North Carolina, county governments serve an important role for local populations, as they are tasked with the responsibility for ensuring availability of a variety of human services including public health.[146, 147] Counties have the authority to collect revenue from residents and are the recipients of state and federal funding for many public health programs including public health departments (G.S. 130A-34), and therefore counties are an interesting unit of analysis with regard to the health and healthcare use of residents within a county. From a methodological perspective, North Carolina counties are a good unit of analysis because of their relatively uniform size, compared with counties in many western states, and because many state and national datasets are available at the county level. Choice of county as a geographic unit may introduce some bias in that the service area for different types of service, namely primary care versus orthopedic surgical care, varies; this limitation will be discussed in more detail throughout the paper.

County-level age adjusted knee arthroplasty utilization rates are summarized from individual inpatient discharges for each year in the analysis, based on patient residence. Consequently, the county rates reflect utilization of the residents who lived in the county, regardless of the location where surgery was performed. Annual discharge files contain information for every inpatient encounter in a short-term acute care non-federal hospital in North Carolina, thus representing the actual volume of utilization during the study period with the exception of those at military, veterans', or out-of-state hospitals. Ten years of data (2000 – 2009) are summarized for each of the 100 North Carolina counties, and merged with other county data for the same years.

3.4. Data Sources

Data are drawn from multiple secondary datasets for various levels of analysis. Procedure utilization data, the focus of this analysis, are drawn from the North Carolina Discharge Databases. Supporting data are taken from the North Carolina Medical Board Physician Licensure the North Carolina Department of Health and Human Services Division of Health Service Regulation Hospital Data, the Area Resource File, Nielsen Claritas® data, The Current Population Survey data, and the Centers for Disease Control's county summary of obesity from the Behavioral Risk Factor Surveillance System. Each source of data is described in the following section, along with details regarding the development of measures and methods of analysis.

3.4.1. NC Discharge Databases

Discharge data are retrieved from uniform claim forms used by institutions to bill payers, the UB-04 and UB-92 for hospitals and CMS 1500 for ambulatory surgery centers. Annual summary files contain a record for every discharge in the state's non-federal, short-stay general and specialty hospitals or ambulatory surgery centers. Each record represents a single visit and includes information about patient characteristics (age, sex, FIPS and ZIP code of residence), the medical encounter (institution and attending physician provider identifiers, date(s) of service, diagnoses, procedures, length of stay, number of days from admission to procedure, DRG and MDC codes, discharge status, admission type, and service line), and payment (primary payer and charges). Inpatient data contains up to ten procedure codes and 24 diagnosis codes, while ambulatory surgery center discharges contain up to 17 diagnosis and procedure codes. In summary, inpatient discharge data are utilized from the years 2000 through 2009 to identify all knee arthroplasty procedures (ICD-9 procedure code 81.54) and four reference conditions, described in greater detail later in this chapter, in North Carolina. Ambulatory Surgery Center data from 1997 through 2006 are utilized to identify all knee arthroscopy procedures (ICD-9 procedure code 80.20 and 80.26) as a 3-year lagged independent variable.

3.4.2. North Carolina Office of State Budget and Management

The State Demographics branch of the Office of State Budget and Management produces annual estimates of the population of North Carolina counties for use in distribution of resources to local governments. Estimates are made using data from local governments including annexation data, institutional data, and military population data. These data are used to calculate population-based procedure rates at the county level throughout the study period. Population estimates were obtained for the years 1997 through 2009.

3.4.3. Area Resource File

The Area Resource File (ARF) is a county-level database containing more than 6,000 variables for each county and county equivalent areas in the United States. The ARF is a database compiled from a variety of sources including the US Census Bureau, the Centers for Medicare and Medicaid Services, the National Center for Health Statistics, the American Medical Association, and various others. The database contains variables defining each county's health care supply (facilities and professionals), health status (indicators such as 3-year mortality rates by cause), healthcare utilization (hospital visits), health insurance coverage, and socioeconomic characteristics of residents. Annual county-level population estimates from the Census are also present in the file. County-level variables of interest for this dissertation include demographic characteristics (proportion of residents by race), socioeconomic indicators (percent of population unemployed, percent in poverty) and healthcare resource availability (number of ambulatory surgery centers and skilled nursing facilities). Given the guidance of the Andersen model, these variables are hypothesized to have an effect on utilization of knee arthroplasty at a community level. The ARF data for this study span all years between 2000 and 2009; however, some variables are not available in all years.

3.4.4. Current Population Survey Estimates

The U.S. Census Bureau conducts annual nationwide surveys to identify demographic and socioeconomic characteristics of the U.S. population. One survey, The Annual Social and Economic Supplement, inquires about health insurance coverage. While the sample size of the survey is generally considered insufficient to produce estimates for geographic areas smaller than states, researchers at the Cecil G. Sheps Center for Health Services Research and North Carolina Institute of Medicine, have, since 1995, employed multivariate regression methods to produce county-level estimates of the uninsured rate for North Carolina.[148-152] These annual county-level estimates of the uninsured have been merged into a single file for the years 2000 through 2009.

3.4.5. Nielsen Claritas® Demographic Data

County-level economic and demographic data are drawn from the Nielsen Claritas® proprietary market research database, primarily used to target marketing based upon population characteristics, consumer spending behavior, and household income. For this dissertation, variables of interest are Claritas' measures of population economic resources, including per capita income and median household income by age group, education, and demographic characteristics (race, gender) of the population. Because knee arthroplasty requires some out of pocket expenditures and potential loss of wages during post-operative recovery, there may be an association between utilization and the financial resources of age groups most likely to utilize the procedure. Claritas® data are available for the years 2000 and 2003-2009.

3.4.6. North Carolina Medical Board's Physician Licensure Data

Data for North Carolina physicians are available from the N.C. Medical Board's licensure files, maintained by the North Carolina Health Professions Data System at the Cecil G. Sheps Center for Health Services Research. These data include all physicians with licenses including those who are enrolled in postgraduate medical training. Data elements available for physicians include demographic characteristics (race, gender, and age), practice characteristics (type of practice setting, ZIP code, and hours of patient care per week), and training information (medical school location, graduation date, residency site, and specialties). These data are linked to inpatient discharge data by Uniform Provider Identification Number (UPIN) or National Provider Identification (NPI) and state licensure identification numbers, using a crosswalk file that was created specifically for this study.

3.4.7. Division of Health Service Regulation (DHSR) Data

Hospitals are regulated by the North Carolina Division of Health Service Regulation (formerly known as the Division of Facility Services or DFS). Information for all licensed facilities is available on the agency's website[7], including location (address, county), license identification code, number of beds, number of operating rooms, and number of endoscopy

[7] http://www.dhhs.state.nc.us/dhsr/reports.htm

rooms. Hospital locations were geocoded using “batchgeo”, an online geocoding resource[8]. Data for three facilities that closed during the study period[9] were obtained through an online directory of hospital and nursing homes[10]. These hospital data, last updated in February 2011, were linked to discharges using the facility identification number.

3.4.8. Centers for Disease Control and Prevention County Summary of Obesity from the Behavioral Risk Surveillance System (BRFSS) Data

The BRFSS is an annual cross-sectional telephone survey, which has been conducted by the Centers for Disease Control and Prevention (CDC) and state health departments since late 1990s. Survey participants include non-institutionalized adults 18 years or older, selected using a multi-stage probability sample design. The survey contains information about health risk behaviors, clinical preventive practices, and health care access and use, related primarily to chronic diseases and injury. The survey requests anthropomorphic measurements from respondents including height and weight, which are used to calculate Body Mass Index (BMI).

Because BRFSS samples are small in all but the largest U.S. counties, they are generally considered unsuitable for county-level analysis[153] In North Carolina, BRFSS data are reported for only 22 individual counties; the remaining 78 are aggregated into 13 multi-county regions.[11] However, CDC scientists have recently employed Bayesian multilevel modeling techniques to produce estimates of obesity and diabetes for all 3,141 counties in the United States, which were downloaded from the CDC’s website for 2004-2008[12]. [154]

[8] www.batchgeo.com
[9] District Memorial Hospital in Andrews, NC, closed in 2003; Crawley Memorial Hospital in Boiling Springs, NC, closed in 2008; and Good Hope Hospital in Erwin, NC closed in 2006.
[10] www.hospital-data.com
[11] http://www.schs.state.nc.us/SCHS/brfss/2008/index.html
[12] http://apps.nccd.cdc.gov/DDT_STRS2/NationalDiabetesPrevalenceEstimates.aspx?mode=OBS

“The Bayesian multilevel model treats available BRFSS data as observed data collected from a larger set of complete U.S. Census data, and then builds a probability model for the unobserved data. The model borrows information across years and counties and estimates prevalence for all 3,141 counties, including those for which direct estimates ordinarily are not reliable. The model-based estimates are validated against direct estimates obtained from 298 large counties. To do this, 95% confidence intervals for the differences between the two estimates are calculated for each county; if the interval does not contain zero, the estimates are considered to be in disagreement.”[154]

3.5. Measures

3.5.1. Dependent Variable

The dependent variable of interest for this study is *age-adjusted knee arthroplasty utilization* rate per 100,000 persons by county and year. Discharges with knee arthroplasty were extracted using the ICD-9 procedure code 81.54, and summarized by county using the patient’s residence. County utilization rates were age adjusted using the indirect method and the statewide age distribution as the standard population. Statewide rates (Figure 10) were age adjusted using the U.S. age distribution and the indirect method. Age adjusting is an important method of data standardization when comparing healthcare utilization, because crude rates do not take into account the differences in population distributions among geographic areas. For procedures that are used disproportionately by older people, such as knee arthroplasty, crude rates may be more of a reflection of differences in the county’s proportion of elderly residents. Age adjusting produces rates of use that would be expected if the age distribution of every county were consistent statewide. As discussed later in this chapter, the procedure utilization rate is modeled in two forms: first as the county rate in 2008 and second as the change in a county's utilization rate between 2004 and 2008.

3.5.2. Independent Variables

As suggested by the conceptual framework of this study, the variables of interest for predicting use of knee arthroplasty are related to the healthcare resources and population characteristics of a county. Variables are described below, with additional detail provided in Figure 7. Like the dependent variable, two multivariate regression models are fitted with these independent variables, one using the value of the variable in 2008, and a second using the difference in the 2004 and 2008 variables.

Population characteristics are known to affect healthcare utilization, including the age, gender, and racial distribution of an area's residents. Consistent with prior literature, age is expected to have a positive association with knee arthroplasty utilization, and a series of age group variables was tested in the multivariate regressions: ages 0-44 years, age 45-54 years, ages 55-64 years, ages 65-74 years, ages 75-84 years, and 85 or more years old. However, the sacrifice in degrees of freedom for the purpose of the regression analyses was deemed too great given the weak significance of these parameters, and an alternative age variable, *proportion of the population ages 55 to 84,* is included in the models. Because knee arthroplasty is most common among people between 55 and 84, inclusion of one age covariate was considered sufficient and expected to yield a positive association with knee arthroplasty utilization. Age was obtained from the North Carolina Office of Budget and Management.

Figure 7. Data Sources and Description of Measures

Variable Name - Model	Description	Source File	Years
Dependent Variable			
E_TKA100K	Age-adjusted knee arthroplasty procedures per 100,000 persons	1 and 8	00-09
Independent Variables			
Provider Supply			
Ortho Surgeons doing TKA per 100,000	Number of orthopedic surgeons who perform TKA, per 100,000 persons	1, 2 and 8	00-09
Primary Care MDs per 100,000	Number of primary care physicians, per 100,000 persons	2 and 8	00-09
High volume TKA hospitals	Number of hospitals performing more than 200 TKA procedures/year	1 and 8	00-09
TKA Hospitals	Number of hospitals with any TKA volume	1 and 7	00-09
Skilled Nursing Facilities	Number of skilled nursing facilities	3	00-09
County Variables			
Rural	Dummy variable indicating whether county is rural (population under 50,000)	3	2008
Population Characteristics			
Ages 55-84	% of population between ages of 55-84	8	00-09
Female	% of population who are female	4	00, 03-09
Poverty	% of population living at or below the federal poverty level	3	00-08
Nonwhite	% of population who are non-white	4	00, 03-09
Median Income 65-69 y.o.	Median household income for population ages 65 to 69 ($1000)	4	03-09
Median Income 70-74 y.o.	Median household income for population ages 70 to 74 ($1000)	4	03-09
Median Income 75-79 y.o.	Median household income for population ages 75 to 79 ($1000)	4	03-09
Median Income 65-69 y.o.	Median household income for population ages 80 to 84 ($1000)	4	03-09
Per Capita Income	Per Capita Income ($1000)	4	00, 03-09
Unemployment	% of population unemployed	3	00-09
Group Quarters	% of population living in group quarters	4	03-09
High School Education	% of population with less than high school education	4	03-09
College Degree	% of population with college degree	4	03-09
Uninsured	% of population without health insurance	6	00-09
Obese	Estimated % adults with diabetes or obesity, age-adjusted	5	04-08
Health Resource Utilization			
Admissions for marker conditions	Age-adjusted admissions for 4 marker conditions per 100,000 persons	1 and 8	00-09
Knee arthroscopy per 100,000	Age-adjusted knee arthroscopy procedures per 100,000 persons, 3-year lag	1 and 8	00-09

Data Sources: 1 - North Carolina Discharge Databases; 2 - NC Licensure Data; 3 - Area Resource File; 4 - Nielsen Claritas; 5 - CDC Obesity and Diabetes Data; 6 - Current Population Survey estimates (NC IOM); 7 - NC Division of Healthcare Services Regulation; 8 - North Carolina Office of State Budget and Management.

Literature on knee arthroplasty utilization shows that knee arthroplasty is used disproportionately by people who are white, thus *proportion of population that is nonwhite* is incorporated into the multivariate model. Socioeconomic characteristics are known to affect knee arthroplasty utilization, and are included in the multivariate analyses. Educational attainment is measured as the *proportion of residents with at least a college degree*. Other educational attainment variables, including proportion of the population with at least a high school degree, were tested and found to be less powerful predictors than proportion with a college degree. Economic indicators are also important for the model because financial resources may affect the choice whether to undertake knee arthroplasty, due to out-of-pocket costs or post-operative recovery that limits work and other activities. *Per capita income* was included as a covariate in the model. Other economic indicators were tested, in accordance with stated hypotheses, but not retained in the reduced model. Those variables include median household income by age group, percent of population in poverty, and percent of the population unemployed. Race, education, and income variables were obtained from obtained from Claritas and the Area Resource File as specified in Figure 7.

As in most studies of healthcare use, inclusion of a measure of health insurance coverage is preferable because insurance provides improved access to medical care for covered patients. Three decades ago, the RAND Health Insurance Experiment established that for the procedures and treatments studied, healthcare utilization declines as cost-sharing increases.[155] County-level estimates of the *percent of population uninsured* were obtained from previous analyses of the Current Population Survey by North Carolina Institute of Medicine and Sheps Center staff.

Physician and orthopedic surgeon supply within a county is expected to have a positive relationship with utilization of knee arthroplasty. This hypothesis follows the theory of physician induced demand for medical care use, presented earlier in the conceptual framework for this study, which posits that healthcare providers increase the use of medical care. In the case of knee arthroplasty, the supply of primary care physicians is relevant in that these physicians provide referrals to orthopedic surgeons for severe knee osteoarthritis. The supply of orthopedic surgeons, particularly those who perform knee replacement surgery, is important for the obvious reason that they are the only type of physician trained and experienced in performing knee arthroplasty. Physician supply data are drawn from the NC physician licensure files and assigned to a county using their primary practice location in a given year. Only physicians who were active, in-state, nonfederal employees engaged in direct patient care were counted in the physician supply. Primary care physicians include providers whose self-reported primary specialty was either Family Practice (code=10), General Practice (code=12), Internal Medicine (code=19), Obstetrics-Gynecology (code=30), or Pediatrics (code=38). Orthopedic surgeons included physicians whose self-reported primary specialty was either Orthopedic Surgery (code=63), Spinal Reconstructive Surgery (code=113), Orthopedic Sports Medicine (code=136), Orthopedic Surgery of the Spine (code=137), Orthopedic Surgery – Adult Reconstructive (code=138), Orthopedic Surgery – Musculoskeletal Oncology (code=139), Orthopedic Surgery – Pediatrics (code=140), or Orthopedic Surgery – Trauma (code=141). Orthopedic surgeons who performed knee arthroplasty were identified for each year of the analysis based on the attending provider identification codes found on inpatient discharges with a procedure code of 81.54 for knee arthroplasty. The *number of primary care physicians* and the *number of orthopedic surgeons who performed knee arthroplasty* were included in multivariate analyses and both were expected to have a positive relationship with knee arthroplasty utilization.

The number of *short-term general hospitals performing knee arthroplasty* within a county is hypothesized to have an impact on the county's utilization of knee arthroplasty surgery by providing a convenient location of care to the county's population. Hospitals that perform a high volume of knee arthroplasty (more than 200 procedures per year) are expected to have an even greater positive influence on utilization of the procedure within the county, and is included as the *number of high volume knee arthroplasty hospitals in a county*. These variables indicating county location for hospitals performing any and a high volume of knee arthroplasty were created using NC Inpatient discharge data, merged with facility data from the Department of Healthcare Services Regulation. Skilled nursing facilities, which are traditionally inhabited by the frail elderly, are included in the model because they represent a density of potential patients and because skilled nursing facilities are sites for post-surgical care for knee arthroplasty patients in need of intense physical therapy and rehabilitation. The *number of skilled nursing facilities* in a county is included as a continuous variable and expected to have a positive relationship with knee arthroplasty utilization.

Knee arthroscopy is a procedure that involves the removal of frayed articular cartilage, unstable meniscal tears, or loose bodies and synovectomy [28-30]. The procedure is less invasive than knee arthroplasty and is typically used for patients with moderate knee osteoarthritis. However, the benefit of this other procedures depends on the severity and site of the osteoarthritis and [27] some evidence suggests that knee arthroscopy may offer little clinical benefit or potential harm to the joint [28-30]. As such, use of knee arthroscopy may degrade the knee joint such that the need for knee arthroplasty is accelerated; however, no previous studies have confirmed this relationship or determined what period of time might pass between arthroscopy and arthroplasty, if they are strongly linked. In order to estimate the effect of arthroscopy utilization on future arthroplasty utilization, this study includes an age-adjusted *3-year lagged rate of arthroscopy utilization* as a covariate in multivariate analyses of knee arthroplasty utilization. The 3 year lagged rate is calculated using North Carolina ambulatory surgery center discharge data from 1997-2006, extracting all cases with an ICD-9 procedure code of 80.20 or 80.26. Age-adjusting was conducted using the indirect method and the statewide age distribution as the standard population.

Because obesity causes mechanical stress on knee joints, it is believed to accelerate knee osteoarthritis by degrading the natural cartilage in the joint. Effects of the obesity epidemic are only beginning to emerge, and data on the incidence and prevalence of obesity and overweight are limited at best. CDC county-level estimates of the *proportion of the population who are obese,* the construction of which are discussed earlier in this chapter, were included in these analyses as a covariate and expected to have a positive relationship with knee arthroplasty utilization.

Several recent studies have identified "marker" medical conditions that are thought to occur randomly in the population without sensitivity to prevention efforts. Additionally, hospital care for these conditions is thought to be less sensitive to access barriers because of their medical severity and consequences [156, 157]. Marker conditions include appendicitis, acute myocardial infarction, gastrointestinal obstruction, and hip fracture (Figure 8). The utilization rates of these "marker" or "admission sensitive" conditions have been used as a point of reference in studies of utilization for conditions that do vary according to provider access or quality, such as ambulatory sensitive conditions (ASCs). [156, 157] *Age-adjusted county rates of these four maker conditions* are employed in this dissertation as a covariate in the regression analyses, as a control variable to represent baseline utilization of hospital care in a county. This variable is most important for border counties where some population hospital use is not captured because residents seek care across state lines.

Figure 8. Definitions of "Marker Conditions"

Conditions	ICD-9 Procedure Codes	ICD-9 Diagnosis Codes	Notes
1 Appendicitis with Appendectomy	540, 541, 542	47.0 or 47.1	Both procedure and diagnosis code required
2 Acute myocardial infarction		410	Only cases with LOS > 5 days or discharge status of death
3 Gastrointestinal obstruction		560	
4 Fracture of hip or femur		820	Age 45+ only

Source: Agency for Healthcare Research and Quality. Using administrative data to monitor access, identify disparities, and assess performance of the safetty net, Appendix B. http://archive.ahrq.gov/data/safetynet/billing2.htm#AppendixB. Accessed April 7, 2011.

A dummy variable identifying whether a county is considered rural was included in the model, as populations living in rural places are often considered to be disadvantaged with respect to economic or health care resources. *Rural* was defined using the U.S. Office of Management and Budget's Core Based Statistical Area (CBSA) definitions for metropolitan and micropolitan areas in 2008, drawn from the Area Resource File. For the purpose of this analysis, rural counties include those classified as "micro" or "neither", representing all counties with populations under 50,000.

3.6. Hypotheses

Previous research has identified individual characteristics which increase the risk of utilization of knee arthroplasty, including demographic and socioeconomic factors. These studies show that individual utilization of knee arthroplasty is positively associated with age, being female, and being white, while a negative relationship has been estimated for education. Studies have also established a positive relationship between body weight and the incidence of knee osteoarthritis, which suggests obesity may be an important risk factor for knee arthroplasty. At a population level, it follows that these individual risk factors may be associated with variation in population rates of knee arthroplasty utilization.

Previous ecological analyses have been conducted which relate population characteristics to knee arthroplasty utilization at a population level. Studies have shown a positive relationship between income and knee arthroplasty utilization, presumably because of the out-of-pocket expenses and lost wages associated with such care.[138] Research on the relationship between local healthcare resource supply and knee arthroplasty offers contradictory findings.[138] One of the few studies of knee arthroplasty utilization at a population level by Zhou [138] found that orthopedic surgeon supply had a negative effect on knee arthroplasty utilization; while other studies [82-86] suggest that overall provider supply is associated with higher utilization of medical care, especially for elective procedures. For this study, physician supply of primary care and orthopedic surgeons are incorporated into the multivariate regression models as provider supply per capita.

Knee arthroscopy, a less invasive procedure than knee arthroplasty, has become a controversial procedure since a 2002 study was released that suggests poor efficacy.[28, 29] Furthermore, it is considered by some clinicians to accelerate the need for knee arthroplasty. As such, knee arthroscopy utilization, as a 3-year lagged variable, is included as a covariate in this dissertation's model of knee arthroplasty utilization.

Seven specific research hypotheses are tested in this dissertation, developed from the conceptual framework, supported by prior research and which flow from the main research questions for this study:

1. Counties with a high proportion of population who are elderly, female, and white have high utilization of knee arthroplasty.
2. Counties with high income, low poverty, and high median income for the population over 50 years old have high utilization of knee arthroplasty.
3. Counties with low unemployment rates, low rates of the uninsured, and a low proportion of residents with at least a high school degree have high utilization of knee arthroplasty.
4. Counties with high proportions of residents who are obese or overweight have high utilization of knee arthroplasty.
5. Counties with a high density of orthopedic surgeons who perform knee arthroplasty have high utilization of knee arthroplasty.
6. Counties with hospitals performing a high volume of knee arthroplasty and a high density of hospital beds have high utilization of knee arthroplasty.
7. Counties with high (lagged) utilization of knee arthroscopy have high utilization of knee arthroplasty.

3.7. Analytical Methods By Research Aim

3.7.1. Aim 1: Change in Patient Characteristics

Have there been changes in the characteristics of patients receiving knee replacement surgery during the study period?

Using bivariate statistical analysis, data were analyzed to describe trends in the characteristics of patients who experienced knee arthroplasty between 2000 and 2009. Discharges were analyzed with respect to the patients' age, gender, primary insurance type, and home residence. Age was analyzed as a continuous variable and by age groups (under 45 years old, 45-54 years old, 55-64 years old, 65-74 years old, 75-84 years old, and 85 or more years). Age was of particular interest as recent literature suggests that knee procedure is becoming more commonly used in younger adults than was typical until the end of the 20th century. Characteristics of the hospital encounter were also examined to determine if the diagnoses or inpatient experience for knee arthroplasty changed throughout the study period. Admission type and length of stay were analyzed to determine if the proportion of elective cases of knee arthroplasty had changed over time and to assess trends in the duration of inpatient stay of patients. Total and surgery charges were analyzed for discharges with knee arthroplasty; all charges were adjusted for inflation using the Bureau of Labor Statistics (BLS) Consumer Price Index (CPI) for medical care for all urban consumers (U.S. city average). Data were obtained on April 1, 2011 from the BLS website[13].

In order to compare the health status of patients over time, diagnoses were analyzed and coded using the Charlson comorbidity index, a scale commonly used in analysis of administrative claims data.[158-160] Though this measure is imperfect for assessing health status due to the inclusion of only 17 conditions, it has been validated for use in studies of outcomes and resource use with administrative claims data. Figure 9 identifies the diagnostic categories and ICD-9 codes with weights used in the measure for this dissertation, which were adapted to include some diagnosis codes that have emerged since the index was originally created.[158, 160-165]

[13] www.bls.gov/data/#prices. Series ID CUUR0000SAM, CUUS0000SAM.

Figure 9. Charlson Comorbidity Index Diagnosis Codes and Weights

Diagnostic Category	ICD-9 Diagnosis codes	Weight
Myocardial infarction	410, 412	1
Congestive heart failure	398.91, 402.01, 402.11, 402.91, 404.01,404.03, 404.11, 404.13, 404.91, 404.93, 425.4, 425.5, 425.7 - 425.9, 428	1
Peripheral vascular disease	093.0, 437.3, 440 - 441, 443.1 - 443.2, 443.8 - 443.9, 447.1, 557.1, 557.9, V43.4	1
Cerebrovascular disease	362.34, 430 - 438	1
Dementia	290, 294.1, 331.2	1
Chronic pulmonary disease	416.8 - 416.9, 490 - 496, 500 - 505, 506.4, 508.1, 508.8	1
Rheumatologic disease	446.5, 710.0 - 710.4, 714.0 - 714.2, 714.8, 725	1
Peptic ulcer disease	531-534	1
Mild liver disease	571, 573	1
Diabetes	250 - 250.3, 250.8, 250.9	1
Hemiplegia or paraplegia	334.1, 342 - 343, 344.0, 344.1 - 344.6, 344.9	2
Moderate or severe renal disease	403.01, 403.11, 403.91, 404.02 - 404.03, 404.12 - 404.13, 404.92 - 404.93, 582, 583.0, 583.1, 583.2, 583.4, 583.6, 583.7, 585 -586, 588.0, V420, V451, V56	2
Diabetes with complications	250.4 - 250.7	2
Malignancy, including leukemia and lymphoma	140 -165, 170 - 172, 174 - 176, 179 - 195, 200 - 208, 238.6	2
Moderate or severe liver disease	456.0 - 456.2, 572.2 - 572.4, 572.8	3
Metastatic solid tumor	196 - 199	6
AIDS	042 - 044	6

3.7.2. Aim 2 (part 1): Change in orthopedic surgeons performing TKA

Have there been changes in the supply, distribution, or volume of orthopedic surgeons performing knee arthroplasty in North Carolina during the study period?

Individual discharges were merged with physician data using the attending provider identification number in the discharge (UPIN or NPI) and North Carolina license number. In order to merge these datasets, it was first necessary to construct a provider ID crosswalk file, described previously. The process of merging discharge files to the physician licensure data unveiled a minor problem with physician identification numbers on some of the discharges. Between 2000 and 2009, there were 1,448 unique provider IDs found on the 132,499 discharges with a knee arthroplasty; however, only 620 of those identification numbers were matched to an orthopedic surgeon in the physician licensure files (Figure 10)[14]. Since knee arthroplasty is only performed by orthopedic surgeons[15], discharge data associated with providers of any other specialty were excluded from the analysis of provider trends. This resulted in the exclusion of 828 (57%) of physicians throughout the study period, but only 8,866 (4.3%) of discharges with a knee arthroplasty. Non-orthopedic surgeons may have been identified as the attending physician on these discharge records due to involvement in the admission process or medical management of the patient during the inpatient stay, but because they were not the provider performing knee arthroplasty they were deemed irrelevant to the analysis of providers.

Figure 10. Number of Knee Arthroplasty Discharges and Providers Analyzed

Year	# Knee Arthroplasty Discharges	# Unique NPIs and UPINs	# NPIs and UPINs for Orthopedic Surgeons	# Discharges Linked to Orthopedic Surgeons	% Discharges Excluded from Provider Analysis
2000	7,742	559	374	7,106	8.2%
2001	8,888	538	375	8,467	4.7%
2002	9,947	447	369	9,519	4.3%
2003	10,877	459	370	10,223	6.0%
2004	12,436	465	384	11,923	4.1%
2005	14,391	489	375	13,671	5.0%
2006	15,169	475	377	14,536	4.2%
2007	16,721	454	377	15,821	5.4%
2008	17,917	477	384	17,391	2.9%
2009	18,411	475	383	18,083	1.8%
Total (Unique)	**132,499**	**1,448**	**620**	**126,740**	**4.3%**

Sources: NC Inpatient Discharge Databases 2000 - 2009. NC Physician Licensure File 2000 - 2009. NC Office of State Budget and Management 2000 - 2009.

[14] The data use agreement for NC Discharge Data provides access to only one of the three attending provider ID variables contained in the raw discharge files.
[15] Dr.Scott Kelley, an orthopedic surgeon, advised me that only orthopedic surgeons would perform knee arthroplasty and therefore providers with other specialties were excluded.

Orthopedic surgeons performing knee arthroplasty during the study period were examined with respect to their individual and professional characteristics, as well as their volume of knee arthroplasty between 2000 and 2009. Physicians were grouped according to their annual volume of knee arthroplasty into four categories based on the distribution in the data: low (1-12), intermediate (13-49), high (50-99) and very high (more than 100). These categories were defined based on the findings in prior research identifying a relationship between provider volume and outcomes.[48, 166] Physician data were summarized by primary practice location (ZIP code and county) to determine the number of orthopedic surgeons performing knee arthroplasty in every North Carolina county during every year between 2000 and 2009. These county-level estimates of orthopedic surgeon supply are incorporated into the regression model of knee arthroplasty utilization as a control variable.

3.7.3. Aim 2 (part 2): Change in hospitals performing TKA

Have there been changes in the characteristics or volume of hospitals performing knee arthroplasty during the study period?

Individual discharges were merged with hospital data using the facility ID in the discharge record. Between 2000 and 2009, there were 95 hospitals that performed knee arthroplasty in at least one year according to the discharge data. Among those hospitals were two that opened during the study period including The Outer Banks Hospital in Nags Head (2002) and Presbyterian-Huntersville in Huntersville (2005), as well as one hospital (Good Hope Hospital in Erwin) that closed and merged with a neighboring hospital in 2006. Other hospitals opened or closed during the period but did not record any knee arthroplasty procedures in any year between 2000-2009.[16] Information about the hospital's location,

[16] Two other hospitals (with no knee arthroplasty volume in any year 2000-2009) closed including District Memorial Hospital in Andrews, NC (2003) and Crawley Memorial Hospital in Boiling Springs, NC (2008).

size, and number of operating rooms was obtained from the Division of Healthcare Services Regulation in February 2011, and those characteristics were ascribed to the facility for all years of the analysis. Information for the facility that closed during the study period was obtained through an online directory of hospital and nursing homes.

Annual volume of knee arthroplasty was summarized by institution and coded using three categories. Prior research on the relationship between hospital volume and outcomes provided a basis for the volume categories which included low (1-24), intermediate (25-199), and high (200 or more). [40, 46-48, 166] The number of hospitals with any volume of knee arthroplasty was summarized by county and incorporated into the regression model of knee arthroplasty utilization.

3.7.4. Aim 3: Factors associated with county utilization of TKA

What factors are associated with high utilization of knee arthroplasty in North Carolina counties?

Multivariate regression methods were used to examine the relationship between county utilization of knee arthroplasty and the area's characteristics, as specified in hypotheses presented earlier in this chapter. Multivariate analysis was conducted using 2008 cross sectional and 2004-2008 data because the most comprehensive set of covariates, including several specified in the conceptual model and seven hypotheses, was available during those years (Figure 8) but not in 2000-2003 or 2009.

Highsmith Rainey Memorial Hospital in Fayetteville, NC opened in 2004, but had no knee arthroplasty volume in any year 2000-2009.

In the case of knee arthroplasty utilization, an elective surgical procedure, there is some expectation of a spatial pattern in the utilization which may result from a variety of factors, which would suggest use of spatial instead of linear regression methods. First, it is possible that regional differences in utilization may be affected by factors physically constraining or easing access to the surgical service, such as terrain or transportation. As well, utilization may be affected by patient or provider feedback that promotes diffusion or adoption of the procedure, and feedback is generally considered to be influenced by spatial proximity.[167, 168] Further, the marketing of providers who specialize in the procedure may exhibit a geographic pattern that influences patient preferences or referrals from primary care in treatment of knee osteoarthritis. Exploratory cartographic analysis, presented in Figures 31-40, suggests localized clustering of knee arthroplasty utilization rates and encourages formal assessment of spatial autocorrelation in the multivariate analysis. Adjacent counties demonstrate high-high utilization in some years, and visual inspection identifies county clusters where spatial autocorrelation may exist.

Spatial autocorrelation is “the coincidence of value similarity with locational similarity”, and the existence of spatial autocorrelation confirms Tobler’s first law of geography that “everything is related to everything else, but near things are more related than distant things.” [169-171] Spatial analysis techniques detect the existence and assess the nature of spatial autocorrelation by employing a spatial weights matrix that identifies neighboring geographic areas. For all analyses in this dissertation, a first order “Queen’s contiguity” matrix was used, in which all adjacent counties, including those with only a single point touching, are weighted equally.

Spatial data analysis is a relatively new field for improving econometric modeling, but the method used here allows analysis of data from only a single point in time. As such, regression models and specification tests could be estimated for only one year at a time. This constraint called for a creative approach to incorporate both time and space into a regression model, for there is concern that the sharp increase in knee arthroplasty utilization in recent years may be related to commensurate changes in county characteristics. The resulting approach was to conduct two separate sets of multivariate analyses.

The first set of analyses estimates a county's age-adjusted rate of knee arthroplasty utilization as a function of county characteristics in the same year. The second set of analyses models the change in a county's age-adjusted rate of knee arthroplasty utilization between 2004-2008 as a function of change in covariates during the same time period. For the first set of analyses, 2008 data are modeled because they represent the most recent year and the end point of the change model. The utility in presenting both sets of models is that the 2004-2008 difference model captures the effects of longitudinal changes in county characteristics on knee arthroplasty utilization, while the 2008 model estimates the relative effects of various characteristics in a county's population or healthcare resources. Spatial autocorrelation was detected in the 2008 models, therefore indicating Ordinary Least Squared (OLS) and Fixed Effects (FE) models would be undesirable. Diagnostic tests on the 2004-2008 change model did not yield statistically significant evidence of spatial autocorrelation and therefore only OLS was estimated for the change model.

Spatial autocorrelation creates inefficiency in the linear regression estimates because errors are not independent and identically distributed.[169, 172] Statistical inference, particularly the identification of statistically significant parameters, is unreliable because the OLS estimated standard errors will be too small. [168, 173] Additionally, goodness of fit measures such as R^2 may be overstated in the presence of spatial autocorrelation. [168]

Spatial autocorrelation in the dependent variable is detected using Global Moran's I, a test similar to the Durbin-Watson test for temporal autocorrelation. Global Moran's I is available as a standard test in spatial data analysis software packages such as GeoDa, which was used for all spatial analyses in this dissertation.[174, 175] Global Moran's I is a calculation of correlation between nearest neighbors, with coefficient values ranging from -1 to 1. Global Moran's I values close to zero indicate no or low spatial autocorrelation. Assessment of spatial autocorrelation requires use of a spatial weights matrix, which relates values in one location to the values in neighboring locales. Anselin shows that Moran's I is calculated as $I = \left(\frac{e'We}{e'e}\right)$, where $e = y - X\beta$ is a vector of OLS residual, $\beta = (X'X)^{-1}X'y$, and W is the spatial weights matrix.[169]

When Moran's I indicates spatial clustering or spatial autocorrelation, the Lagrange Multiplier test is used to assess the nature of the covariance in the model residuals and inform the choice of a spatial lag or a spatial error model. The spatial lag model is preferred when high residual clustering of the dependent variable is detected, and the interpretation of this model is often likened to a spillover effect.[169] In the case of high residual clustering of neighboring values, which is assumed to be associated with unobserved structural factors, the spatial error model is considered most appropriate and generally considered to reflect the spatial autocorrelation in measurement errors. [169] In simple terms, when tests indicate there is a statistically significant relationship among neighbors in the dependent variable, the nature of that relationship can be identified (and appropriately modeled) as either resulting from similarity in processes represented by the independent variables (spatial lag) or omitted variables (spatial error).

In the regression analyses of 2008 knee arthroplasty utilization, the Global Moran's I value of 0.32 strongly confirmed the presence of spatial autocorrelation; that is, utilization rates were correlated in adjacent counties. In the model of knee arthroplasty utilization change between 2004-2008, Moran's I was small, 0.04, indicating weak evidence of spatial autocorrelation. The Lagrange Multiplier test was performed for both datasets and the results recommended a spatial lag model for the 2008 data but did not indicate the need for a spatial econometrics for the 2004-2008 change model.

The spatial lag model is defined as $TKA_c = X\beta + \rho Wy + \varepsilon$, where TKA_c is the age-adjusted knee arthroplasty utilization in county c during in 2008, $X\beta$ is a vector of independent variables including provider supply characteristics, population characteristics, and health resource utilization in county c in 2008, ρWy is the parameter representing the spatial lag term (average value of the neighbors or spatial autocorrelation term), and ε is the error term. The 2004-2008 change model is a linear OLS model defined as $TKA_c = \beta_0 + X\beta + e$, where TKA_c is the change in age-adjusted knee arthroplasty utilization in county c between 2004 and 2008 and $X\beta$ is a vector of independent variables representing the change in provider supply characteristics, population characteristics, and health resource utilization in county c between 2004 and 2008.

4. Results

4.1. Overview of Results

Findings from the analyses are presented in this chapter, describing the patients, providers, and hospitals who received or performed knee arthroplasty surgery between 2000 and 2009, as well as the patterns of utilization among North Carolina during the period. The demographic profile of patients changed slightly, with more people under 65 utilizing knee arthroplasty over time. Average length of stay decreased for knee arthroplasty discharges, while charges increased. Surprisingly little growth was observed in the number of orthopedic surgeons or hospitals providing knee arthroplasty surgery, which means that both institutions and providers had higher volume by the end of the study period.

4.2. Longitudinal Trends in Knee Replacement Utilization

Between 2000 and 2009, the incidence rate of knee replacement surgery doubled in North Carolina, increasing from 96 to 196 procedures per 100,000 persons per year. Rates for the U.S. were comparable or slightly higher to those observed in North Carolina; in 2008 knee arthroplasty was performed at a rate of 203 per 100,000 nationally but 194 per 100,000 (crude rate) in North Carolina.[17] Adjusting for differences in the NC age structure of relative to the entire U.S. produced slightly lower knee arthroplasty utilization rates (Figure 11).

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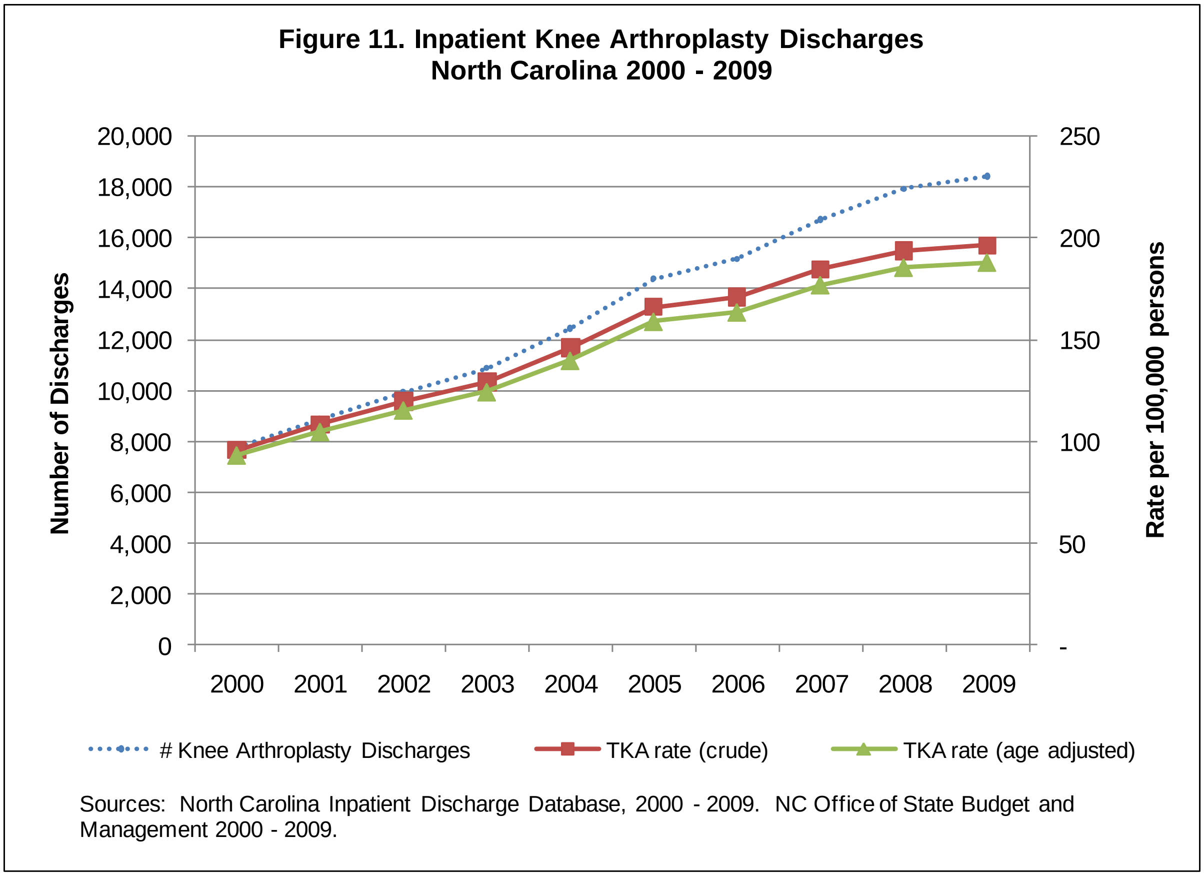
[17] National procedure volume obtained from http://hcupnet.ahrq.gov/HCUPnet.jsp and population estimates from http://www.census.gov/popest/states/NST-ann-est.html on 1/4/2011.



4.3. Characteristics of Knee Arthroplasty Discharges

The characteristics of patients who had knee arthroplasty in North Carolina changed little throughout the study period. In 2009, nearly two thirds of all knee replacement patients were female and the average age was 66 years old (Figure 12). There was a slight shift noted in the age structure and primary source of insurance for patients receiving knee replacement surgery in North Carolina between 2000 and 2009 (Figures 13 - 14). Although the mean age decreased by only one year from 2000 to 2009, the number and proportion of patients less than 65 years old increased from 38% to 45% for all knee replacement discharges (Figure 13). Similarly, there was a decline in the dominance of public insurance among knee arthroplasty recipients. Fully two-thirds of all inpatient knee arthroplasty was paid for by Medicare, Medicaid and other government insurance in 2000, and by 2009 the proportion was only 57% (Figure 14). Just over one third of all patients resided in rural counties in both years (Figure 12).

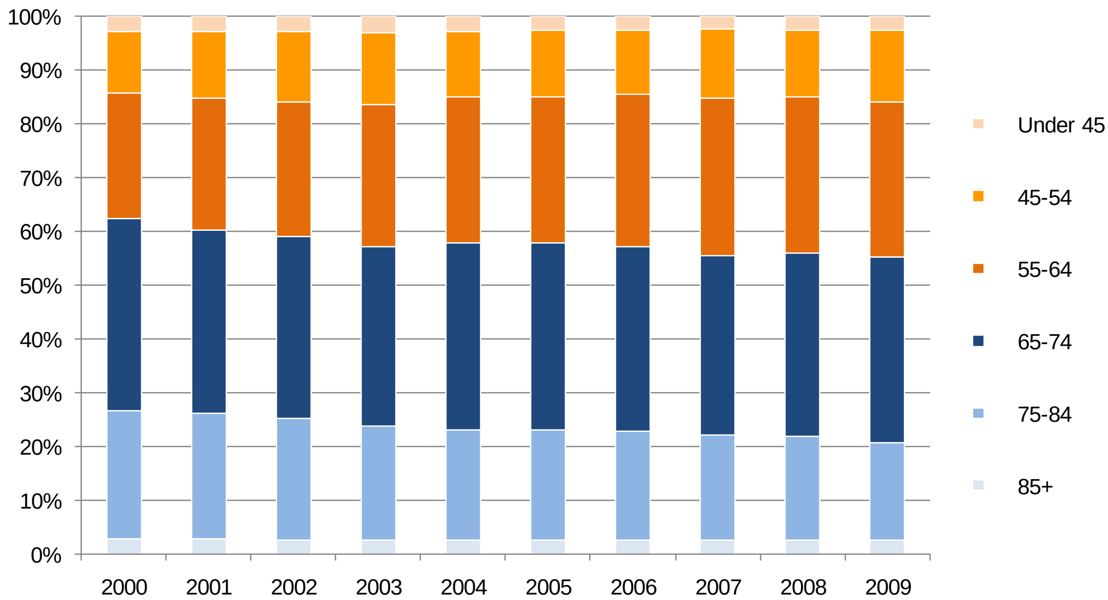
The travel patterns of patients receiving a knee replacement also remained constant through the 2000s. In 2000, only three percent of patients who had knee replacement at a North Carolina hospital were from out of state, compared with five percent in 2009. In 2000 and 2009 the proportion of patients who received care at a hospital in their county of residence was 59% and 57%, respectively. In both 2000 and 2009, just over a quarter of patients traveled at least 15 miles from their home to the hospital where knee arthroplasty was performed, and the mean distance was 19 miles in both periods.

Figure 12. Descriptive Statistics for Inpatient TKA Discharges, NC

	2000	2009
Patient Characteristics		
Female (%)	68%	65%
Mean age (years)	67	66
Payer		
Public	67%	62%
Private	28%	36%
Other	5%	3%
Unknown	0%	0%
Rural (%)	37%	35%
Patient Travel for TKA		
NC residents (%)	97%	95%
Hospital in same county as residence (%)	59%	57%
Travel 15 or more miles to hospital (%)	27%	28%
Mean distance to hospital (miles)	18.5	19.2
Characteristics of Hospitalization		
Elective admission (%)	73.0%	85.3%
Mean length of stay (days)	4.5	3.5
Charges (in 2009 Dollars)		
Surgery	$ 5,790	$ 9,733
Total	$ 28,347	$ 37,885

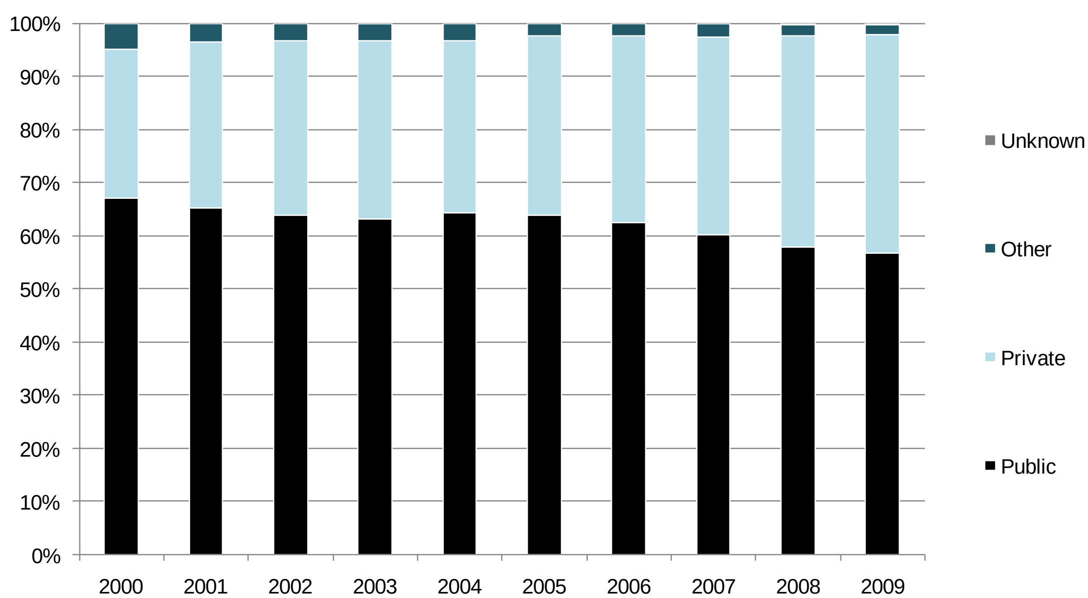
Sources: NC Inpatient Discharge Databases 2000 - 2009. NC Office of State Budget and Management 2000 - 2009. NC Division of Healthcare Services Regulation 2011; Area Resource File 2000-2009.

Figure 13. Age Distribution of Inpatient Knee Arthroplasty
North Carolina, 2000 - 2009



Sources: North Carolina Inpatient Discharge Database, 2000 - 2009; NC Office of State Budget and Management, 2000 - 2009.

Figure 14. Primary Payer for Inpatient Knee Arthroplasty
North Carolina, 2000 - 2009



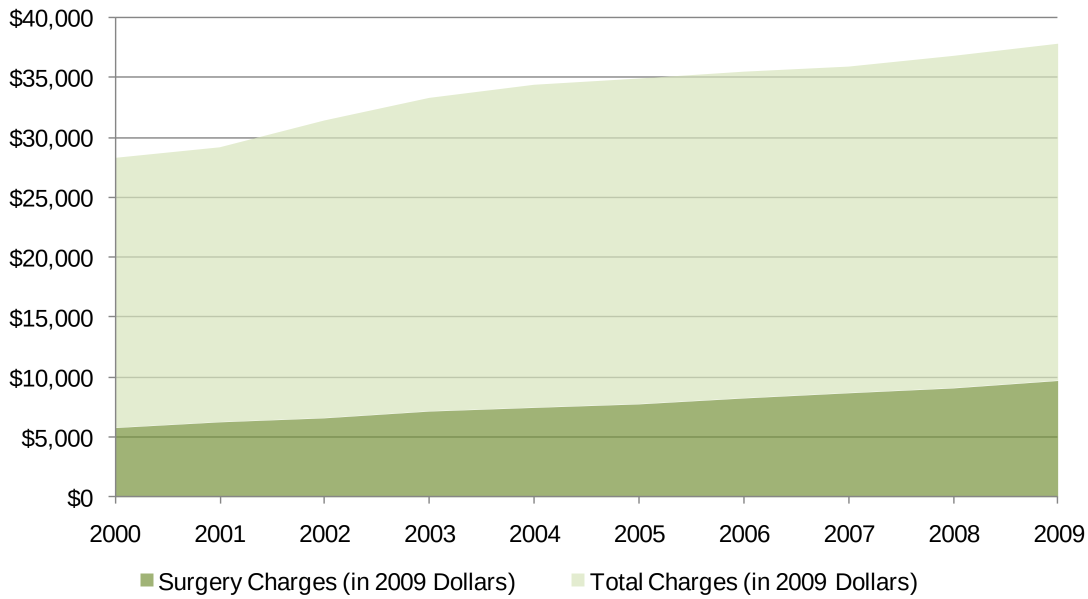
Source: North Carolina Inpatient Discharge Database, 2000 - 2009.

Between 2000 and 2009, there was a notable shift in the source admissions for inpatient knee replacement surgery. Whereas 73 percent of discharges with a knee arthroplasty were considered elective in 2000, 85 percent of cases were elective in 2009 (Figure 12). During the same time frame, the average length of stay for knee arthroplasty discharges declined from 4.5 to 3.5 days, which may be the result of a less acute patient population, supported by the increase in elective admissions.

Despite the large decrease observed in duration of care for inpatient knee arthroplasty during the study period, the average charges for discharges with the procedure increased from 2000 to 2009 (Figure 13). Charges reflect all inpatient expenses billed to a patient, before applying discounts, and include facility fees, diagnostic testing, inpatient therapy services, pharmaceuticals and medical supplies; physicians' professional fees and post-operative care such as therapies are not included in charges. After adjusting all charges for inflation to 2009 dollars, the average total charges for inpatient discharges with a knee replacement procedure grew by almost $10,000 (34%) between 2000 and 2009, with surgery charges increasing 68%.

Consistent with previous studies, the most common diagnosis associated with knee arthroplasty in North Carolina was osteoarthritis in all years between 2000 and 2009. Approximately 98% of all discharges with knee arthroplasty in 2009 had an ICD-9 code for osteoarthritis and this finding varied by only a few percentage points in all years of the study (Figure 14). Other conditions such as joint disorders, surgical complications, deformities, and rheumatoid arthritis were found with very limited frequency in all years of the analysis, which is consistent with published literature on indications for knee arthroplasty.

Figure 15. Charges for Discharges with Knee Arthroplasty, North Carolina 2000 - 2009



Source: North Carolina Inpatient Discharge Database, 2000 - 2009.
Notes: Charge data adjusted for inflation using the BLS medical CPI for U.S. cities. Adjusted to 2009 dollars.

Figure 16. Diagnoses for NC Inpatient Discharges with Knee Arthroplasty, 2000 and 2009.

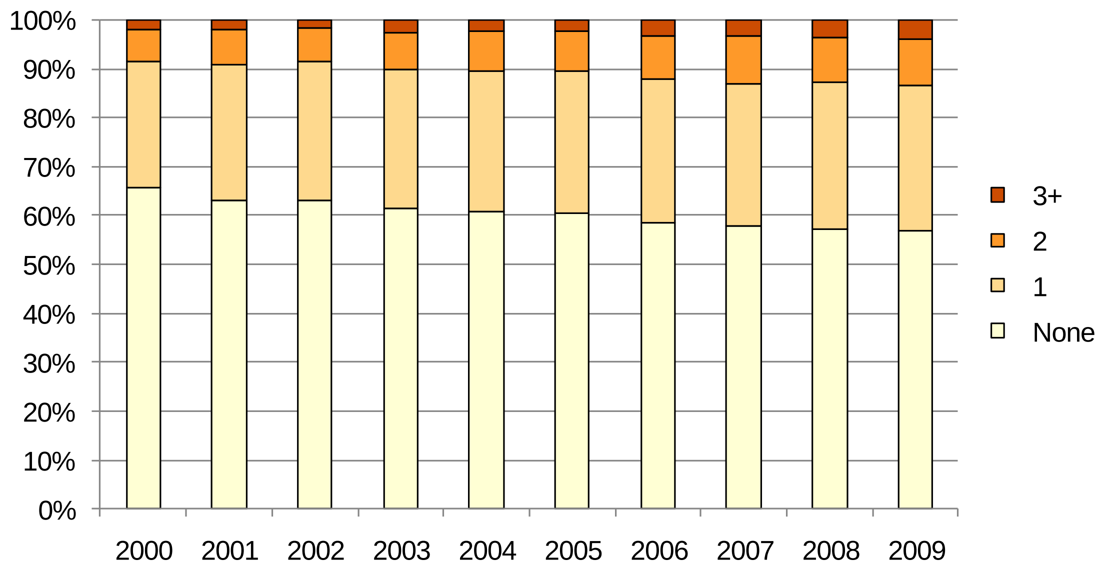
Diagnosis	2000	2009
Osteoarthritis	95.9%	98.0%
Non-traumatic joint disorders	2.9%	6.6%
Complications of surgical procedures or medical care	7.2%	4.8%
Other acquired deformities	4.9%	4.5%
Rheumatoid arthritis related diseases	4.2%	3.6%
Other bone disease and musculoskeletal deformities	1.7%	2.5%
Joint disorders and dislocations, trauma-related	1.6%	1.8%
Complication of device, implant, or graft	0.8%	0.6%
Cancer of the bone and connective tissue	0.2%	0.1%

Source: NC Inpatient Discharge Database, 2000 - 2009.

Overall, patients receiving knee arthroplasty in all years had few comorbid conditions, defined by the Charlson Comorbidity Index (listed in Figure 9). However, the presence of comorbidities in knee arthroplasty patients increased over time such that approximately 43% of patients had one or more comorbidities in 2009, compared with 34% in 2000 (Figure 17).

Changes in the presence of four specific Charlson comorbidities, Chronic Pulmonary Disease (COPD), renal disease, and diabetes with and without complications explained nearly all of the increase in frequency of comorbidities on knee arthroplasty discharges. COPD increased in frequency from 10% to 14% of discharges between 2000 and 2009, and renal disease increased from .1% to 3.3%. The largest change was in presence of diabetes, which increased in frequency on knee arthroplasty discharges from 15% in 2000 to 22% by 2009.

Figure 17. Frequency of Charlson Comorbidities on Inpatient Knee Arthroplasty Discharges, North Carolina 2000 - 2009



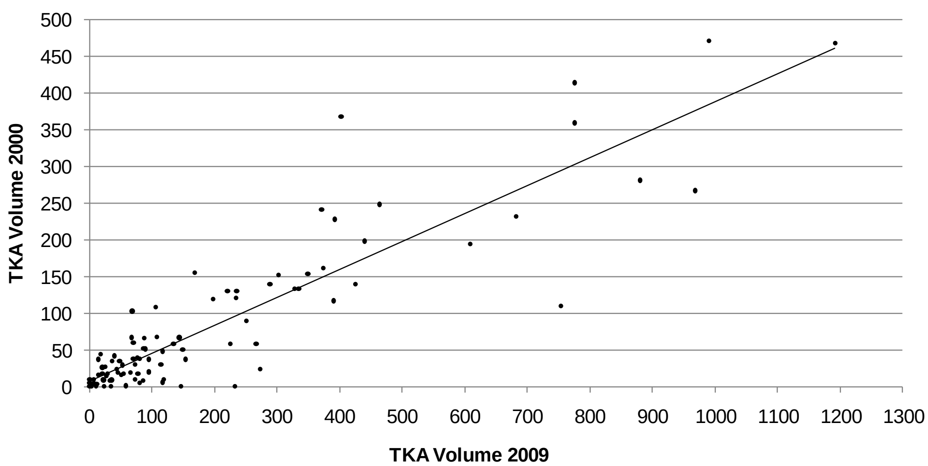
Sources: NC Inpatient Discharge Databases 2000 - 2009.

4.4. Hospitals Performing Knee Arthroplasty

Ninety three of North Carolina's 116 inpatient acute care hospitals performed knee arthroplasty in at least one year between 2000 and 2009. The number of knee arthroplasty procedures at a single institution ranged from 1 to 471 in 2000, and from 3 to 1,192 in 2009.

Many hospitals experienced strong growth in the provision of knee arthroplasty, marked by increases in every year between 2000 and 2009; however other institutions, particularly those with low or intermediate volume of knee arthroplasty in 2000, had periods of growth and decline during the period. Figure 20 is a scatterplot of individual hospitals by their knee arthroplasty volume in 2000 and 2009. With a few exceptions, the graphic shows an across-the-board increase in volume, with high and low TKA volume institutions remaining so through the study period. The scatterplot also shows a handful of facilities, located at zero on the y- or x-axes, which began or stopped providing knee arthroplasty during the study period, respectively. Additionally, the cluster of dots near the origin demonstrate that in both years, several facilities performed five or fewer knee arthroplasty procedures.

Figure 18. Scatterplot of Hospital Knee Arthroplasty Volume 2000 and 2009



Note: Each dot represents a single hospital's TKA volume in 2000 and 2009. Only includes institutions that performed TKA in at least one of the two years.

Sources: NC Inpatient Discharge Databases 2000 - 2009; NC Division of Healthcare Services Regulation, 2011.

Between 2000 and 2009, the number of hospitals performing fewer than 25 knee arthroplasty procedures was reduced by half to only 15 facilities, and the number of institutions performing more than 200 procedures nearly tripled (Figure 20). Consequently, the total number of procedures performed in low-volume hospitals declined by nearly 40% between 2000 and 2009, while the volume in high-volume facilities simultaneously tripled

(Figure 20). In 2009, 78% of all knee arthroplasty procedures were performed in facilities that had total TKA volume of 200 or more, compared with 46% in 2000 (Figure 21).

Figure 19. Number of NC Hospitals Performing Knee Arthroplasty

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Knee Arthroplasty Volume										
Low (1-24)	30	30	20	18	17	15	16	8	13	15
Intermediate (25-199)	46	42	49	48	50	48	48	53	46	45
High (200+)	11	14	18	21	23	26	25	27	30	30
Total Number	**87**	**86**	**87**	**87**	**90**	**89**	**89**	**88**	**89**	**90**
Bedsize										
1-24 beds	0	0	1	1	1	1	1	1	1	1
25-99 beds	24	23	22	25	25	25	25	24	24	26
100-399 beds	49	49	50	47	50	50	50	50	50	50
400+ beds	14	14	14	14	14	13	13	13	14	13
Location										
Rural	43	42	41	44	44	43	44	43	43	45
Urban	44	44	46	43	46	46	45	45	46	45
Hospital Type										
General Acute Care	85	84	85	85	88	87	87	86	87	88
Specialty Hospital	2	2	2	2	2	2	2	2	2	2

Sources: NC Inpatient Discharge Databases 2000 - 2009; NC Division of Healthcare Services Regulation 2011.

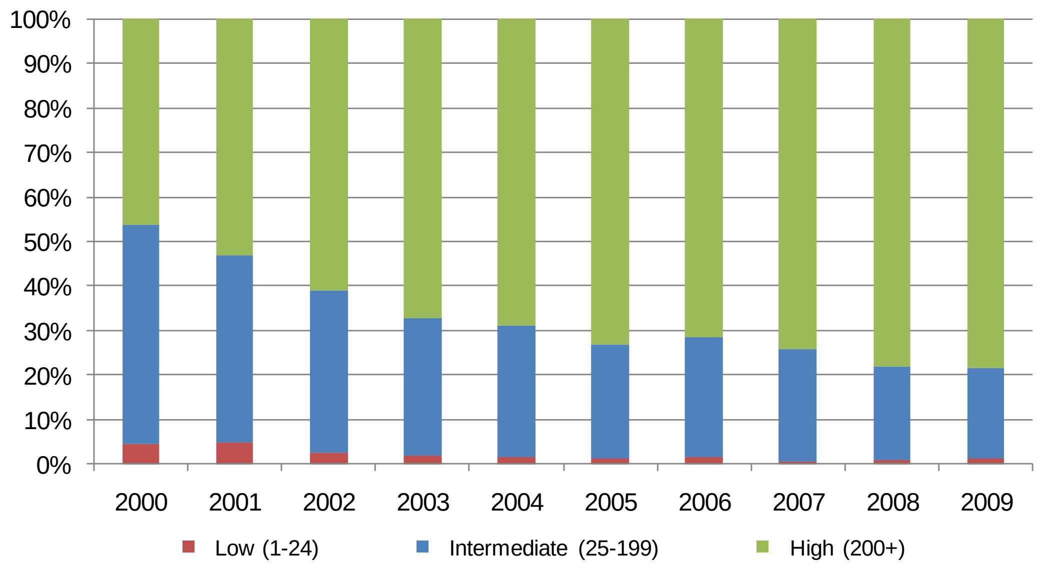
Figure 20. Volume of Knee Arthroplasty Procedures in NC Hospitals

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total Volume	7,742	8,888	9,947	10,877	12,436	14,391	15,169	16,721	17,917	18,411
Knee Arthroplasty Volume										
Low (1-24)	352	431	264	208	171	184	223	85	177	217
Intermediate (25-199)	3,813	3,742	3,632	3,342	3,701	3,682	4,080	4,217	3,765	3,777
High (200+)	3,577	4,715	6,051	7,327	8,564	10,525	10,866	12,419	13,975	14,417
Bedsize										
1-24 beds	-	-	3	4	9	14	14	8	16	23
25-99 beds	537	612	685	775	995	1,116	1,175	1,443	1,533	1,590
100-399 beds	3,948	4,541	5,039	5,460	6,352	7,462	7,743	8,401	8,899	9,239
400+ beds	3,257	3,735	4,220	4,638	5,080	5,799	6,237	6,869	7,469	7,559
Location										
Rural	2,174	2,491	2,628	2,738	3,200	3,806	3,930	4,388	4,462	4,576
Urban	5,568	6,397	7,319	8,139	9,236	10,585	11,239	12,333	13,455	13,835
Hospital Type										
General Acute Care	6,960	8,027	8,969	9,847	11,357	13,031	13,863	15,268	16,575	17,233
Specialty Hospital	782	861	978	1,030	1,079	1,360	1,306	1,453	1,342	1,178

Sources: NC Inpatient Discharge Databases 2000 - 2009; NC Division of Healthcare Services Regulation 2011.

Throughout the study period, only one hospital with fewer than 25 beds performed knee arthroplasty, and the number of procedures in that one facility ranged from three in 2002 to 23 in 2009. In all years, the majority of the hospitals performing knee arthroplasty and approximately 50% of procedures were performed in hospitals with 100-399 beds (Figures 19 and 20). Throughout the study period, the number of knee arthroplasty procedures increased in hospitals located in both rural and urban locations, but the observed increase was greater in urban places (Figure 20). In all years, the overwhelming majority of knee arthroplasty procedures were performed in urban hospitals; three-quarters of all knee replacements were done in urban hospitals in 2009, representing three times the number performed in rural facilities. North Carolina’s two orthopedic specialty hospitals performed 782 knee arthroplasty procedures in 2000 and 1,178 in 2009, representing 10% and 6% of the total volume for the state respectively (Figure 20). Growth in the volume of knee replacements in the state’s general acute care hospitals was stronger than in the specialty hospitals, increasing by nearly 150% from 6,960 to 17,233 procedures between 2000 and 2009.

Figure 21. Knee Arthroplasty Utilization by Institution Volume, NC



Sources: NC Inpatient Discharge Databases, 2000 - 2009. NC Division of Healthcare Services Regulation, 2011.

4.5. Orthopedic Surgeons Performing Knee Arthroplasty

Between 2000 and 2009, inpatient knee arthroplasty was performed by a total of 620 orthopedic surgeons in North Carolina. Approximately one-third of orthopedic surgeons who performed knee arthroplasty during the study period did so in all ten years of the study, while others practiced the procedure for shorter periods of time ranging from 1 to 9 years (Figure 22). The number of orthopedic surgeons performing knee arthroplasty remained relatively constant over time, on average 378 physicians per year, and consequently the average provider volume of knee arthroplasty increased from 18 in 2000 to 46 in 2009 (Figure 23).

Figure 22. NC Orthopedic Surgeons Performing TKA 2000 - 2009, By Provider-Years

Number of Years	# Providers
In All 10 Years	204
In 9 Years	33
In 8 Years	35
In 7 Years	28
In 6 Years	39
In 5 Years	32
In 4 Years	46
In 3 Years	51
In 2 Years	72
In 1 Year	80
Total	**620**

Closer examination of surgeons' procedure volume showed that, between 2000 and 2009, most surgeons who performed knee arthroplasty experienced a considerable increase in volume. More than half (54%) of the physicians who performed knee arthroplasty in 2000 did 12 or less procedures, compared with only 27% in 2009 (Figure 24). At the same time, the number of orthopedic surgeons with high volume (50-100 per year) of knee arthroplasty more than quadrupled between 2000 and 2009 from 15 to 67 surgeons, and those with very high volume (100 or more per year) increased nearly sevenfold from 7 to 49 (Figure 24).

Figure 23. Volume of NC Inpatient Discharges with Knee Arthroplasty and Number of Providers, 2000 - 2009

Year	# Discharges (Analyzed)	# Orthopedic Surgeons (Analyzed)	Average Volume of Procedures Per Provider
2000	6,791	374	18.2
2001	8,208	375	21.9
2002	9,336	369	25.3
2003	9,852	370	26.6
2004	11,573	384	30.1
2005	13,350	375	35.6
2006	14,330	377	38.0
2007	15,508	377	41.1
2008	17,018	384	44.3
2009	17,667	383	46.1

Figure 24. Characteristics of NC Orthopedic Surgeons Performing Knee Arthroplasty, 2000 - 2009

	2000		**2009**	
Mean Age (Years)	46		48	
% Female	2%		1%	
% Nonwhite	6%		6%	
% NC Medical School	25%		26%	
% NC Residency	27%		28%	
Mean Hours of Patient Care/Week	34.3		44.9	
Practice Type				
Group Practice	239	64%	266	69%
Other	38	10%	47	12%
Solo	35	9%	50	13%
Unknown	62	17%	20	5%
Primary Practice Location				
Rural	101	27%	108	28%
Urban	253	68%	260	68%
Unknown Location	20	5%	15	4%
Knee Arthroplasty Volume				
Low (1-12)	202	54%	103	27%
Intermediate (13-49)	150	40%	165	43%
High (50-99)	15	4%	67	17%
Very High (100+)	7	2%	48	13%

Characteristics of the physicians performing knee arthroplasty changed very little throughout the study period. In all years, orthopedic surgeons were almost entirely male and predominantly white (Figure 24). As well, the average age of providers changed only slightly between 2000 and 2009, from

46 to 48 years old. In all years of the study, approximately one quarter of surgeons were trained in North Carolina medical schools or did their residency in North Carolina.

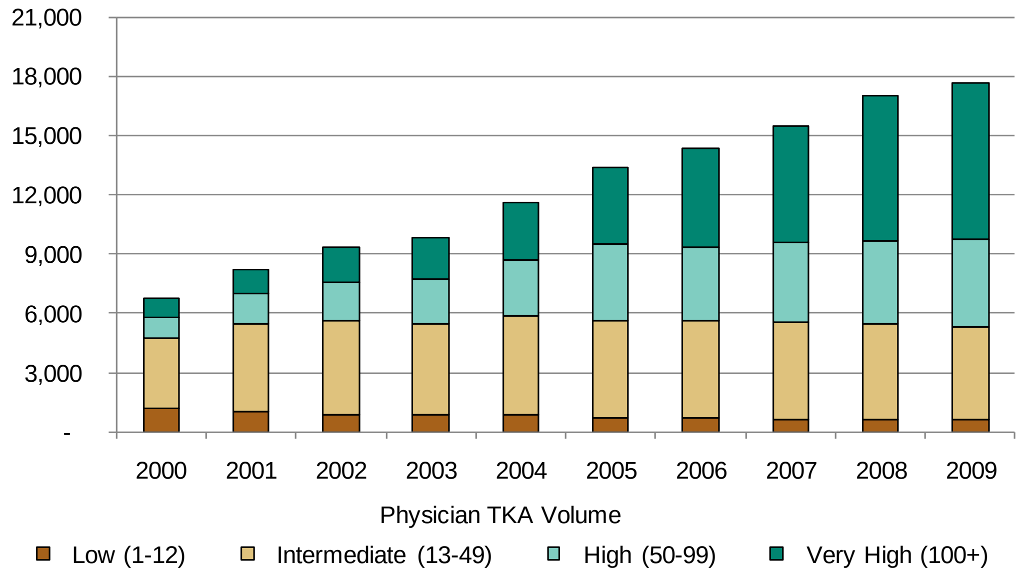
Surgeons performing knee arthroplasty were most commonly part of a group practice, and the proportion increased slightly from 64% to 70% between 2000 and 2009 (Figure 24). Further, these group-practice surgeons accounted for an overwhelming majority of discharges during the study period, 69% in 2000 and 78% in 2009 (Figure 25). The number of surgeons in solo practice also increased modestly from 9% to 13%, but this remained the least common practice setting for orthopedic surgeons performing knee arthroplasty (Figure 24). However, it is noteworthy that the volume of knee arthroplasty procedures among solo practice surgeons more than quadrupled between 2000 and 2009, far outpacing the growth in volume for surgeons in all other practice settings, including group practice which increased nearly threefold (Figure 25). Another practice characteristic that showed considerable change over the time period was the average number of patient care hours per week, which increased from 34 to 45 between 2000 and 2009 (Figure 24).

Figure 25. NC Knee Arthroplasty Procedures by Provider Characteristics, 2000 - 2009

	2000		2009	
Number of Discharges Analyzed	6,791		17,667	
Practice Type				
Group Practice	4,718	69%	13,697	78%
Other	792	12%	1,401	8%
Solo	397	6%	1,765	10%
Unknown	884	13%	804	5%
Primary Practice Location				
Rural	1,798	26%	4,411	25%
Urban	4,662	69%	12,661	72%
Unknown Location	331	5%	595	3%
Knee Arthroplasty Volume				
Low (1-12)	1,184	17%	631	4%
Intermediate (13-49)	3,596	53%	4,717	27%
High (50-99)	987	15%	4,375	25%
Very High (100+)	1,024	15%	7,944	45%

Throughout the study period, just over one quarter of all surgeons who performed knee arthroplasty were located in rural areas (Figure 24). Growth in the volume of knee arthroplasty procedures among surgeons located in rural areas was slightly weaker than for urban providers, 145% growth compared with 172% respectively (Figure 25). The most notable change in knee arthroplasty discharges with respect to the providers was that 70% of all discharges in 2009 were performed by surgeons with annual volume of at least 50 procedures, compared with 30% in 2000 (Figures 25 and 26).

Figure 26. NC Knee Arthroplasty Discharges By Provider Volume, 2000 - 2009



Source: NC Inpatient Discharge Databases 2000 - 2009. NC Physician Licensure Files, NC Health Professions Databases, 2000 - 2009.

4.6. County-level Utilization of Knee Arthroplasty

Analysis of inpatient discharge data by patient origin indicates great variability in utilization of knee arthroplasty across the North Carolina, which intensified over time. In 2000, all but one NC county had some discharges for knee

Figure 27. NC County Rates of Inpatient Knee Arthroplasty Utilization, Age Adjusted per 100,000 Persons, 2000 - 2009

Year	Range	Mean	S.D.	Median
2000	0-152	83.4	31.3	86.7
2001	9-154	94.6	33.0	98.2
2002	11.3-207.7	106.2	34.7	110.6
2003	8.4-182.5	113.4	36.1	116.4
2004	29.7-236.8	131.5	39.1	135.2
2005	28.5-232.5	150.9	46.9	156.6
2006	26.8-257.6	154.5	46.8	159.1
2007	37.7-329.4	170.4	46.7	175.0
2008	41.9-286.1	174.4	53.0	183.3
2009	17.1-282.5	176.7	52.2	186.7

arthroplasty and the mean age-adjusted utilization rate among counties was 83.4 discharges per 100,000 persons (Figure 27). By 2009, every county had some residents seeking inpatient knee arthroplasty and the mean county utilization rate had more than doubled to 176.7 (Figure 27). Age adjusted utilization of knee arthroplasty increased in all but one county (Currituck) between 2000 and 2009. However, the level of growth in counties' annual utilization rates varied considerably and counties with high or low rates in 2000 were not necessarily the same in 2009 (Figures 29 and 30).

Rural counties had lower utilization rates throughout the study period, though the difference was smaller in recent years (Figure 28). On average, rural counties had an age-adjusted knee arthroplasty rate of 79.1 per 100,000 in 2000 and 174.6 in 2009, compared with 89.9 in 2000 and 179.8 in 2009 for urban counties. Another notable difference between rural and urban counties, which persisted throughout the study, period was the smaller standard deviation for urban counties, indicating less variation in county rates among the 40 urban counties than 60 rural ones (Figure 28). This is likely the result of small rural counties having few discharges in some years relative to the population, whereas the larger population base in urban counties produces a more stable utilization rate at the population level.

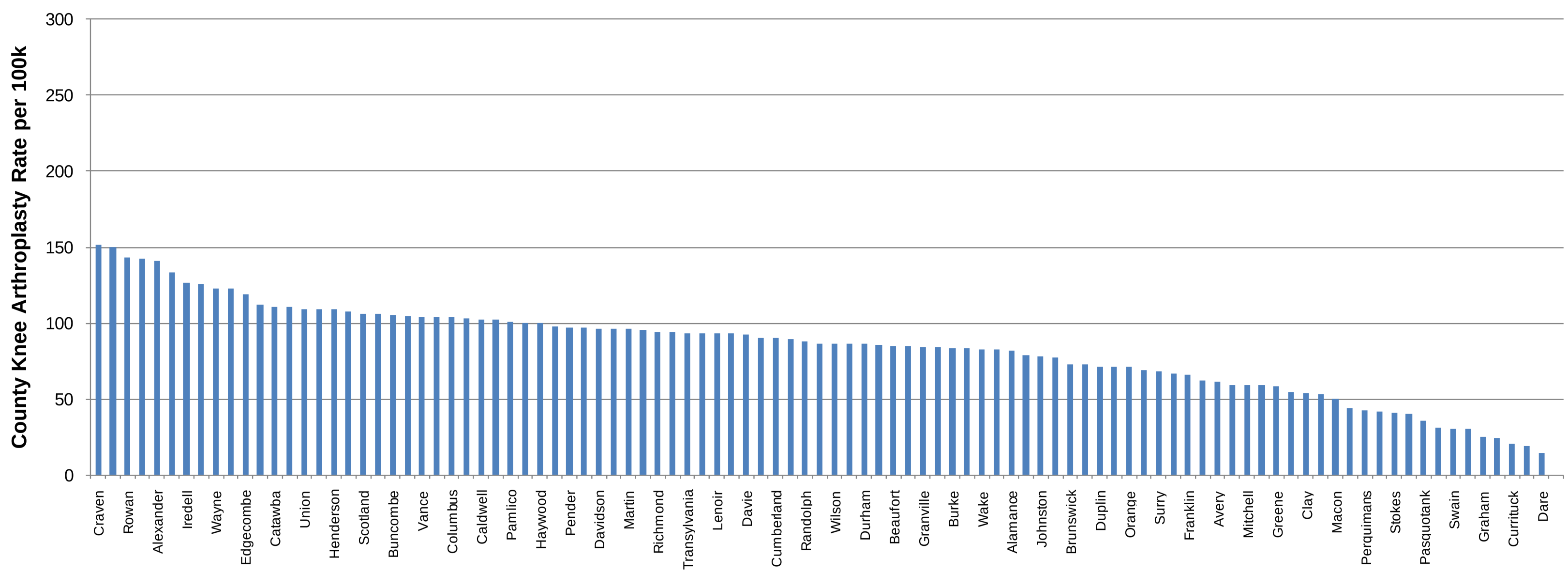
Figure 28. NC County Rates of Inpatient Knee Arthroplasty Utilization, Age Adjusted per 100,000 Persons, By Rural-Urban Location 2000 - 2009

Year	Rural (N=60)		Urban (N=40)	
	Mean	S.D.	Mean	S.D.
2000	79.1	35.5	89.9	22.5
2001	91.6	37.8	99.2	23.8
2002	103.9	38.5	109.6	28.0
2003	109.3	38.4	119.5	31.7
2004	127.6	44.1	137.3	29.6
2005	146.2	53.6	157.8	33.9
2006	151.4	53.9	159.2	33.5
2007	170.4	52.8	170.6	36.4
2008	170.0	60.1	181.1	40.0
2009	174.6	56.6	179.8	45.1

Given the wide variation in utilization of knee arthroplasty among North Carolina counties, age-adjusted procedure rates were mapped to visualize patterns of utilization among contiguous counties or within regions of the state. To provide a richer context for interpreting the county utilization rates, the location of hospitals and orthopedic surgeons providing knee arthroplasty surgery were mapped (Figures 31 – 40). The progressive darkening of counties in these maps demonstrates the longitudinal increase in county-level utilization of knee arthroplasty, as previously discussed in this paper. The added value of these maps is in presenting the visual pattern of county clusters with high or low utilization, which suggest a spatial process in utilization patterns.

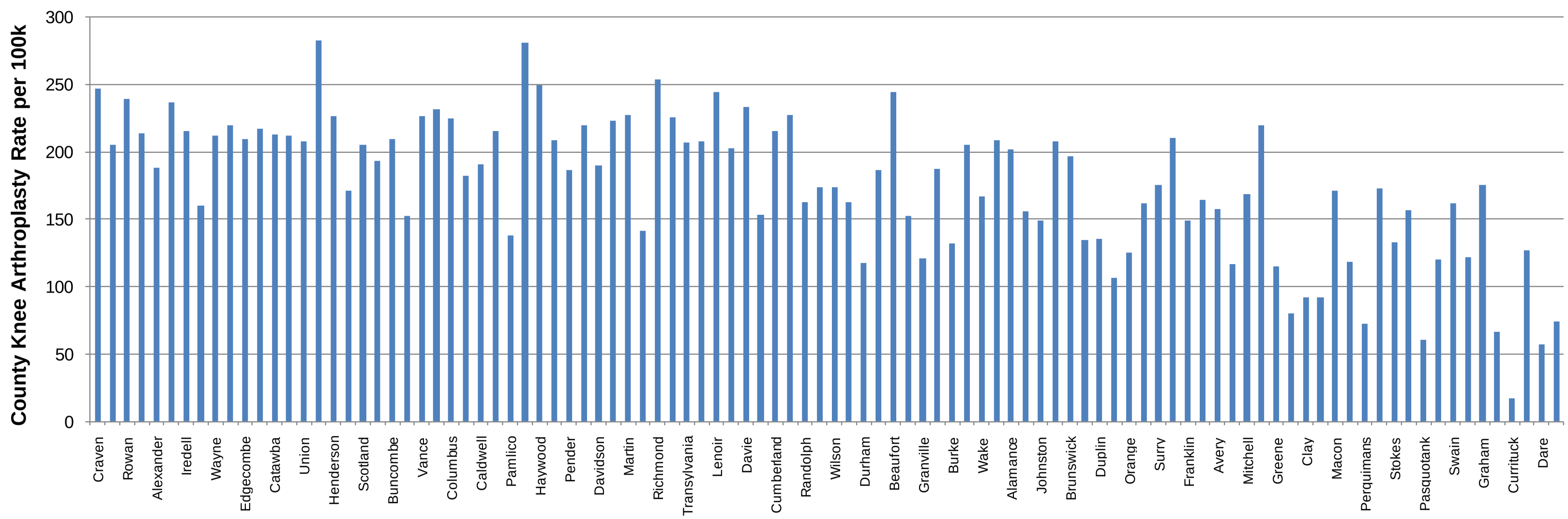
Yellow circles have been drawn around six areas where high utilization of one county may be associated with the rate in a neighboring county, based on the similarity in rates and their proximity. Each area includes a central metropolitan city or town which is identified in the maps; they include Asheville, Charlotte, Greensboro, Greenville, New Bern, and Laurinburg. Over time, the maps show several of these multi-county areas, including the clusters surrounding Asheville, Charlotte, New Bern, and Greenville growing in diameter. This pattern raises questions about whether there is both a geographic and longitudinal process occurring within the data, and supports the need for multivariate regression analysis as presented later in this paper. The maps also show that, over time, the density of orthopedic surgeons appears to increase in the areas with high utilization. Data presented earlier in this chapter shows that the number of orthopedic surgeons performing knee arthroplasty has changed very little over time, but the maps demonstrate that the location of the providers doing TKA seems to have changed and become concentrated in several regions of the state, which constitute the higher utilization regions. While these maps provide an interesting profile of the geographic pattern of knee arthroplasty utilization, the relationship between counties' utilization rates and any association with the location of providers cannot be completely understood by looking at maps.

Figure 29. Knee Arthroplasty Procedures per 100,000 Persons, Age Adjusted 2000



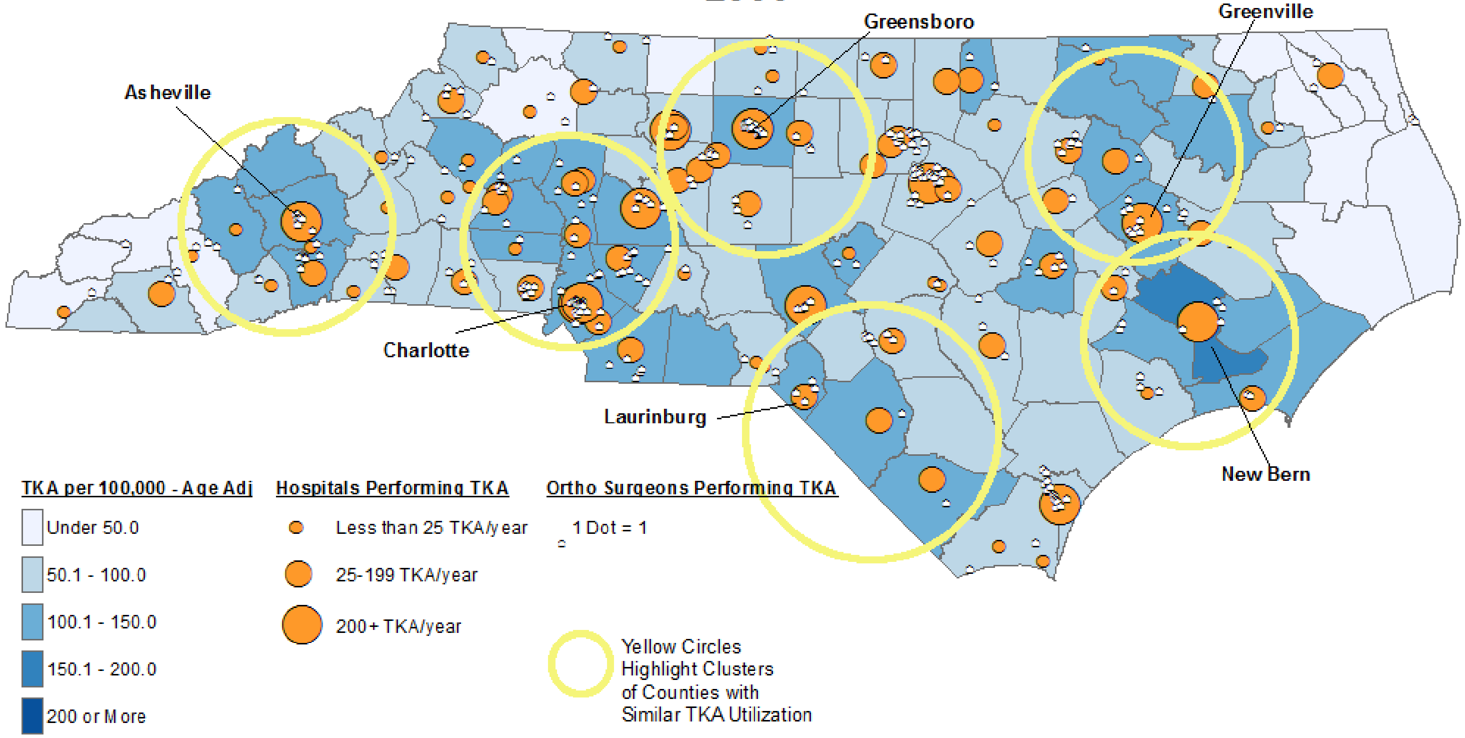
Data Sources: NC Inpatient Discharge Databases, 2000. NC Population Estimates from NC Office of State Management and Budget, 2000.

Figure 30. Knee Arthroplasty Procedures per 100,000 Persons, Age Adjusted 2009



Data Sources: NC Inpatient Discharge Databases, 2009. NC Population Estimates from NC Office of State Management and Budget, 2009.

Figure 31. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2000

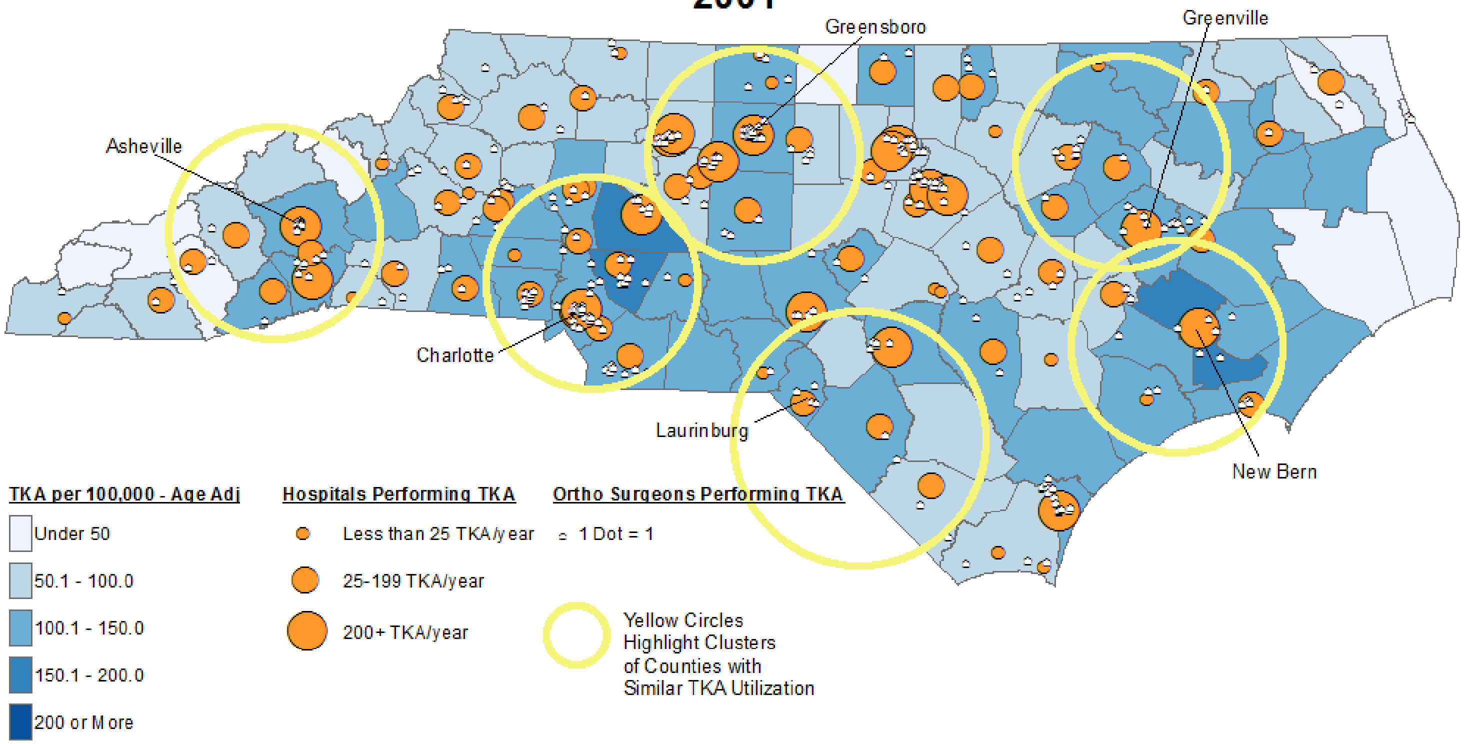


Notes:

1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2000; NC Office of State Budget and Management, 2000; NC Medical Board 2000; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

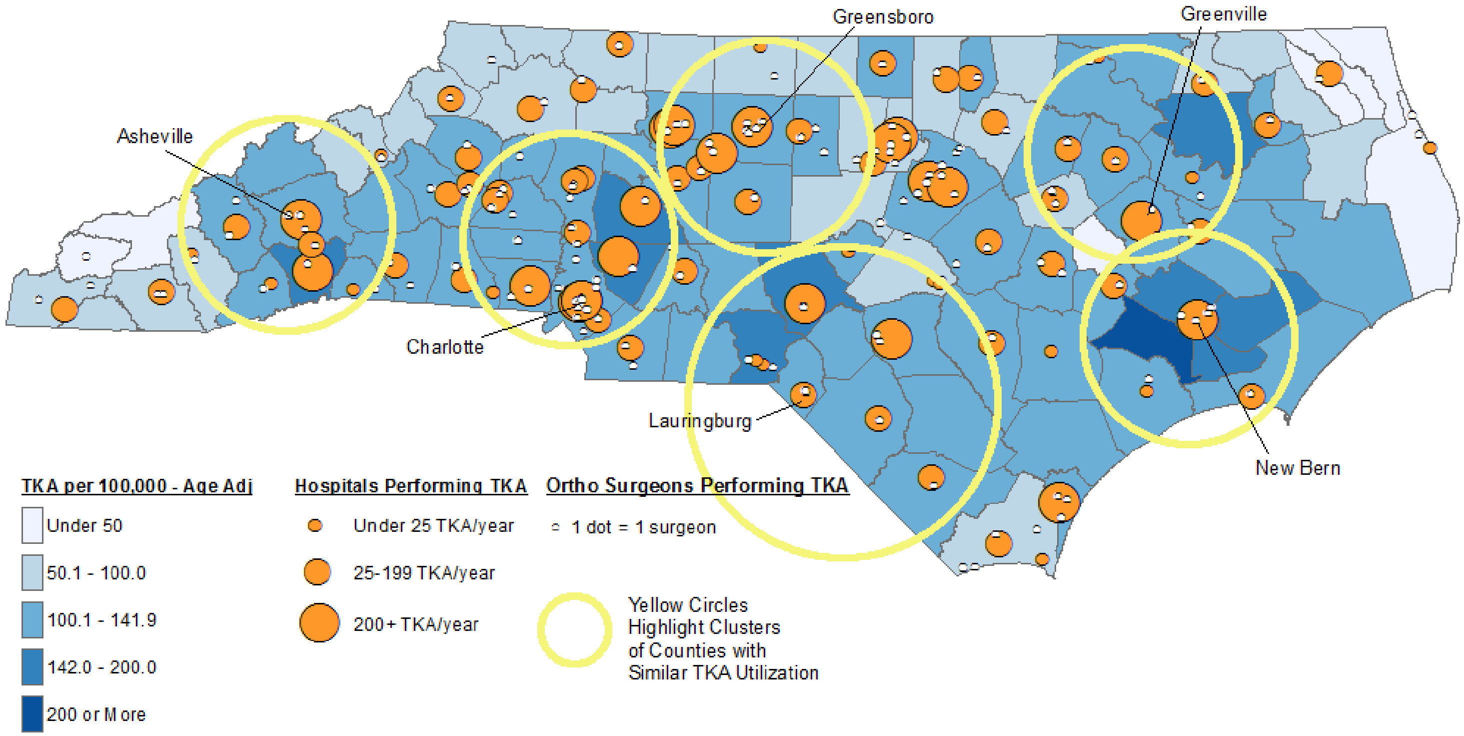
Figure 32. North Carolina
Knee Arthroplasty Utilization Rates with
Location of Hospitals and Orthopedic Surgeons
2001



Notes:
1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2001; NC Office of State Budget and Management, 2001; NC Medical Board 2001; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

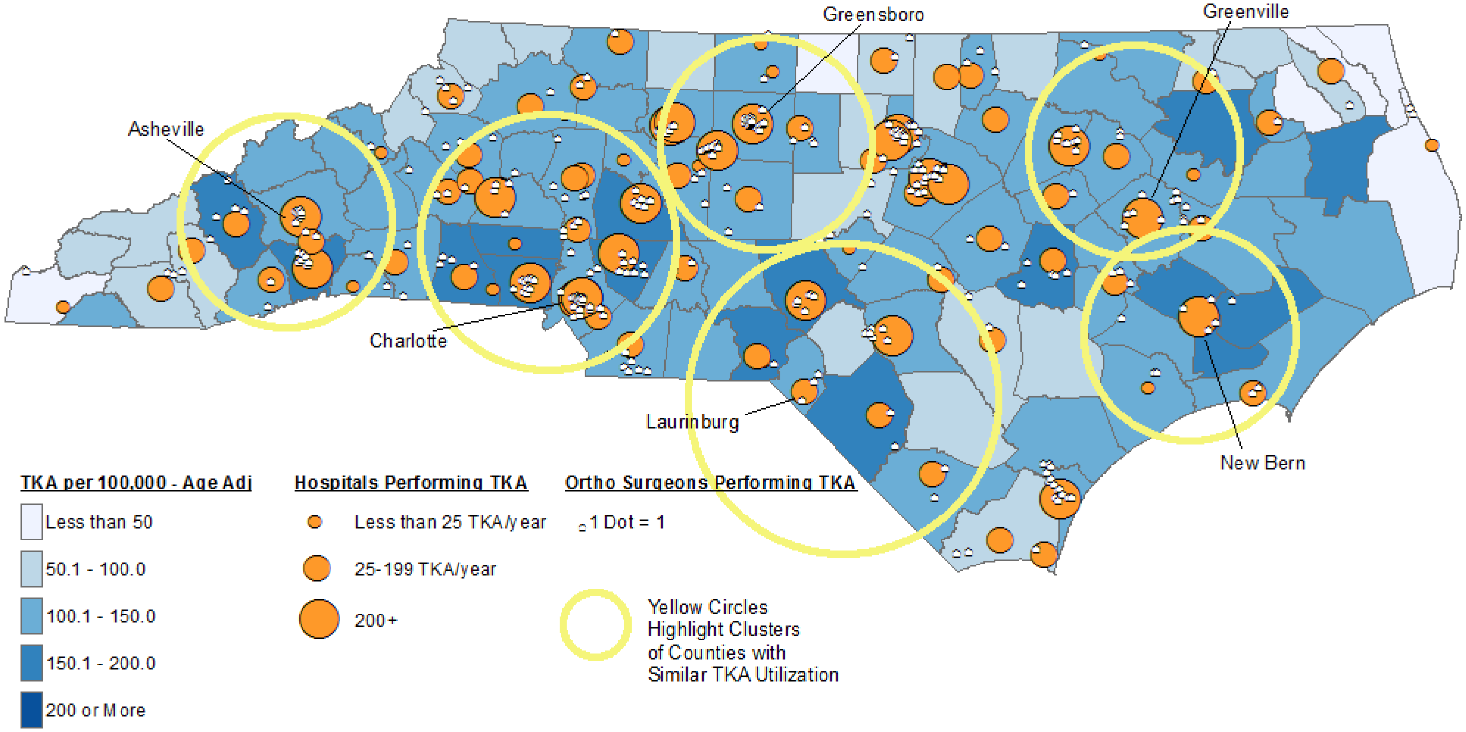
Figure 33. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2002



Notes:
1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2002; NC Office of State Budget and Management, 2002; NC Medical Board 2002; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

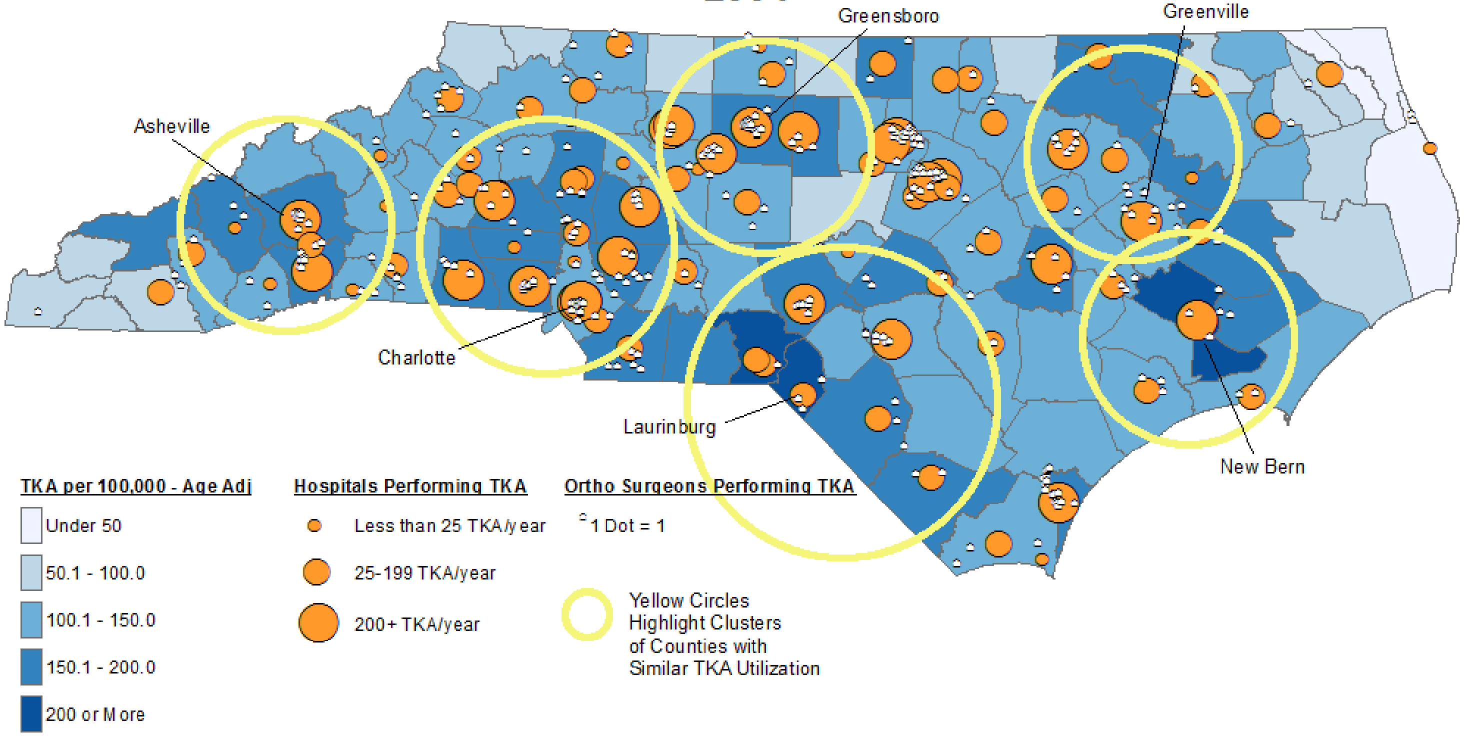
Figure 34. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2003



Notes:
1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2003; NC Office of State Budget and Management, 2003; NC Medical Board 2003; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

Figure 35. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2004

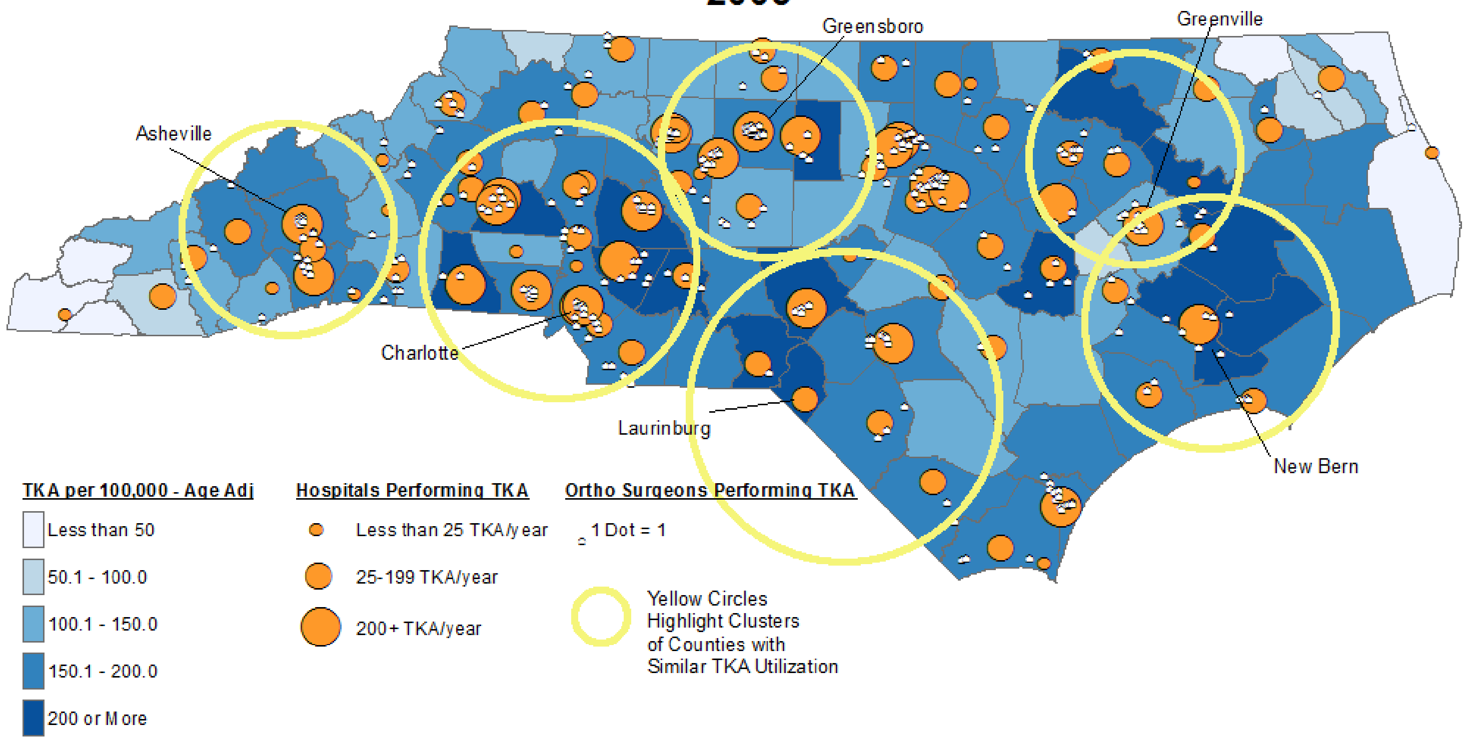


Notes:

1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2004; NC Office of State Budget and Management, 2004; NC Medical Board 2004; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

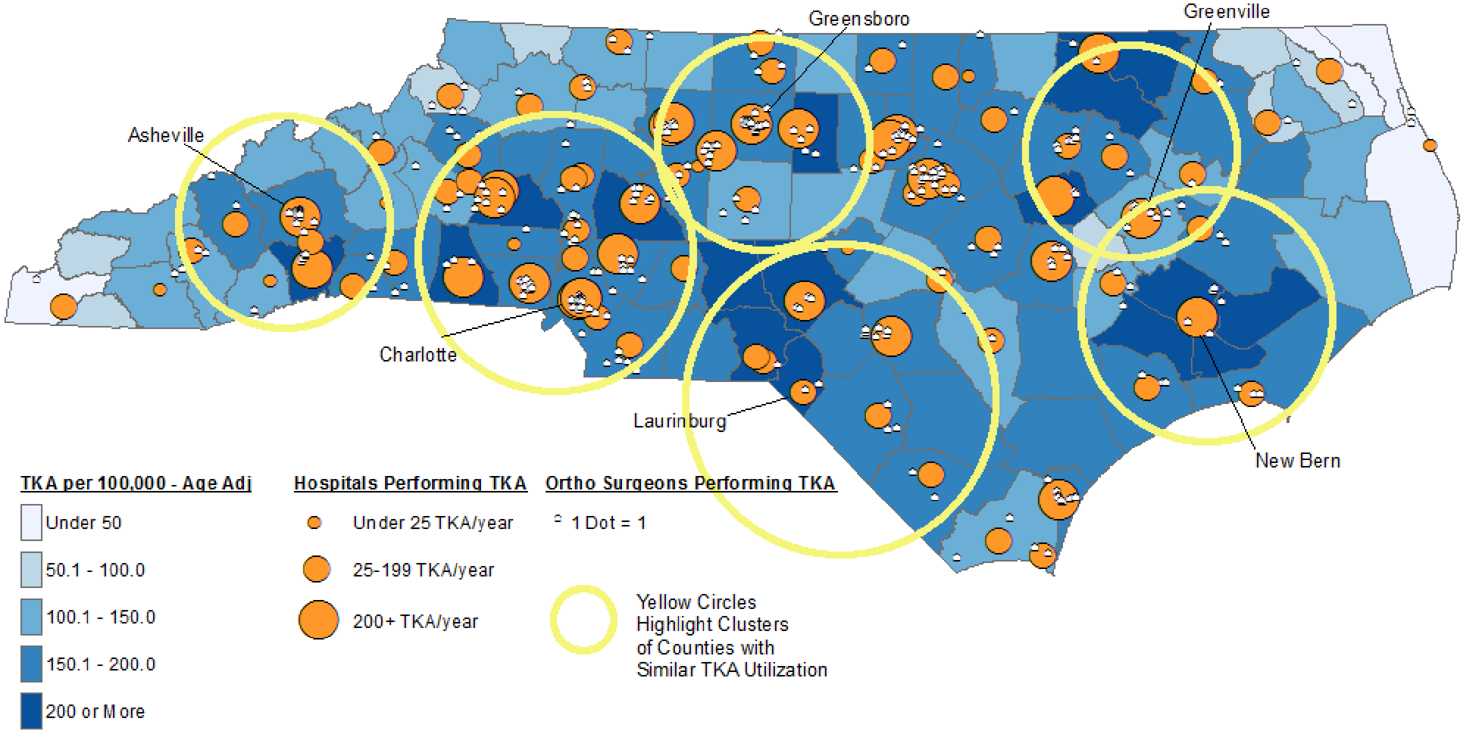
Figure 36. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2005



Notes:
1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2005; NC Office of State Budget and Management, 2005; NC Medical Board 2005; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

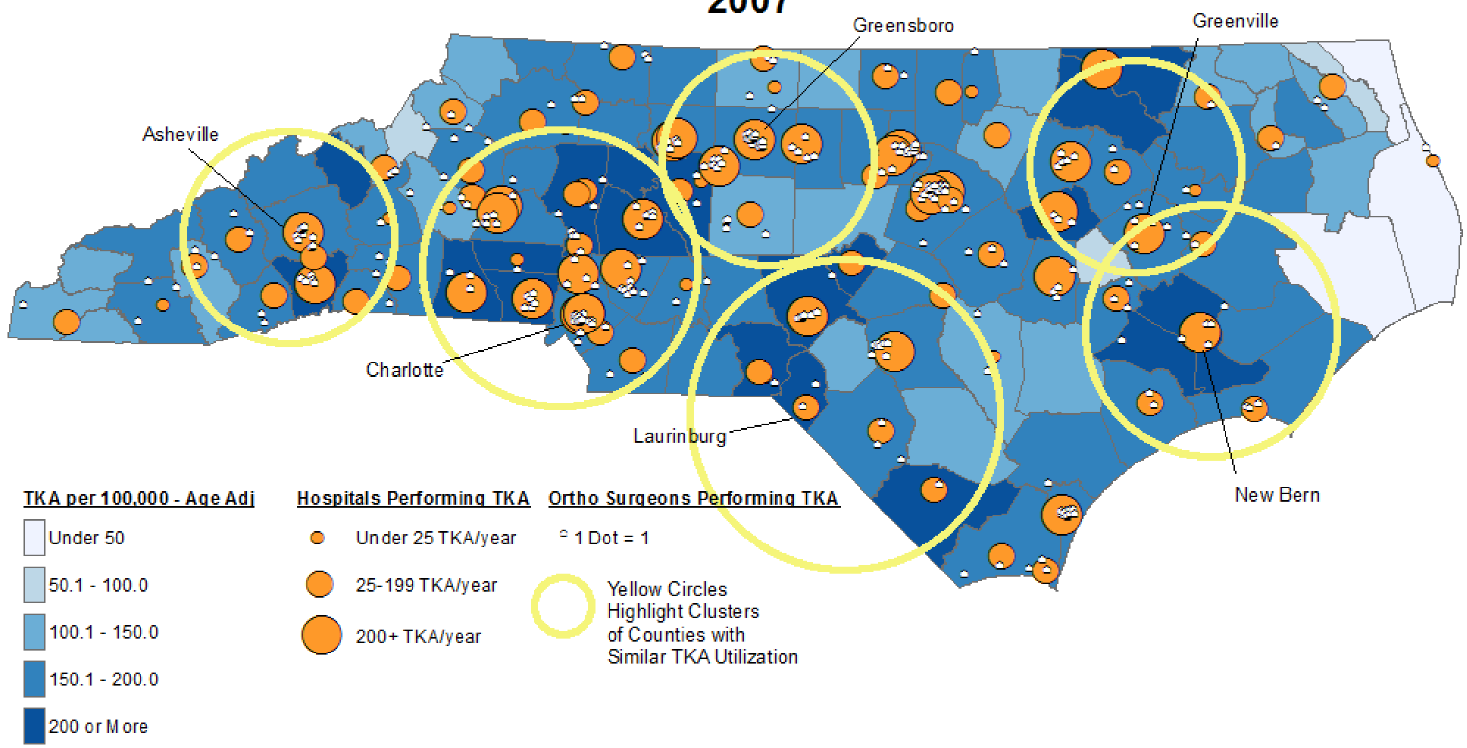
Figure 37. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2006



Notes:
1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2006; NC Office of State Budget and Management, 2006; NC Medical Board 2006; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

Figure 38. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2007

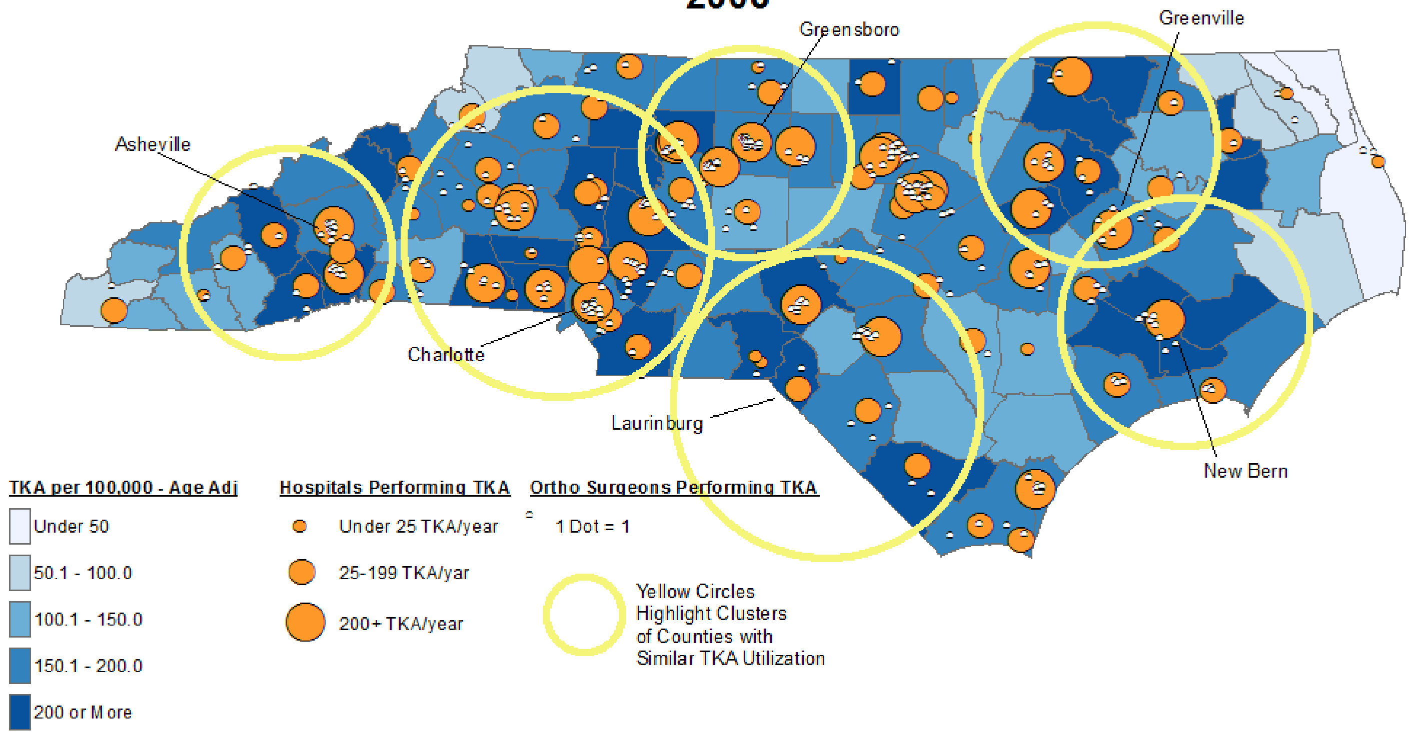


Notes:

1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2007; NC Office of State Budget and Management, 2007; NC Medical Board 2007; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

Figure 39. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2008

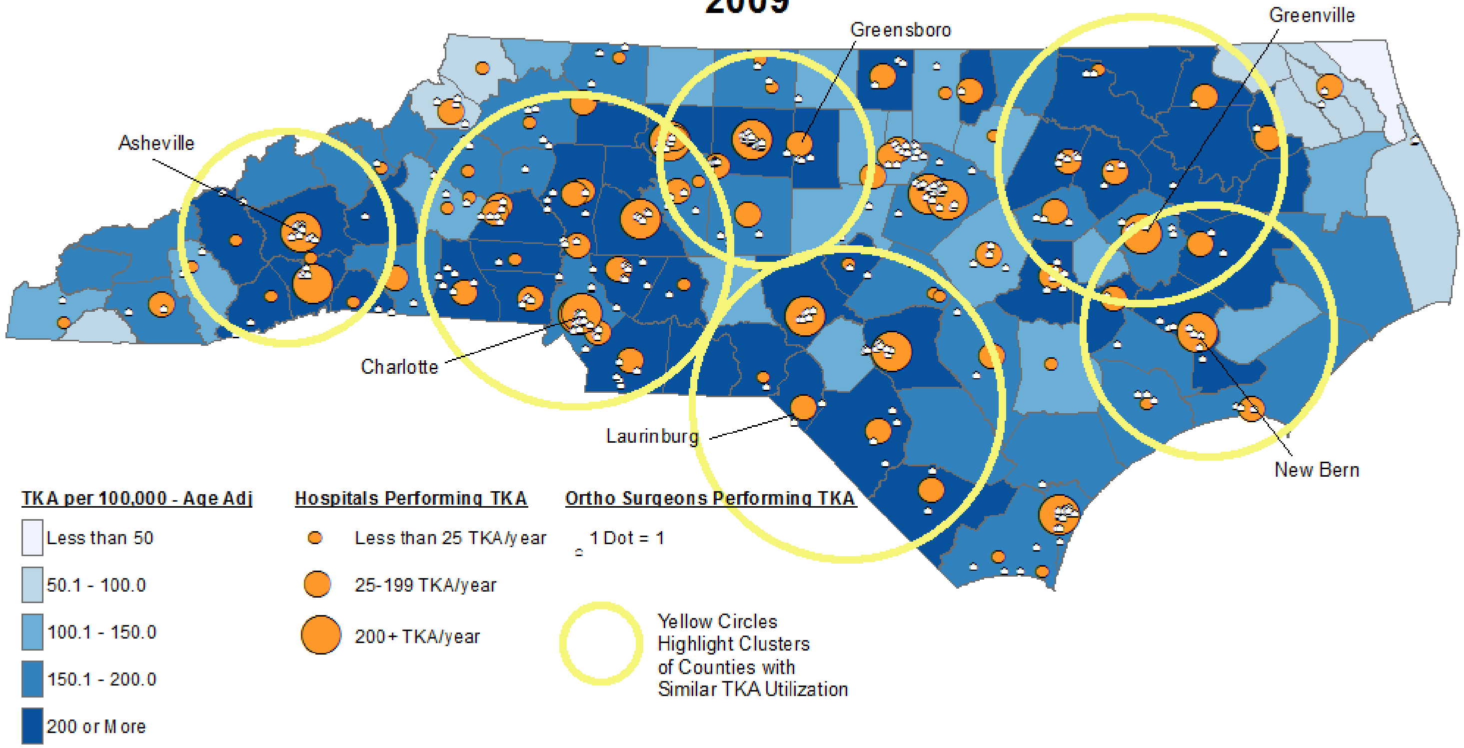


Notes:

1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2008; NC Office of State Budget and Management, 2008; NC Medical Board 2008; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

Figure 40. North Carolina Knee Arthroplasty Utilization Rates with Location of Hospitals and Orthopedic Surgeons 2009



Notes:
1. Orthopedic surgeons include licensed active physicians with a primary or secondary specialty of orthopedic surgery (orthopedic surgery, pediatric orthopedic surgery, spinal reconstructive surgery, adult reconstructive orthopedic surgery, orthopedic sports medicine, orthopedic surgery of the spine, orthopedic trauma surgery, or musculoskeletal oncology orthopedic surgery).
2. Knee arthroplasty procedure rates calculated using discharges with a procedure code for primary knee arthroplasty (81.54).

Data Sources:
NC Inpatient Discharge Database, 2009; NC Office of State Budget and Management, 2009; NC Medical Board 2009; and NC Division of Healthcare Regulation, 2011.
Produced by the Cecil G. Sheps Center for Health Services Research, UNC-CH, February 2011.

Formal multivariate analyses, including spatial and linear regression, were conducted to assess the geographic patterns in knee arthroplasty and estimate the association between county characteristics and utilization. Figure 41 presents sample statistics for the county-aggregated data used in multivariate regression analyses, including the mean, standard deviation, minimum and maximum for all continuous variables. Sample statistics are presented for 2008 and the 2004-2008 change datasets in order to demonstrate the distribution of variables used in each model. Descriptions and units of measurement for each variable are described in Figure 8 of Chapter III. Regression results are presented in Figures 44 and 45 for the 2008 and 2004-2008 change models, respectively.

Sample statistics for 2008 data show utilization of knee arthroplasty, knee arthroscopy, and marker conditions varied considerably across North Carolina in 2008. Between 2004 and 2008, utilization of knee arthroscopy and admissions for marker conditions declined in most counties while use of knee arthroplasty increased in more than half of the counties. The demographic composition of counties was relatively stable between 2004-2008 with respect to gender and race. On average, counties had a nearly even gender balance (51% female), and approximately 50% of counties had minority populations of at least one quarter of the total population in 2008; neither variable demonstrated substantial change between 2004-2008 according to the univariate analyses. The mean and median county proportion of residents who were obese in 2008 was 30%, and most counties experienced a slight increase in their obese population from 2004. There was considerable variation in per capita income among counties in 2008, ranging from $13,850 to $30,960, with a mean of $20,910. On average, per capita income changed by just over $1,000 between 2004-2008 in North Carolina counties. There was also wide variation among counties in the proportion of population with at least a bachelor's degree, ranging from 8% to 53% with a mean value of 16% in 2008; there was virtually no change in this indicator between 2004 and 2008.

The primary care physician supply varied considerably across counties from none (Tyrrell County) to 455 per 100,000 persons in 2008, and the median county value was 72. Between 2004 and 2008, most counties experienced a slight increase in the supply of primary care doctors; the mean change was 0.64 primary care physicians per 100,000. Similarly, 34 counties had no orthopedic surgeons who performed knee arthroplasty, while others had as many as 13 per 100,000 persons in 2008; the median and median ratio was three orthopedic surgeons per 100,000. At least half of all counties experienced no change in the supply of orthopedic surgeons performing knee arthroplasty. In 2008, 66 counties had at least one hospital that performed knee arthroplasty and 22 of those counties' hospitals performed at least 200 procedures. Between 2004 and 2008, hospitals in three counties either closed or stopped performing knee arthroplasty while two other counties experienced an increase in the number of hospitals performing knee arthroplasty. Between 2004 and 2008, institutional volume increased such that seven more counties had high volume (at least 200) knee arthroplasty hospitals. The number of skilled nursing facilities ranged from none (in two counties) to 24 in 2008, and half of all counties had at least 3 skilled nursing facilities; between 2004 and 2008, eight counties lost and eight counties gained skilled nursing facilities. The median number of hospital beds per county was 97 in 2008, with very little change between 2004 and 2008.

Figure 41. Sample Statistics for County Aggregated Data, North Carolina

	2008					Change 2004 - 2008				
Variable	Mean	Median	S.D.	Min	Max	Mean	Median	S.D.	Min	Max
TKA per 100,000 (age adj)	174.40	83.99	53.03	41.91	286.07	42.91	41.99	35.74	-65.99	154.09
Female	0.51	0.51	0.02	0.43	0.54	0.00	0.00	0.01	-0.03	0.02
Nonwhite	0.28	0.25	0.18	0.02	0.68	0.00	0.01	0.01	-0.04	0.03
Obese	0.30	0.30	0.03	0.22	0.39	0.03	0.03	0.02	-0.02	0.08
Age 55 to 84	0.26	0.25	0.05	0.13	0.40	0.01	0.01	0.01	0.00	0.03
Uninsured	0.19	0.19	0.02	0.15	0.28	0.01	-0.01	0.02	-0.06	0.05
Per Capita Income	20.91	20.14	3.29	13.85	30.96	1.19	1.19	0.77	-0.76	2.98
Bachelors Degree	0.16	0.14	0.08	0.08	0.53	0.00	0.00	0.00	0.00	0.01
Rural	0.60	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Primary Care MDs per 100,000	83.91	71.94	61.78	0.00	455.26	0.64	0.33	10.23	-24.48	28.77
Ortho Surgeons doing TKA per 100,000	3.15	3.12	2.99	0.00	13.21	-0.30	0.00	1.69	-6.76	6.31
Number High Volume TKA Hospitals	0.30	0.00	0.66	0.00	4.00	0.07	0.00	0.26	0.00	1.00
Skilled Nursing Facilities	4.20	3.00	4.26	0.00	24.00	0.01	0.00	0.44	1.00	2.00
Hospital Beds	205.05	96.50	340.16	0.00	1,996.00	-0.12	0.00	9.42	-72.00	60.00
Knee arthrosocopy per 100,000 (age adj)	57.72	35.49	64.67	0.00	403.24	-24.24	-15.37	84.90	-284.29	343.33
Marker Conditions per 100,000 (age adj)	471.17	475.32	114.82	120.87	792.98	100.14	-109.14	74.35	-243.32	207.49

Figure 42. Knee Arthroplasty per 100k in 2008, NC

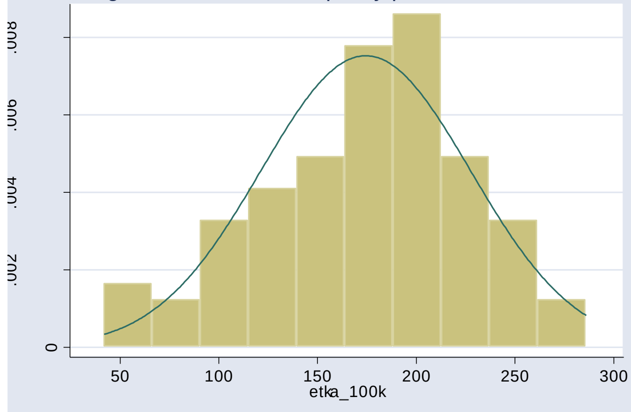
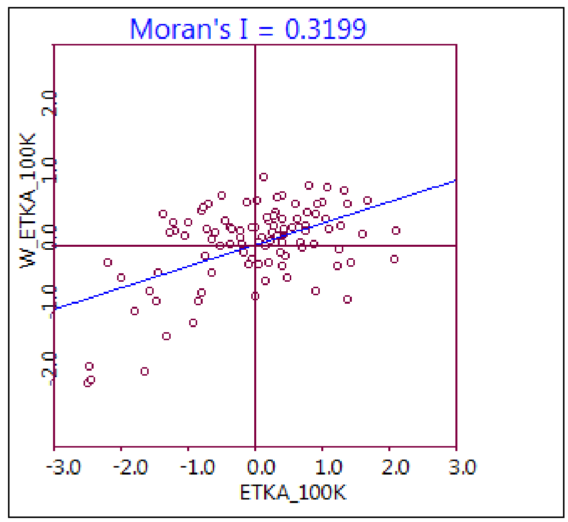


Figure 43. Moran's I for TKA Utilization, 2008



A histogram of county knee arthroplasty utilization rates per 100,000 persons (Figure 42), shows that the dependent variable was slightly skewed compared to a normal distribution. Local Moran's I was computed for the dependent variable, with results (I=0.3199) indicating the presence of spatial autocorrelation. The Moran's I scatterplot (Figure 43) shows the standard deviation of each county's utilization rate on horizontal axis, plotted against the standard deviation of the county's neighbors as defined by a first order Queen's-contiguity matrix on the vertical axis. The slope of the line through points in the scatterplot is equivalent to the Moran's I statistic (I=0.3199), which is positive because high-high and low-low neighbor relationships dominate. These data are also presented using a local indicators of statistical autocorrelation (LISA) map to illustrate the low-low and high-high clusters, which were informally identified earlier in this chapter (Figure 44). As seen previously, counties in the northeast region of the state demonstrate a spatial pattern of low utilization, while clustering in the Charlotte area indicate high utilization. Only statistically significant neighbor relationships are shaded in the LISA map. Exploratory analyses presented in Figures 43 and 44 confirm the presence of spatial autocorrelation and justify the need for further diagnostics of spatial autocorrelation. As such, multivariate regression was estimated using

OLS to estimate Global Moran's I and assess the nature of spatial autocorrelation in the model.

Figure 44. LISA Map of TKA Utiliz, 2008

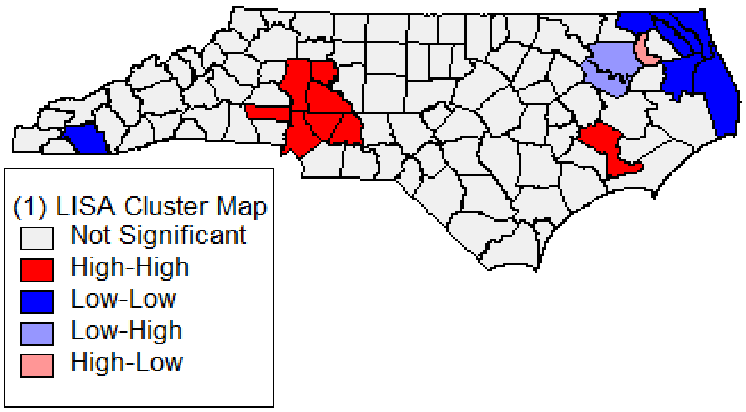
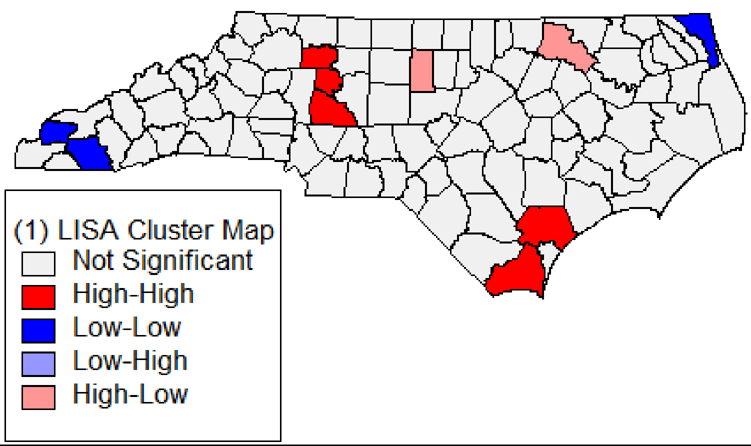


Figure 45. LISA Map of Multivariate Regression Residuals, 2008



A LISA map of the residuals from the multivariate regression (Figure 45) showed substantial reduction in spatial autocorrelation and was supported by the Global Moran's I (0.04, ns) which indicated weak spatial autocorrelation. This finding implies that inclusion of the selected covariates in a linear regression model largely eliminates the problem of spatial autocorrelation; however, the Lagrange Multiplier test (Robust LM (lag) = 13.44, p=.0002) strongly indicated that the spatial autocorrelation in the dependent variable, after controlling for covariates, was still statistically significant and that the model should be fitted using spatial lag regression techniques. That is, the knee arthroplasty utilization rate in one county is directly dependent, through some process, on the utilization rate in neighboring counties. Chapter III describes in detail the problems that spatial autocorrelation presents for linear regression, but to summarize simply, OLS estimators are considered unreliable because the errors are correlated; spatial regression corrects this problem by including a parameter which represents the average value of the dependent variable for every county's neighbors. Given this information, a spatial lag model was estimated for 2008 knee arthroplasty utilization and the results are presented in Figure 46. Interpretation will focus largely on results from the spatial lag model, but OLS results are included in the table to demonstrate the improvements made using spatial regression.

Figure 46: Multivariate Regression Results for 2008 Model of NC County Knee Arthroplasty Utilization

Variable	OLS		Spatial Lag	
	Coeff	p	Coeff	p
CONSTANT	313.22		173.33	
Female	-209.91		-147.66	
Nonwhite	111.02		89.09	
Obese	-239.37		-143.76	
Age 55 to 84	89.36		81.86	
Uninsured	-815.30	**	-641.72	*
Per Capita Income	2.11		2.85	
Bachelors Degree	-208.83		-221.41	
Rural	6.36		8.26	
Primary Care MDs per 100,000	0.32	**	0.34	***
Ortho Surgeons doing TKA per 100,000	0.63		0.85	
Number High Volume TKA Hospitals	34.44	**	35.11	**
Skilled Nursing Facilities	4.79	*	4.07	*
Hospital Beds	-0.10	**	-0.10	**
Knee arthrosocopy per 100,000 (age adj)	-0.07		-0.03	
Admissions for Marker Conditions per 100,000 (age adj)	0.20	***	0.16	***
Spatial Parameter			0.33	***
R2	0.51		0.56	
AIC	1,037.20		1,031.67	
Log Likelihood	-502.60		-498.83	
Local Moran's I	0.32			
Global Moran's I	0.04			

***Significant at the .05 level**
****Significant at the .01 level**
*****Significant at the .001 level**

Test	value	p	value	p
Multicollinearity Condition	204.73			
Jarque-Bera	0.31			
Breusch-Pagan	11.84		10.01	
Robust LM(lag)	13.50	***		
Robust LM (error)	6.49	**		
Likelihood Ratio Test			7.53	**

Spatial lag results, presented in Figure 46, show a statistically significant spatial parameter, indicating that parameter estimates are overstated for all covariates in OLS. The spatial parameter represents “spillover” effects, but the coefficient (0.33) itself is not easily interpretable. In this model of knee arthroplasty utilization, spatial lag regression produces smaller parameter estimates for all covariates and slightly different p values than OLS. However, spatial lag does not result in elimination or addition of any statistically significant variables compared with OLS. Six covariates, including four which represent health resource availability, were found to be statistically significant predictors of knee arthroplasty utilization. The presence of healthcare institutions in a county was found to have a positive effect on knee arthroplasty utilization. For every additional high volume TKA hospital in a county, utilization of knee arthroplasty increased by 35.11 procedures per 100,000. Likewise, the addition of one skilled nursing facility in a county was associated with 4.07 more knee arthroplasty procedures per 100,000 persons. For every additional primary care physician per 100,000 persons in a county, the utilization rate of knee arthroplasty increases by 0.34. The number of orthopedic surgeons performing TKA was not found to be a statistically significant predictor of utilization of TKA. However, the number of beds was found to have an inverse effect on knee arthroplasty utilization; for every additional hospital bed in a county, utilization decreased by -0.10 procedures per 100,000. The only population characteristic found to have a statistically significant effect on knee arthroplasty utilization was the percent of the population lacking health insurance. A one percent increase in the percent uninsured was associated with a decrease in knee arthroplasty procedures equal to 641.72 per 100,000 persons. Finally, admissions for marker conditions were found to have a positive association with utilization of knee arthroplasty. For every one unit increase in the rate of admissions (per 100,000) for the four marker conditions, there was a 0.16 unit increase in utilization of knee arthroplasty (per 1000,000).

Overall, the spatial lag model showed improvements in goodness of fit relative to OLS. Compared with the OLS model, the spatial lag model had a slightly higher R^2 (0.56 compared with 0.51) and log likelihood (-498.83 compared with -502.6), and slightly lower AIC (1031.7 compared with 1037.2). Additional diagnostic tests were calculated, including the Jarque-Bera test (value=0.31, ns) which show normal errors and the Breusch-Pagan test (value=11.84, ns), which show homoskedastic errors. These results imply proper specification of the model with regard to the selection of covariates and their functional form. Test statistics did indicate high multicollinearity (value = 204.73), which was not unexpected given the preponderance of variables describing local healthcare resources, which tend to be related. However, since multicollinearity does not affect the overall predictive power of the model, all variables deemed conceptually important were left in the model despite their correlation with one another. The likelihood ratio test (value=7.53, p=.006) showed that the spatial lag regression model was preferred over OLS, as the former was successful in treating spatial autocorrelation. In light of these findings, the spatial lag model is considered a methodological improvement over OLS and parameter estimates are thought to be suffer less bias.

Turning to the multivariate analysis of change in knee arthroplasty between 2004-2008, regression results were more straightforward because tests did not reveal the presence of spatial autocorrelation. Thus, the model was fitted using OLS regression with unexpected results of only one statistically significant variable (Figure 47). Overall, the model explained very little of the variation among counties in knee arthroplasty utilization change between 2004-2008; R^2, the best measure of goodness of fit in OLS, was a low 0.16, indicating that only 16% of the variation in knee arthroplasty utilization change was explained by this model. Only one variable was found to be a statistically significant predictor of knee arthroplasty utilization change at a 0.05 significance level. A one unit change in (lagged) knee arthroscopy utilization was associated with a -0.11 change in utilization of knee arthroplasty utilization per 100,000. All other variables were found to be insignificant in predicting the change in utilization of knee arthroplasty between 2004-2008. These results, combined with those of the cross-sectional multivariate spatial regression analysis of 2008 county utilization of TKA suggest that provider and population factors are useful in predicting geographic variation, but the change utilization rates between 2004-2008 was not significantly associated with changes in county level factors during the same time period.

Figure 47. Multivariate Regression Results for Change in NC County Utilization of Knee Arthroplasty Utilization, 2004-2008

Variable	OLS	
	Coeff	p
CONSTANT	50.82	
Female	-720.79	
Nonwhite	312.45	
Obese	-124.77	
Age 55 to 84	-555.95	
Uninsured	-37.11	
Per Capita Income	6.09	
Bachelors Degree	-694.15	
Primary Care MDs per 100,000	0.18	
Ortho Surgeons doing TKA per 100,000	-1.32	
Number High Volume TKA Hospitals	14.91	
Skilled Nursing Facilities	1.18	
Hospital Beds	-0.05	
Knee arthrosocopy per 100,000 (age adj)	-0.11	*
Admissions for Marker Conditions per 100,000 (age adj)	0.09	
R2	0.16	
AIC	1,010.83	
Local Moran's I	0.04	
Global Moran's I	-0.05	

*Significant at the .05 level
**Significant at the .01 level
***Significant at the .001 level

Test	value	p
Multicollinearity Condition	10.55	
Jarque-Bera	1.98	
Breusch-Pagan	19.20	
Robust LM(lag)	1.92	
Robust LM (error)	2.48	

5. Discussion and Conclusions

5.1. Summary and Interpretation of Findings

Utilization of knee arthroplasty increased rapidly from 2000 to 2009 in North Carolina. The total volume of procedures more than doubled, as did the per capita rate of utilization in the State. North Carolina's utilization of knee arthroplasty remains slightly below the U.S. rate, but the observed increase was consistent with national trends.

Analysis of inpatient discharges showed interesting changes in utilization among population subgroups, particularly among people younger than 65. While the growth rate in utilization of knee arthroplasty nearly doubled among the elderly (over 65 years old), it nearly tripled for those under 65. Consequently, the proportion of knee arthroplasty discharges billed to private insurance also increased substantially during the study period and this trend has the potential to cause a change in the financial and contractual relationships between orthopedic surgeons and public and private third-party payers. At the same time, modest changes were observed in the comorbidity of knee arthroplasty patients, as a greater proportion of patients receiving knee arthroplasty had at least one comorbidity in 2009 than in 2000. This finding may signal a shift in how primary care physicians and orthopedic surgeons screen and refer patients for knee replacement surgery, though more research is needed to adequately understand this issue. Specifically, analysis of more detailed clinical data would be useful in describing how case complexity, beyond the 16 comorbidities identified by the Charlson index, may be changing as utilization increases. This is of considerable importance with respect to access to care, as some providers may be selecting less complicated cases in order to maximize volume and reimbursement. Despite a rapid increase in utilization of knee arthroplasty, the supply of orthopedic surgeons and hospitals performing TKA remained relatively constant. Analyses showed that a subset of hospitals and orthopedic surgeons became high-volume providers during the study period. Instead of an even absorption of the increased volume across institutions and surgeons, there seems to be a trend towards specialization in knee arthroplasty. Whether this is by choice or response to need in the absence of new joint replacement surgeons is unclear and should be examined in future studies. Equally surprising was the knee arthroplasty volume increase observed among small and medium hospitals, compared with larger facilities. Between 2000 and 2009, the number of knee arthroplasty discharges approximately doubled in hospitals with 400 or more beds, but more than doubled in both medium (100-299 beds) and small (25-99 beds) hospitals. As discussed in greater detail later in this chapter, this suggests that community hospitals may have identified knee arthroplasty as a niche service to offer residents locally, which could have positive financial implications for the facilities, while at the same time improving access to local populations for orthopedic surgical care. The increase in high-volume hospitals and surgeons also has potential implications for patient outcomes, which is discussed in greater detail later in this chapter.

Multivariate analyses results support the idea of provider induced demand hypothesis, as supply-side factors were positively associated with county utilization of knee arthroplasty. However, results were somewhat unexpected in that the provider-induced demand found to be significant in this analysis was not among surgeons who perform the procedure, but instead among referring physicians and health care institutions. Of all variables tested in the multivariate regression model, including population socioeconomic indicators and health resource availability, the group of variables found to be most significant in predicting knee arthroplasty utilization included those that described the local healthcare supply. Surprisingly, the county supply of primary care providers was found to be positively associated with TKA utilization, suggesting that local access to a source of referral may be more important than local access to an orthopedic surgeon to perform knee arthroplasty. However, the magnitude of the coefficient for primary care providers per 100,000 was very small and represents a modest impact on utilization when considering its marginal effect. Furthermore, it is important to keep in mind that counties may be a more appropriate proxy of service area for primary care than orthopedic surgical care, thus producing a non-significant result for the latter. The healthcare variable representing greatest marginal effect in the model was the presence of a high-volume TKA hospital in the county. This finding makes sense from a practical standpoint, in that potential patients may be more inclined to proceed with knee replacement surgery if the hospitals (and pre- and post-operative ancillary care) are available in close proximity to their residence. Further, these findings support the idea that hospitals may be intentionally growing specific service lines, such as knee replacement surgery, and hospitals with a high volume of procedures may be disproportionately investing resources in marketing those services in their local communities. However, it is interesting to note that a region of the state with a significant density of orthopedic surgeons and institutions performing TKA, including Durham and Orange counties, do not have high utilization rates; this may be an indication that hospitals in this region draw a high proportion of their patients from outside the county and possibly state boundaries. The inverse relationship between hospital beds in a county and knee arthroplasty surgery was a surprising and difficult-to-explain finding. In fact, this result may be the result of measurement error, but since the magnitude of the coefficient is quite small

(β=0.34) the overall predictive power of bed size for county knee arthroplasty utilization is rather inconsequential.

The most powerful predictor of knee arthroplasty utilization with respect to estimated marginal effect was insurance coverage. This finding was not surprising considering that the procedure is elective and expensive, so insurance coverage provides an important mechanism of access to patients in need of knee replacement. A 1% increase in the rate of the uninsured was found to be associated with 642 fewer procedures per 100,000. This finding is even more interesting when considered in the context of a decade of declining rates of health insurance coverage. Although knee arthroplasty utilization rates increased rapidly during the time period, particularly for the under 65 population (for whom uninsurance rates describe), these rates may have actually been depressed by record high uninsurance. Should healthcare reform succeed in expanding health insurance coverage to the non-elderly, we may observe additional increases in knee arthroplasty utilization rates.

The lack of significant findings for other covariates was unexpected. Many hypotheses were not supported by the analyses, especially those which assumed high utilization would be driven by county characteristics such as gender, race, and income. Prior research has found these factors to be strong predictors of knee arthroplasty utilization, and the differences in these results may be caused by use of a different study methodology. While this study examined utilization of knee arthroplasty by all payers, most of the prior literature examined only Medicare discharges. [63, 111, 114, 117, 138, 140, 176, 177] This difference in approach has several implications for the difference in findings. First and most obviously, utilization among younger patients is captured in my study but not those of Medicare only data. In fact, estimation of county variation in utilization could be substantially affected by the inclusion of these cases in the dependent variable, given the recent increase observed in utilization for this age group. Furthermore, covariates representing county characteristics (for all residents) may be more appropriate and precise in a model of utilization of all residents than only Medicare, and this difference could produce different results. Alternatively, the difference in sample size between studies (only North Carolina counties in this study versus all U.S. counties) may affect results.

Obesity was not found to be a significant predictor of knee arthroplasty utilization in this study. This finding may be related to the increased risk of complication or poor outcomes associated with obesity. In fact, obesity may have a negative relationship with knee arthroplasty utilization, as providers may choose to avoid cases with higher risk of complication. However, the same relationship may not exist for overweight and future research may benefit from inclusion of an indicator of county proportion overweight; such a variable was not available at the time of this study. Moreover, the variable used for obesity prevalence was estimated from the BRFSS and may not be a precise measure of the condition at a population level for North Carolina counties.

Figure 48. Knee Arthroscopy Discharges, NC 1997 - 2006

Year	Frequency
1997	10,445
1998	9,741
1999	9,242
2000	9,384
2001	8,692
2002	6,428
2003	5,690
2004	5,401
2005	4,362
2006	2,970

Source: NC Ambulatory Surgery Center and Inpatient Hospital Discharge Databases, 1997 - 2006.

Utilization of knee arthroscopy was not found to be a significant predictor of TKA use in this study. While the idea that arthroscopy may induce or expedite need for total knee replacement makes sense theoretically and clinically, several factors may have resulted in an insignificant finding. First, in the absence of information to guide development of the measure, a three-year lag was used in constructing knee arthroscopy utilization; however, this lag period may not be adequate. Second, analysis of knee arthroscopy in the discharge data showed a rapid decline in the number of knee arthroscopy procedures performed between 1997 - 2006, likely the result of growing evidence of marginal clinical benefit (Figure 48). [28, 29] By 2008, the year modeled in this cross-sectional multivariate spatial analysis, the number of procedures was likely too small in most counties to produce statistically significant effects. This trend of considerable longitudinal variation also explains why knee arthroscopy was found to be the only statistically significant variable in the change model; no other independent variable had such strong measured change between 2004 and 2008. Furthermore, the lack of statistically significant results in the 2004-2008 change model indicated that, while county-level population and provider factors are useful in explaining geographic variation in TKA use, changes in those factors was not associated with the dramatic change in TKA utilization during the same time period.

The detection and treatment of statistically significant spatial autocorrelation represents an important methodological improvement in ecological analysis of healthcare utilization data. While ecological analysis is imperfect and sometimes criticized for being underpowered and potentially biased, some questions are simply unanswerable using other levels of analysis due to data availability.[178] Understanding and parsing out the spatial relationships in multivariate analysis allows for more efficient and consistent estimation of the influence of covariates on healthcare use at a population level. Still, spatial data analysis has limitations which are discussed in more detail later in this chapter.

5.2. Implications for Quality, Access, and Costs

The increase in utilization of knee arthroplasty has considerable economic implications, both direct and indirect. Medicare remains the preeminent payer for knee replacement surgery in North Carolina, and the increase in procedure volume has a commensurate increase in cost to society through Medicare and Medicaid expenditures. This study found the overall and surgical costs associated with inpatient knee arthroplasty escalated during the study period, thus exacerbating the economic burden of the increase in utilization. In 2000, the average inpatient charges for a hospital stay involving knee arthroplasty in North Carolina was $28,347 (in 2009 dollars); by 2009, charges had increased by 34% to 37,885, even after adjusting for inflation. Even more remarkable was the observed increase in inpatient charges for surgical procedures, which rose by 68% during the study period from $5,790 to $9,733 (both in 2009 dollars). Pre- and post-hospital care including imaging and rehabilitation were not possible to analyze with available data, so these figures underestimate the total cost of care for knee arthroplasty. However, analyses of the cost of care, particularly cost-benefit studies, should also take into account the medical expenses avoided by knee arthroplasty in order to attain a comprehensive understanding of the economic impact of the procedure.

Given the escalating costs associated with knee arthroplasty utilization increases, public and private insurers have begun to consider alternative payment approaches for knee arthroplasty such as bundled payment. Bundled payment builds on the capitation strategy, but folds reimbursement for providers and institutions into one payment. In 2009, two demonstration programs began testing bundled payment for knee arthroplasty including PROMETHEUS Payment, Inc., and in Medicare through the Acute Care Episode (ACE) Demonstration [179]. Bundled payment has become a popular concept since being identified in the Patient Protection and Affordable Care Act (PPACA) of 2010 and the strategy has shown promise in reducing spending for some procedures such as coronary artery bypass graft (CABG). [179-182] However, implementation is complicated and healthcare providers are not universally enthusiastic to participate. Determining the appropriate providers, services and timeframe of a bundle can be challenging for insurers, and risk-adjusting is important to prevent financial harm to the providers caring for the sickest patients. [179] Still, knee arthroplasty is thought to be a suitable procedure for bundled payment because the episode of care is fairly predictable and complications are rare. As such, additional insurers are likely to follow suit and test bundled payment as utilization continues to increase and expenditures burgeon. Furthermore, it is likely that private insurers may pass along some of the increasing cost to consumers by making price adjustments in age-banded insurance premiums.

The observed increase in utilization of knee arthroplasty for individuals under 65 may create additional downstream financial implications. Prior research has shown that the durability of prosthetic knee joints is worse in younger patients [27, 35-38]; younger patients have been shown to have a higher need for revision knee arthroplasty due to a more active lifestyle and longer life expectancy post-surgery. Between 2000 and 2009, the number of patients under 65 years old more than nearly tripled, and growth in utilization of knee arthroplasty for this age group far outpaced the over 65 year old group. Meeting the future demand for revision surgery not only requires financial resources, but also workforce planning to ensure an adequate orthopedic surgical workforce. However, workforce planning is difficult because of uncertainty about prosthesis survival in younger patients. Until recently the procedure has been used primarily in elderly patients, thus survival curves and studies of revision surgery may not accurately predict outcomes for younger patients. It will be important to follow changes in the survival curves for patients receiving knee arthroplasty over the past decade to assess whether outcomes are different for this younger and, potentially more active, cohort of patients. In general, younger patients have less comorbidity at the time of surgery and more years afterward that could positively affect outcomes and extend the life of the prosthesis [39-41]. However, a more active lifestyle could accelerate aseptic loosening or lead to traumatic joint injury and require earlier revision [27, 35-38]. In both cases, it is certain that nonelderly patients have a higher likelihood of revision knee arthroplasty which will affect costs and the orthopedic surgical workforce in coming decades. However, if surgeons are avoiding more complex cases in order to maximize patient volume, outcomes may, in fact, improve overall.

Outcomes for knee arthroplasty may also be affected by the increase in comorbidities among patients undergoing the surgical procedure. Risk of complications increases with more comorbidity[19], and this study found a 9% increase in the presence of at least one major health condition among knee arthroplasty patients between 2000 and 2009. It is of special interest that diabetes increased by 7% in the study period, as diabetes is often associated with and used as a proxy for obesity. As previously discussed, obesity is associated with worse outcomes due to greater aseptic loosening and mechanical stress, therefore the observed increase in comorbidity among knee arthroplasty patients may lead to worse overall outcomes for the procedure. [36, 42-45]

Changes in the volume and geographic location of knee arthroplasty procedures have had a profound effect on physician and hospital caseload, which in turn has implications for quality of care. This study showed a dramatic increase in utilization of knee arthroplasty between 2000 and 2009, but the number of providers and hospitals performing the procedure changed very little during the same time frame. As such, the volume of knee arthroplasty procedures per surgeon and per hospital increased considerably during the study period. In general, this is regarded as a good thing. Prior research has established a link between hospital and surgeon volume and outcomes for knee arthroplasty, showing lower complication and readmission rates among providers with higher procedure volume [46-48, 166]. This study found that by 2009, 80% of all knee arthroplasty procedures in North Carolina were performed in hospitals with a minimum annual volume of 200 procedures.

High volume hospitals, performing at least 200 procedures per year, represent one-third of the hospitals performing knee arthroplasty in 2009. Similarly, 60% of all knee arthroplasty procedures were performed by surgeons who had a minimum annual volume of 50 procedures. These findings imply quality of care should be improving for knee arthroplasty, and also show that a natural process of centralization is occurring in North Carolina for knee replacement surgery. However, it will be important to monitor knee arthroplasty revision rates in the coming decades to assess whether increasing volume spread among the existing joint replacement workforce has had any negative impact on outcomes.

Centralization is a controversial idea which originates from an interest in directing patients to high-quality sites of care. Case volume has become a commonly discussed basis for organizing or centralizing healthcare services and establishing payment policy around "Centers of Excellence" due to the evidence linking outcomes and volume. In the case of knee arthroplasty, the concept is especially controversial because complications and mortality are very rare even at low volume centers, providing little justification for systematically excluding providers from the market and reducing patient access to services [46]. This dissertation found the volume of knee arthroplasty increased across nearly all types of institutions, but was especially strong in hospitals with 25-99 beds and may indicate development of a niche service in small hospitals. Niche service lines, including orthopedic surgery, can be a profitable specialty care service for small hospitals which offset other losses and keep the doors open. Formal regionalization or centralization of services, which directs patients to high volume hospitals or surgeons for knee arthroplasty, could have a detrimental effect on small hospitals with limited ability to achieve high volume standards required for payment in a formal regionalized system of care. However, the strategy does provide an opportunity to identify the providers with the best outcomes and most efficient practices; potentially excluding those surgeons with high rates of revision surgery and above average costs.

The effect of changes in knee arthroplasty utilization on access is difficult to evaluate. Knee arthroplasty is a procedure recommended for end stage knee osteoarthritis, a condition for which population prevalence data are not currently available. As such, it is impossible to assess how utilization of knee arthroplasty relates to need at a population level. While utilization is certainly not a trusted proxy for need in medical care, the finding of a consistent increase in utilization across space and over time suggests access to knee arthroplasty expanded for most areas of North Carolina. The age adjusted utilization rate increased in all but one county between 2000 and 2009, and the disparity in utilization between rural and urban counties narrowed considerably. Still, the persistent variation in utilization rates among counties remains of concern with regard to access, particularly for the counties with low utilization.

The findings of this study also have implications for workforce planning. While the increased volume of knee arthroplasty between 2000 and 2009 was generally accommodated by the existing orthopedic surgical workforce, it is unclear whether this is a sustainable pattern. Very little is known regarding the motivation of orthopedic surgeons for specializing in knee arthroplasty and whether they have the capacity to take on higher caseloads. It is also unclear whether more orthopedic surgeons, who have not had a high-volume of TKA are willing or able to increase their caseload of knee replacements. Increasing the training and production of surgeons skilled in performing knee arthroplasty may be necessary in order to adequately meet future demand, and should take these issues into consideration. Furthermore, workforce planning must also consider the impact of TKA subspecialization on the providers available to perform other orthopedic surgical procedures. It is important to comprehensively understand whether the observed increases in providers' knee arthroplasty volume has been at the expense of other cases, or whether these surgeons are simply working more hours and doing more procedures overall.

5.3. Limitations

This dissertation has several important limitations, primarily related to data and methodology. Data used to calculate knee arthroplasty utilization rates, from the North Carolina's Inpatient Discharge Databases, is constructed from claim forms used by hospitals to bill payers. This dataset only captures utilization in North Carolina's short-term acute care hospitals. Utilization by residents in military and federal hospitals or in facilities in other states is not included in this study, and the omission of these procedures causes underestimation of utilization. As such, low utilization of knee arthroplasty should be interpreted with some caution. This is especially true for border counties, because residents may cross into neighboring states for hospital care. Rates may be biased and underestimate utilization in the counties where residents commonly cross state borders, such as the northeastern, western, and northwestern parts of the state. Bias in utilization rates due to utilization in military or federal hospitals is largely mitigated by using only civilian population estimates in calculating rates, but may cause some underestimation in counties surrounding the state's three military bases that have inpatient facilities. Those areas include Fort Bragg in Fayetteville (Womack Army Medical Center), Camp Lejeune in Jacksonville (Naval Hospital), and Seymour Johnson Air Force Base in Goldsboro (US Air Force Hospital). To address the problem of utilization leakage into other counties or across state lines, the rate of utilization for four "marker" conditions is included in multivariate analyses. The occurrence of these four conditions (appendicitis with appendectomy, acute myocardial infarction, gastrointestinal obstruction, and hip fracture) is generally considered to be insensitive to prevention efforts and therefore their admission rates are have been used as indicators of inpatient use absent the influence of access factors like socioeconomic advantage or provider supply. Utilization rates for "marker" conditions are employed in this study as a control for leakage, as the border crossing behavior should be similar for all hospital care. Leakage measured in utilization of "marker" conditions reduces the residual errors that would otherwise affect parameter estimates because of omitted variable bias.

Figure 49. Characteristics of Discharges That Do Not Link to Provider Licensure Data

Year	All Discharges	Unmatched Discharges	
		N	%
2000	7,742	951	12.3%
2001	8,888	680	7.7%
2002	9,947	611	6.1%
2003	10,877	1,025	9.4%
2004	12,436	863	6.9%
2005	14,391	1,041	7.2%
2006	15,169	839	5.5%
2007	16,721	1,213	7.3%
2008	17,917	899	5.0%
2009	18,411	744	4.0%
Total	**132,499**	**8,866**	**6.7%**

Miscoding is another concern in the NC Discharge database. Variables that are essential for payment, such as diagnosis and procedure codes, are less likely to have errors than non-essential variables such as provider identifier and patient demographics. During the course of a hospital visit, patients are commonly managed by multiple doctors and the surgeon is but one among them. Due to provisions of the NC Inpatient Discharge data use agreement, only one provider identification number is included in the dataset, thus limiting the ability to match all discharges to surgeons. Despite this problem, the process of linking knee arthroplasty discharges to providers in the NC Physician Licensure file yielded a high match rate overall; approximately 93% of all knee arthroplasty discharges were matched to an orthopedic surgeon (Figure 49). Because knee arthroplasty is a procedure that is only performed by orthopedic surgeons, all discharges linked to physicians of other specialties were excluded from the analysis of providers. Patient characteristics of the excluded discharges were compared to the total sample and no notable differences were detected among the excluded discharges (Figure 50). However, when the location of care was examined it became apparent that the excluded discharges were most commonly associated with large tertiary care hospitals. Approximately 50% of the discharges that were excluded from provider analysis were performed at five hospitals including NC Baptist in Winston-Salem, Forsyth Medical Center in Winston-Salem, Carolinas Medical Center in Charlotte, Rex in Raleigh, and Carolina East Health System in New Bern. This finding suggests that the volume of providers who practice in these facilities may be underestimated because surgeries they performed were not linked through discharge analysis. The mismatching of provider IDs also prevented analysis of subspecialization trends among providers during the time period, as there was no way to be sure that the discharges associated with orthopedic surgeons represented their true caseload.

Figure 50. Characteristics of Discharges Not Matched to Orthopedic Surgeons

	All Discharges	Unmatched Discharges
Number	132,499	8,866
Age Group		
Under 45	2.7%	3.7%
45-54	12.6%	14.3%
55-64	27.6%	29.1%
65-74	34.5%	31.5%
75-84	20.4%	19.1%
85+	2.6%	2.4%
Primary Payer (%)		
Public	61.8%	58.2%
Private	35.5%	38.7%
Other	2.7%	3.1%
Unknown	0.1%	0.0%
Female (%)	66%	66%
Mean Age (Years)	66	65
NC Residents (%)	95.8%	94.6%
Average Distance Traveled (Miles)	19.1	20.9
Elective Admission (%)	79.7%	79.3%
Mean Length of Stay (Days)	4.1	4.3
Charlson Score		
None	59.8%	58.5%
One	28.8%	28.6%
Two	8.5%	9.1%
Three +	2.9%	1.6%

A common problem in ecological studies is the potential bias and inconsistency of empirical findings that results from selection of a geographic unit and use of individual data to describe relationships at the population level. Research has shown that the magnitude and significance of correlations can change as geographic areas increase in size, thus findings are dependent on the scale of geography.[183, 184]   Although there is no solution for this problem, it is important to keep the issue in mind when interpreting regression results.

While this study adds to and potentially improves upon the body of literature describing factors that impact geographic and longitudinal variation in knee arthroplasty surgery, data limitations continue to stymie researchers who yearn for rich patient data at a national level, such as could be collected by a Joint Registry.[185] Future research should build upon spatial analysis techniques employed in this study while expanding the geographic area included in the study.

5.4. Conclusions

This purpose of this dissertation was to examine whether geographic variation in knee arthroplasty utilization can be explained by population or provider-related factors, and the analyses showed that both are important in predicting county rates of TKA. Multivariate spatial regression analysis of knee arthroplasty utilization in 2008 showed that the most significant predictors of county TKA use include the percent of the population that is uninsured, the supply of primary care providers per 100,000 persons, the presence of a hospital performing a high-volume of TKA procedures, the number of skilled nursing facilities, and the number of hospital beds. These results indicate that healthcare market factors and population characteristics are both important in explaining use of knee arthroplasty.

This dissertation also identifies trends in how the characteristics of patients receiving knee arthroplasty has changed in recent years, and describes how the orthopedic surgical workforce and hospitals have adapted to accommodate increasing demand for the procedure. This dissertation also improves upon methods for small area analysis and geographic variation. Using spatial analysis techniques, the study describes patterns of utilization and provider supply for knee arthroplasty, and estimates the effect of community characteristics on local utilization of TKA.

Findings from this study suggest that outcomes for knee arthroplasty may change in the future as the number of nonelderly patients receiving the procedure increases and providers expand their caseload. Future research might explore whether the recent changes in knee arthroplasty utilization have affected a change in outcomes or quality. This study shows that county characteristics, particularly those describing provider supply and to a lesser extent the area's population, are useful in explaining geographic variation in TKA utilization. Health insurance coverage, the ratio of primary care providers to population, and the presence of a hospital performing a high volume of knee arthroplasty were identified as the most useful predictors of TKA utilization in a cross-sectional analysis of 2008 data. However, changes in county characteristics were not associated with the dramatic and concurrent increase in TKA utilization. The current focus on expansion of health insurance coverage and interest in regionalization of hospital care, via the PPACA, may influence future rates of knee arthroplasty through these conflicting mechanisms of access. As knee arthroplasty utilization seems poised for continued growth, it will be important to carefully monitor the adequacy of the orthopedic surgical workforce to accommodate more demand and to begin assessing whether the increased demand has had effect on outcomes for population subgroups, providers, or institutions.

This study was conducted with approval (study # 10-0301) by the Institutional Review Board at the University of North Carolina at Chapel Hill.

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