READMISSION RISK, RATE, AND COST-EFFECTIVENESS OF USING COMMERCIALLY AVAILABLE BUNDLED PAYMENTS FOR TOTAL HIP ARTHROPLASTY AMONG WORKING-AGE PATIENTS

by

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ABSTRACT

SUBHANWITA GHOSH. Readmission risk, rate, and cost-effectiveness of using commercially available bundled payments for Total Hip Arthroplasty among working-age patients. (Under the direction of DR. AHMED A. ARIF)

Hip osteoarthritis is a common form of osteoarthritis causing work disability. Total hip arthroplasty (THA) is the treatment for hip osteoarthritis when primary treatments fail. THA is associated with a high cost, success, and improved quality of life and its utilization is exponentiating worldwide. The bundled payment program under Medicare was cost-effective and reduced the remission risk and readmission rate for patients over 64 years old undergoing THA. Some hospitals and insurers attempted to implement commercial bundled payment for THA. The research investigating the effectiveness of the commercial bundled payment failed due to managerial and legal barriers, and low data availability. In this study, I hypothesized that the working-age patients undergoing THA under commercial bundled payment have lower unplanned readmission risk and unplanned readmission rate than those under non-bundled payment. Additionally, I hypothesized that the commercial bundled payment for working-age patients undergoing THA provides more days between THA and readmission, and it is more cost-effective compared to those under non-bundled payment. The unplanned readmission risk after THA among working-age patients using commercial bundled payment and non-bundled payment was examined by unadjusted and adjusted logistic regression followed by two propensity score matching analyses: nearest neighborhood matching and inverse probability weighted analysis. I compared the post-THA rate and rate ratio of unplanned readmission among working-age patients between bundled and non-bundled payment groups using negative binomial regression followed by marginal effect analysis. The association of commercial bundled payment

on the count of days and the total cost between unplanned readmission compared to non-bundled payment was analyzed by unadjusted and adjusted regression analyses, followed by an incremental cost-effectiveness ratio analysis. I downloaded the data for this study from the electronic health record system of OrthoCarolina. A total of 2774 working-age patients had THA within the specified period and were included in the study. I found that the risk of unplanned readmission after THA among working-age patients was lower (Unadjusted:4%, Adjusted:10%) in the bundled payment group compared to the non-bundled payment group. The rate ratio for unplanned readmission in the commercial bundled payment group was 19% and 24% lower in unadjusted and adjusted analyses respectively, compared to the non-bundled payment group. However, due to the small sample size, the result failed to achieve statistical significance. The bundled payment group got more days between THA and unplanned readmission (unadjusted: 18.55, SE=11.6, P-value=0.110 and unadjusted: 12.87, SE=12.99, P-value=0.322) and was associated with higher costs compared to the non-bundled payment group. Even though the bundled payment was costlier, it was more effective than the non-bundled payment group. This study highlights the importance of commercial bundled payment programs. It may encourage policymakers to reevaluate and possibly expand the use of commercial bundled payments for working-age patients undergoing THA. Revising contractual agreements to include healthcare supplies within this coordinated care model could lower costs.

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LIST OF ABBREVIATIONS

ACS NSQIP	American College of Surgeons National Surgical Quality Improvement Program
AS	Ankylosing Spondylitis
ATET	Average Treatment Effect on the Treated
AVN	Avascular Necrosis
BMHSU	Behavioral Model of Health Services Use
BMI	Body Mass Index
CCR	Cost-to-Charge Ratio
CDC	Centers for Disease Control and Prevention
CEAC	Cost-Effectiveness Acceptability Curve
CJR	Comprehensive Care for Joint Replacement
CMS	Centers for Medicare & Medicaid Services
CPT	Current Procedural Terminology
CT	Computed Tomography
GDP	Gross Domestic Product
HRRP	Hospital Readmission Reduction Program
ICD-10	10th revision of the International Classification of Diseases
ICER	Incremental Cost Effectiveness Ratio
IPW	Inverse Probability Weights
IRR	Incidence Rate Ratio
MRI	Magnetic Resonance Imaging

OA	Osteoarthritis
PSM	Propensity Score Matching
RA	Rheumatoid Arthritis
SQL	Structured Query Language
THA	Total Hip Arthroplasty
THR	Total Hip Replacement
TJA	Total Joint Arthroplasty
TJA	Total Joint Arthroplasty
U.S.	United States

CHAPTER 1: BACKGROUND OF THE RESEARCH

Introduction

The Centers for Disease Control and Prevention (CDC) reported that according to the National Health Interview Survey data, from 2019 to 2022 about 53.2 million adults in the United States (US) were annually diagnosed with arthritis by their healthcare provider (Centers for Disease Control and Prevention, 2023c). The prevalence of physician-diagnosed arthritis according to the National Center for Health Statistics, National Health Interview Survey, 2022, was 53.9%, 44%, 29%, and 3.6% in patients aged 75 and older, 65 to 74, 50 to 64, and 18-44, respectively. Arthritis predominantly affects women, approximately 21.5% higher than in men (Centers for Disease Control and Prevention, 2022). The projected number of US adults aged 18 years or older having physician-diagnosed arthritis is going to increase by 49% by 2040 from 2010-2012 (Kristina A Theis, 2021). It is the leading joint disease causing chronic pain and disabilities (Mehta et al., 2019). In the US, 33 million adults are affected by osteoarthritis and occurs mostly in the hands, hips, and knees (Centers for Disease Control and Prevention, 2024a). Among all types of osteoarthritis, hip osteoarthritis (OA) is the most common in the world (Centers for Disease Control and Prevention, 2024a, 2024b; Loppini, Pisano, Gandolfi, Morenghi, & Grappiolo, 2021). The risk factors for osteoarthritis include injury, age, gender, race, obesity, and genetics. When treatments, such as increasing physical activity, medication, physical therapy, weight loss, and using supportive devices fail, surgery is used as a last resort (Centers for Disease Control and Prevention, 2024b).

Total Hip Arthroplasty

Total Hip Arthroplasty (THA), or Total Hip Replacement (THR), is a common elective surgical procedure for patients with end-stage osteoarthritis (Springer, Cahue, Etkin, Lewallen, & McGrory, 2017; Wylde, Marques, Artz, Blom, & Gooberman-Hill, 2014). Among all the surgical procedures in the United States, THA is the fourth most common surgical procedure (Mehta et al., 2019). THA is a cost-effective treatment for end-stage osteoarthritis that improves the quality of life(Jameson et al., 2015) by reducing pain and disabilities (Lavernia, Alcerro, Contreras, & Rossi, 2011). The survival rate of THA was found to be as high as 86% at 15 years, 79% at 20 years, and 78% at 25 years (Sodhi & Mont, 2019). Due to its high success rate and low mortality and morbidity risk, the utilization of THA has increased in an exponential rate worldwide (Daigle, Weinstein, Katz, & Losina, 2012). The number of THA cases per annum is about 370,000 in the United States, and the current projection estimates it will be as high as 635,000 by 2030 (Turan et al., 2023).

Bundled Payment Program for Increasing Access to THA

Surgery to treat osteoarthritis is expensive, and accounts for more than $6.2 billion in hospital costs (Centers for Disease Control and Prevention, 2021b). The average cost of implants used in THA ranges from $2,392 to $12,651, which is 87% of the total surgery costs (Gardezi et al., 2021). To increase access, the Centers for Medicare & Medicaid Services (CMS) enacted a bundled payment pilot program in 2011, as the Affordable Care Act specified (Whitcomb et al., 2015). The bundled payments encourage hospitals, physicians, and other healthcare providers to work together to deliver better patient care during and after discharge. This program, also known as episode-based payments, represents the projected cost reimbursement over the episode of care. The bundled payment is a replacement to the fee-for-service payment system (Whitcomb et al.,

2015). In fee-for-service, providers receive payments for individual courses of treatment. The fragmented billing for separate providers increases the cost and the likelihood of poor communication between the providers, compromising the overall health outcome and the quality of the care. The bundled payment program reduces the sky-rising care price by moving healthcare delivery away from the fee-for-service payment system, providing more coordinated care (Gruessner, November 10, 2015).

CMS implemented the Comprehensive Care for Joint Replacement (CJR) program in 2016 to provide quality care at a lower cost. CMS pays a fixed payment to the participating hospitals for all healthcare services like THA, from admission until 90 days after discharge for patients under Medicare.

Initiative to Increase Accessibility of THA for Working-age Patients

By 2030, it is expected that more than half of the THA patients will be younger than 65 (Soleimani et al., 2023), and hence not be covered by Medicare. American Academy of Orthopaedic Surgeons projected that, in 2023, 28% of the 572,000 THA patients were expected to be under the age of 55 (American Academy of Orthopaedic Surgeons, 2023). About 70% of the working-age population were able to return to work after THA (Soleimani et al., 2023). The rate of return to work increased to about 88% among those who could work before surgery and 28.1% for patients who could not work before surgery (Soleimani et al., 2023). According to the CDC, about 8 million working-age adults in the US complained of their inability to perform work due to arthritis (Centers for Disease Control and Prevention, 2021a). The working-age adults with arthritis have a higher rate of earning losses than adults without arthritis. An intervention to keep people with arthritis in a working state is needed (Centers for Disease Control and Prevention, 2021b).

Osteoarthritis was also declared the most expensive condition for patients hospitalized with private insurance, accounting for more than $6.2 billion in hospital costs (Centers for Disease Control and Prevention, 2021b). Some commercial health insurance providers have adopted similar surgical bundled payment programs and aim to provide quality care at lower costs while gaining better outcomes (Asche, Dagenais, Kang, Ren, & Maurer, 2019). Though the bundled payment program for elective surgery among Medicare patients was successful, the effect of the bundled payment is barely known for the patients under commercial insurance, who pay considerably higher prices than Medicare-covered patients (Christopher M. Whaley, 2021; Christopher M Whaley, Dankert, Richards, & Bravata, 2021). The bundled payment has gained popularity among policymakers, hospital owners, and insurers as an attempt to lower and streamline all the costs utilized in an episode of care such as THA (P. M. Courtney, Ashley, Hume, & Kamath, 2016).

Readmission After THA: An Additional Cost Contributor

Though the success rate of THA is high, several reasons exist for failure, including periprosthetic joint infection, aseptic loosening, dislocation, and bone or implant fractures, leading to readmission for revision surgery to manage those problems (Aqil & Shah, 2020; Springer et al., 2017). The readmission rate for surgical site infection after arthroplasty is 18.8% in the USA. Despite the attempt to provide quality care at a lower cost, in some cases, the failure of THA leads to patient dissatisfaction, readmission, and revision surgery, thereby increasing the cost of care (Epinette, Lafuma, Robert, & Doz, 2016). One of the indicators of a hospital's quality of care is readmission rates. The 30-day readmission rate after THA has been used as an indicator of a hospital's performance (Ali, Loeffler, Aylin, & Bottle, 2017). The American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) argued that 30-day

readmission is truncated due to the follow-up period issue, and one cannot be readmitted unless they are discharged. In most cases, THA patients require therapeutic treatment after surgery and in some cases, require prolonged visitations. Considering the THA as an episode of treatment, it includes not only the surgery but also aftercare therapies and post-surgery evaluation. Within this period the readmission is overlapped with the primary THA episode and thus the data might not show the readmission as a separate treatment episode. In that case, 90-day readmission can be a better measurement. Also, the 90-day readmission rate analysis captures a higher percentage than the 30-day readmission rate (among Medicare patients, the 30-day readmission rate is 19%, and the 90-day readmission rate is 34%)(Lucas & Pawlik, 2014). Identifying the risk factors for poor outcomes, such as readmission, has become important due to the quality of patient care and economic reasons (Tiberi, Hansen, El-Abbadi, & Bedair, 2014).

Readmission After THA: A Measure of the Quality of Care

Readmission after initial hospitalization is a costly event that questions the quality of care. CMS recommends including readmissions after THA under the umbrella of their Hospital Readmission Reduction Program (HRRP) (Merkow et al., 2015). Reducing the risk of readmission has become a priority and important criterion for healthcare quality in the United States. In 2014, the Hospital Readmissions Reduction Program (HRRP) under the Patient Protection and Affordable Care Act (ACA), included THA for penalizing excessive readmission after surgery (Ramaswamy et al., 2019). The 30-day window of readmission has become a standard for analyzing the readmission rate. The 30-day all-cause readmission after major hip surgery is 9.9% and after other hip surgery is 17.9%, accounting for 1.5% and 0.8% of all rehospitalizations, respectively. The causes of readmission mainly include aftercare, major hip or knee problems, postoperative infections, hip and knee fractures along with pneumonia,

gastrointestinal bleeding, and urinary tract infections (Lucas & Pawlik, 2014). Despite the high success rate for THA, 25% of the unplanned readmissions were caused by other medical causes, and 75% were caused by post-operative complications. Additionally, half of the postoperative complications that resulted in readmission were avoidable (Schairer, Sing, Vail, & Bozic, 2014).

Surgical Optimization Before THA to Optimize the Outcome

Besides the non-modifiable patients' characteristics, other characteristics can be modified to get better treatment outcomes. Readmission after a surgical procedure is the most undesired outcome. It is an indicator of the quality of the care (Schairer et al., 2014). To ensure that the patient is in the best condition for surgery, the patient needs to go through patient optimization. Patient optimization is a critical aspect to be considered by the surgeon for quality care. This process begins with the history and physical examination, obtaining the correct measures to minimize the risk of complications before surgery (Cole, Familia, Miskimin, & Mulcahey, 2022). Smoking is strongly associated with pulmonary and cardiovascular diseases and increases the risk of postoperative morbidity and mortality. Smoking cessation is highly recommended in the week before surgery. The patients should be screened for smoking before scheduling the surgery to allow patients to get smoking cessation education and resources(Vu & Lussiez, 2023). Clinically obese people are defined as people with a BMI ≥ 30 kg/m2, and the severe condition is a BMI ≥ 40 kg/m2. Obesity affects the natural healing process due to insufficiency in the vascular system and prolonged inflammatory stage, which places obese people at higher risk of postoperative infection. The lower micronutrients and macronutrients in obese people also cause delayed healing(Pierpont et al., 2014). Among all the orthopedic cases, 12% of the patients are diagnosed with diabetes. Patients with diabetes are at higher risk of orthopedic injury and complications with healing and rehabilitation (Stolarczyk, Sarzyńska, Gondek, & Cudnoch-

Jędrzejewska, 2018). Approximately, half of the patient with diabetes suffers from severe hip and knee arthritis, which requires total joint arthroplasty (Shichman et al., 2023). Diabetes is a prevalent comorbidity among patients undergoing hip surgery. This comorbid condition is associated with postoperative complications (Heimroth et al., 2023; Lovie, Clement, MacDonald, & Ahmed, 2022; Singh et al., 2021), such as surgical site infection, periprosthetic infection, and loosening of implants, leading to a longer hospital stay and higher expenses as a consequence.

Research Model

The most frequently used model of healthcare service utilization is the Behavioral Model of Health Services Use (BMHSU), developed by Ronald M. Andersen in the 1960s (Andersen, 1995; Lederle, Tempes, & Bitzer, 2021). Since then, the model has been modified many times. The recent one, developed in 2013, focuses on access to healthcare, which is determined by contextual characteristics, individual characteristics, health behavior, and outcomes (Lederle et al., 2021). In my research model, the contextual characteristics were defined by the environment, that was, orthopedic healthcare. The individual characteristics were defined by demographic characteristics such as age, sex, and race, enabling factors such as insurance coverage, employment, and bundled payment. The individual characteristics also included the needs of the patients, such as treatment of Primary osteoarthritis (OA), Ankylosing spondylitis (AS), Avascular necrosis (AVN), Rheumatoid arthritis (RA), and trauma, which lead to Total Hip Arthroplasty (Kumar, Sen, Aggarwal, & Jindal, 2020). Health behavior is defined by the individual's behavior or lifestyle that affects health and healthcare use. For this research, I focused mainly on readmission rate, readmission risk, and Incremental cost-utility ratio as outcomes (FIGURE 1). Due to data unavailability, I had to concentrate only on unplanned readmission due to orthopedic reasons.

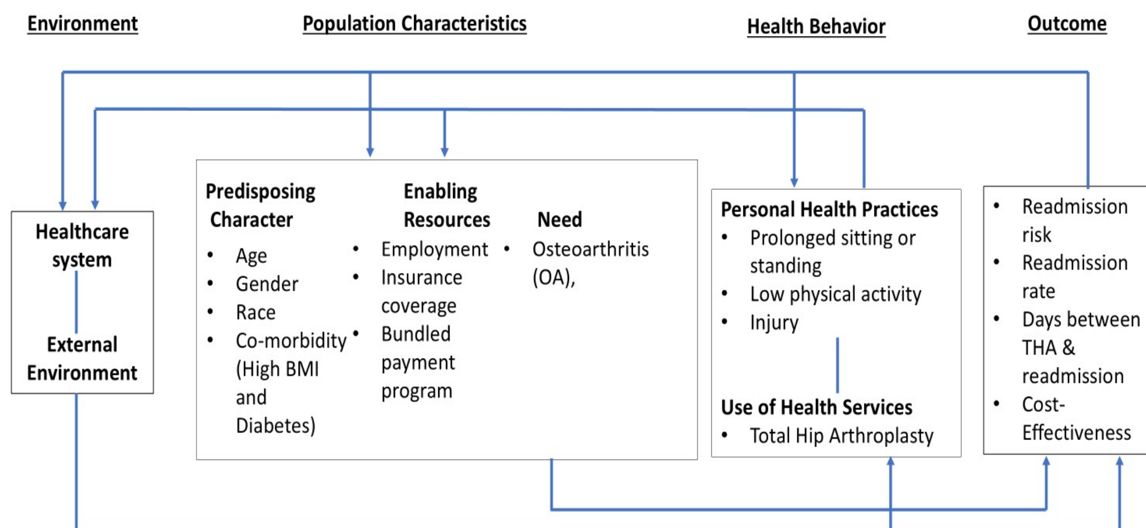

FIGURE 1: BMHS of readmission rate, readmission risk, and cost-effectiveness ratio of bundled payment for working age population

Purpose of the Study

Arthritis is increasing exponentially worldwide. Osteoarthritis is the most common among all kinds of arthritis and affects hands, hips, and knees. Hip osteoarthritis is the most prevalent form of osteoarthritis. Not only elderly people above 64 years old but younger adults are also diagnosed by doctors with osteoarthritis in increasing numbers. Osteoarthritis impacts workability and quality of life by causing joint pains and disabilities. THA or THR is the common elective procedure to treat hip osteoarthritis when all other primary treatments fail. The number of THA cases among working-age adults (18 -64 years old) is increasing and is projected to be more than half of THA cases by 2030. While THA is a costly procedure, unplanned readmission after THA increases the treatment cost even more. Monitoring readmission risk after

THA is important for assessing the success of THA and managing the health care cost. The readmission risk after THA among older Medicare patients is well-documented. The study on the readmission risk of working-age patients after THA is scarce. Another key measure of healthcare quality and outcome is the readmission rate. Reducing the readmission rate is a potential factor for both improving care quality and lowering costs. Like readmission risk, the studies on readmission rates for working-age patients after THA are limited.

Bundled payment programs under Medicare aim to reduce these high costs by moving away from fee-for-service models. It is a coordinated care program that encourages providers to work together as a team. Evidence shows that bundled payments for Total Joint Arthroplasty (TJA) under Medicare effectively reduced hospital stays, readmissions, and rehabilitation, thus effectively lowering the costs of treatment. Some commercial insurers also adopted bundled payment models to reduce costs and enhance healthcare quality. Implementing commercial bundled payment for THA was challenging and very limited data was available. While the bundled payment systems have been successful for Medicare beneficiaries, the effectiveness of commercial bundled payment for THA in reducing readmission risk, readmission rate, and cost was not well studied.

My dissertation aimed to assess the effectiveness of commercial bundled payment in reducing the risk and the readmission rate after THA among the working-age population (18-64 years old) compared to non-bundled payment. I also examined the cost-effectiveness of commercial bundled payment for the working-age population (18-64 years old) who underwent THA.

The specific hypotheses for this study are:

1. The working-age patients (18- 64 years old) under Bundled payment have lower unplanned readmission risk compared to those under regular payments adjusted for age, gender, race, and pre-existing conditions.

2. Post-THA unplanned readmission incident rates and incident rate ratio among working-age patients (aged 18-64 years) are lower among patients with bundled payment programs than non-bundled payments adjusted for age, gender, race, pre-existing conditions such as diabetes, smoking habit, and being overweight
3. A. Using the commercial bundled payment for THA, the working-age (18-64 years old) patients have a longer time before unplanned readmission, that is, the time between index THA and any unplanned readmission after index THA compared to the regular payment.

   B. the THA under commercial bundled payment is cost-effective, as measured by ICER, for working-age patients (18-64 years old) compared to the regular payment.

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CHAPTER 2: READMISSION RISK FOR TOTAL HIP ARTHROPLASTY (THA) PATIENTS YOUNGER THAN 65 YEARS OLD UNDER COMMERCIALLY AVAILABLE BUNDLED PAYMENT

Introduction

Arthritis includes medical conditions that affect the joints, tissue around the joints, and connective tissues. According to the Centers for Disease Control and Prevention (CDC), between 2013 and 2015, about 58.5 million adults in the United States (U.S.) were diagnosed with arthritis by their healthcare providers. The number is projected to increase by 49% by 2040 from 2010-2012 (Kristina A Theis, 2021). According to the National Center for Health Statistics, National Health Interview Survey, 2022, 53.9% of adults were above 74 years and older, 44% of adults aged 65 to 74 years, 29% of adults aged 50 to 64 years, 11.5% of adults aged 35 to 49 years, and 3.6% of adults aged between 18 to 34 years are diagnosed with arthritis by their doctors. Arthritis mainly affects women, about 21.5% higher than the male counterpart (Centers for Disease Control and Prevention, 2022).

Arthritis is classified into one of several types (Centers for Disease Control and Prevention, 2023b). The most common form of arthritis is osteoarthritis, which affects about 33 million adults in the US. Osteoarthritis, the leading joint disease causing chronic pain and disabilities, frequently affects the hands, hips, and knees(Centers for Disease Control and Prevention, 2024a; Mehta et al., 2019). Hip osteoarthritis (OA) is the most common worldwide (Loppini et al., 2021). Age, gender, race, obesity, and genetics are the major risk factors for developing osteoarthritis. Surgery is the last resort when all the treatment options, such as increasing physical activity, medication, physical therapy, weight loss, and supportive devices, fail (Centers for Disease Control and Prevention, 2024a). Total Hip

Arthroplasty (THA), or Total Hip Replacement (THR) is a common elective surgical procedure to treat end-stage osteoarthritis (Springer et al., 2017; Wylde et al., 2014). In the U.S., THA is the fourth most common elective surgical procedure(Mehta et al., 2019). THA improves the quality of life (Jameson et al., 2015) by reducing pain and disabilities (Lavernia et al., 2011) and is a cost-effective treatment for end-stage osteoarthritis(Jameson et al., 2015).

In the past decades, total joint arthroplasty (TJA) in younger patients (younger than 65 years old) has increased. A recent study projects that by 2030, THA in patients below 65 years old will exceed more than 50% of total Joint Arthroplasty (TJA) (Soleimani et al., 2023). Females have a higher prevalence of osteoarthritis and related disabilities compared to men (Götz et al., 2021; Haughom, Erickson, Hellman, & Jacobs, 2015; Lavernia et al., 2011) and are at higher risk of complications after THA than male patients(Haughom et al., 2015). The anatomy and development during the aging of the femoral bone are different in females than in males. Structural differences include bone size, femoral offset, proximal femoral shape, and trabecular pattern (A. J. Johnson, Costa, & Mont, 2011; Kostamo, Bourne, Whittaker, McCalden, & MacDonald, 2009). Moreover, females lose more hip bone during aging than males (Kostamo et al., 2009).
Previous studies have shown racial disparities in access to TJA, specifically THA, and the outcomes such as lower THA utilization but higher readmission risk in blacks and Hispanics than whites (Okike et al., 2019), higher rate of postoperative complications leading to readmission were also found in blacks and Hispanics than whites. African American patients are less likely to utilize THA and are more likely to experience postoperative complications following THA and TJA (Okike et al., 2019). Also, 30-day readmission rates are higher

among Black and Hispanic compared to White patients (M. A. Johnson et al., 2020). Post-THA care for Black patients requires more resources, and thus, the cost of the episode-of-care was increased compared to other races. Higher comorbidities and complications among Black patients may play an important role in increasing the cost of care (Chisari et al., 2021). The racial disparities in healthcare utilization after THA may also be a result of socio-economic disadvantages (Hadad et al., 2023), preoperative functional status, and inequality in access to care (Alvarez et al., 2022).

Readmission after THA is costly and is usually caused by various surgical and medical complications. Almost 75% of readmission cases are due to surgical complications, including dislocation, surgical site infection, and postoperative hematoma. (Schairer et al., 2014). The readmission for further surgical intervention after THA is one of the essential measures for the success of arthroplasty (Tiberi et al., 2014). Despite THA being a procedure with higher survivorship and low morbidity and mortality, total joint infection is associated with mortality and morbidity (Springer et al., 2017). Identifying the risk of poor outcomes, such as readmission, is important for the quality of patient care and economic reasons. (Tiberi et al., 2014).

In 2011, the Centers for Medicare & Medicaid Services (CMS) implemented a bundled payment pilot program as the Affordable Care Act specified to increase access (Whitcomb et al., 2015) to costly treatments like surgery for osteoarthritis. The bundled payments encourage physicians, hospitals, and other healthcare providers to coordinate to deliver better quality of care (Whitcomb et al., 2015), and it reduces the sky-rising care price by moving healthcare delivery away from the fee-for-service payment system (Gruessner, November 10, 2015). Some commercial health insurance providers have adopted similarly bundled payment

programs to provide quality care at lower costs while gaining better outcomes (Asche et al., 2019). A 10.7% relative cost reduction can be achieved using bundled payment for surgery (Christopher M. Whaley, 2021).

In an episode of care, the bundled payment covers the estimated total costs of an episode of treatment, which may include surgery, medication, MRI, CT scan, and hospital stay for a particular or defined episode of treatment for a patient (Gruessner, November 10, 2015). The hospital or the provider group presumes the clinical responsibilities and the associated costs in a bundle to provide quality treatment to the patient in defined episodes of care (Manner, 2019).

Previous research revealed that the bundled payment program under Medicare decreased the length of stay from 4.3 days to 3.6 days after joint replacement surgery (Iorio et al., 2016). The joint arthroplasty patients under Medicare Bundled payment with more than 4 days longer hospital stay had a higher 90-day readmission risk (Williams et al., 2017). Age was also a potential risk factor for unplanned readmission after THA in patients under Medicare Bundled payment. Patients aged 80-89 years who underwent THA had a 9% higher risk of 90-day readmission compared to patients aged 65- 69 years old (Malkani et al., 2017). However, a study by Gold et.al. found no significant difference in unplanned readmission among Medicare Bundled and non-bundled payment groups who underwent THA (Gold, Magnuson, Venkat, Krueger, & Courtney, 2022).

Unlike the success of the bundled payment program for elective surgery among Medicare patients, the effect of the bundled payment on patients under commercial insurance, who are generally younger and who pay considerably higher prices than Medicare-covered patients (Christopher M. Whaley, 2021; Christopher M Whaley et al., 2021) is not well studied.

Moreover, the risk of readmission after THA among older people is well studied, but scant data is available on readmission risk among working-age patients (Franklin, Fehring, Odum, Lewis, & Ayers, 2015).

In this research, I hypothesize that working-age patients (18- 64 years old) under Bundled payment have lower unplanned readmission risk compared to those under regular payments adjusted for age, gender, race, and pre-existing conditions.

Methods

Data source: OrthoCarolina is one of the leading independent academic orthopedic care centers serving the southeast region of the U.S. The electronic health records (from July 15, 2021, to June 30, 2023) of OrthoCarolina patients were used for the current research. Primary demographics such as patients' gender, race, Body Mass Index (BMI), date of admission, and CPT codes and procedure description were obtained from the electronic data warehouse Epic by using SQL query and Epic Slicer-Dicer query. The primary outcome, readmission days, was calculated as the differences in days between the primary admission for THA (CPT code: 27130) and further all-cause unplanned readmission after THA.

Variables:

Dependent variable

Readmission (yes/ no): The difference between the dates of services of the encounter or admission for total hip arthroplasty and the second encounter of any cause unplanned readmission where applicable were calculated. If the readmission days had a non-zero value, the readmission was entered as "Yes", otherwise "No".

Independent variables

Patients' demographics:

Age: Patient age was calculated based on the differences between birth date and service date for THA in years.

Gender: Gender was recorded as identified at the time of the birth and coded as female=0, male=1.

Race: Self-reported race was grouped as white, black, or other.

Body Mass Index (BMI): BMI was calculated as the ratio of patients' weight in kilograms or pounds and the square of height in meters or feet. The variable was categorized as normal or healthy when BMI was <25, overweight when BMI was 25 to <30, and obese when BMI was 30.0 or higher (The Centers for Disease Control and Prevention, June 3, 2022).

Diabetes: The patient's diabetes status was downloaded directly from the electronic data system as "Yes"/ "No" responses.

Smoking status: Smoking status was self-declared by the patients and classified as former, current, or never.

<u>Exposure variable:</u>

Bundled payment: Patients who were included in a commercially available bundled payment program had a bundled ID. Based on the presence of that ID, patients were identified as either bundled patients or non-bundled patients.

Statistical analysis

Descriptive analysis: The sociodemographic and clinical characteristics of the dataset were explored by comparing the two payment groups using the chi2 test. A chi2 test analysis was performed to compare the sociodemographic and clinical characteristics of patients who had unplanned readmission and those who never had readmission.

Logistic regression: The effect of the payment program on readmission risk after THA was compared by univariate logistic regression. The impact of the payment program on readmission risk after THA was explored by adjusted and unadjusted logistic regression analyses.

Propensity score matching: The use of propensity score matching (PSM) to estimate the effect of treatment is increasing for observational data like the data used in this study. I used nearest neighborhood matching and inverse probability weighted matching PSM methods. At first, the propensity score for an individual patient was calculated as a conditional probability of using bundled payment adjusted for the patient's characteristics, followed by adjusted logistic regression to estimate the treatment effect of bundled payment and the odds of unplanned readmission in the bundled payment group.

I created the nearest neighborhood matching weights from the propensity score. I estimated the average effects of commercial bundled payment on unplanned readmission risk as a coefficient and an odds ratio by adjusted logistic regression using the weights created by nearest neighborhood matching. I performed the logistic regression to estimate the treatment effect of bundled payment and the odds of unplanned readmission in the bundled payment group using weights created by nearest neighborhood matching, adjusted for covariates.

I created the inverse probability weights (IPW) from the propensity score. The average effects of commercial bundled payment and odds of unplanned readmission risk in the bundled payment group were estimated by adjusted logistic regression using the IPW, followed by the estimation of average effects of commercial bundled payment and odds of unplanned readmission risk in the bundled payment group by logistic regressions using IPTW, adjusted for covariates.

I estimated the balance of covariates between bundled and non-bundled payment groups as standardized differences (matched standardized difference near 0 indicates balance) and variance ratio (matched variance ratio near 1 indicates balance). The density plots after both matching methods confirm the balance.

Results:

Descriptive Analysis

This study included 2774 patients who had undergone THA at OrthoCarolina between July 15, 2021, and June 30, 2023. Table 1 shows the distribution of the patients' characteristics compared between non-bundled and bundled payment groups. Among them, 2404 (86.66%) used non-bundled payments, and 370 (13.34%) used bundled payment. The mean age of patients under non-bundled payment was 55.36 years (+/-0.16 years), and of patients under bundled payment was 55.85 years (+/-0.3 years). Among the study population, 47.01% were female, of which 47.05% were under non-bundled payment, and 46.76% were under bundled payment. Among male patients, 52.95% were under non-bundled, and 53.24% were under bundled payment. White patients (77.14%) had undergone THA more than African American (16.94%) patients and patients from other races (5.91%). 75.37% of the white patients and 18.22% of black patients were under non-bundled payment, and 88.65% of white and 8.65% of black were under bundled payment. The differences in race of using bundled and non-bundled payment were statistically significant ($p<0.005$). A higher percentage of obese (56.56%) patients had undergone THA than the normal (14.24%) and overweight (28.48%) patients. The percentages of non-bundled users among normal, overweight, and obese were 14.23%, 27.66%, and 57.40% respectively. The percentages of bundled payment users among normal, overweight, and obese were 14.32%, 33.78%, and 51.08% respectively.

Among 339 diabetic patients who underwent THA, 13.06% used non-bundled payment, and 6.76% used bundled payment. Among the patients who never smoked (66.11%), 64.27% used non-bundled payment and 78.11% used bundled payment, among current smokers (7.97%), 8.74% used non-bundled payment and 2.97% used bundled payments, among former smokers (25.41%), 26.41% used non-bundled payments and 18.92% used bundled payments.

Table 1: Comparison of patients' characteristics between non-bundled and bundled payment group

Patients' characteristics	Total Obs (%)	Payment program		p-value
		Non-bundled	Bundled	
Total number of patients (%)	2774	2404 (86.66%)	370 (13.34%)	
Mean Age (+/- SD)		55.36 (+/-0.16)	55.85 (+/- 0.33)	0.250
Gender (%)				
Female	1304 (47.0%)	47.05%	46.76%	0.917
Male	1470 (52.9%)	52.95%	53.24%	
Race (%)				
White	2140 (77.14%)	75.37%	88.65%	<0.005
Black	470 (16.94%)	18.22%	8.65%	
Other	164 (5.91%)	6.41%	2.70%	
Body Mass Index (Kg/m2) (%)				
Normal (<25)	395 (14.2%)	14.23%	14.32%	0.088
Overweight (25 - <30)	790 (28.5%)	27.66%	33.78%	
Obese (30 and higher)	1569 (56.6%)	57.40%	51.08%	
Missing	20 (0.72%)	0.71%	0.81%	
Diabetes (%)				
No	2425 (87.42%)	88.52%	93.24%	0.001
Yes	339 (12.22%)	13.06%	6.76%	
Missing	10 (0.36%)	0.42%	0.00%	
Smoking Status (%)				
Never	1834 (66.11%)	64.27%	78.11%	<0.005
Current	221 (7.97%)	8.74%	2.97%	
Former	705 (25.41%)	26.41%	18.92%	
Missing	14 (0.50%)	0.58%	0.00%	

I compared the distribution of the patients' characteristics between unplanned readmission and no-readmission groups. The mean age of patients who never had readmission was 55. years (+/-0.2 years), and of patients who had unplanned readmission was 56.5 years (+/-0.8 years). Among the patients who had unplanned readmission, 48.57% were female, 81.43% were whites, 14.29% were blacks, 61.43% were obese, 27.14% were overweight, 11.43%

were normal weight patients, 85.71% had no diabetes, 75.71% never smoked, 8.57% were current smokers, and 15.71% were former smokers. Most of the patients (87.14%) with unplanned readmission were in the non-bundled payment group (Appendix Table 2.1).

Unadjusted and adjusted logistic regression

The unadjusted odds of unplanned readmission were 4% lower in the bundled payment group than in the non-bundled payment group (OR=0.96, 95%CI= 0.5, 1.9). After adjusting for age, gender, race, BMI, diabetes, and smoking status, the odds ratio of unplanned readmission in the bundled payment group was 10% lower than patients in the non-bundled payment group (OR= 0.90, 95%CI=0.4, 1.8) (Table 2). However, the results were not statistically significant (Appendix Table 2.2).

Propensity Score Matching:

With only 70 cases of unplanned readmission in the bundled payment group, I used 70 to 1 nearest neighborhood matching of the propensity score matching (PSM) to generate the weights (Appendix Table 2.3). The adjusted weighted odds of unplanned readmission after 70 to 1 nearest neighborhood matching decreased by 8% in the bundled payment group compared to the non-bundled payment group (Table 2). The adjusted weighted odds of unplanned readmission after IPW matching decreased by 4% in the bundled payment group than in the non-bundled payment group. (Table 2).

Table 2: The association of the bundled payment program with the risk of unplanned readmission after THA among working-age adults (unadjusted and adjusted for the independent variables)

Unplanned Readmission	Payment Program	
	Non-bundled Payment	Bundled Payment
Unadjusted		
OR (95% CI)	Baseline	0.96 (0.47, 1.94)
p-value	Baseline	0.905
Adjusted		
OR (95% CI)	Baseline	0.90 (0.44, 1.85)
p-value	Baseline	0.785
PSM (70:1 nearest neighbor matching)		
OR (95% CI)	Baseline	0.92(0.45,1.89)
p-value	Baseline	0.824
IPW		
OR (95% CI)	Baseline	0.96 (0.45, 2.04)
p-value	Baseline	0.920

In both PSM analyses, nearest neighborhood matching, and IPW, the average effect of using bundle payment on the patients who underwent THA was associated with lower readmission risk than patients without bundle payment, but not statically significant (Table 3).

Table 3: Risk of unplanned readmission among the patients who used bundled payment after 70:1 nearest neighborhood matching and after IPW matching

Unplanned Readmission	Coefficient (95%CI)	p-value
Bundled payment (ATET) after the nearest neighborhood matching	-0.0039(-0.023,0.016)	0.697
Bundled payment (ATET) after IPW matching	-0.0028 (-0.02,0.01)	0.752

Note: ATET is the average treatment effect on the treated. Here commercial bundled payment is used as the treatment.

While the small sample size limited my power to reach statistical significance, I assessed the balance in the propensity score matching analyses. Figure 1 shows the balance density plot after 70 to 1 nearest neighborhood matching. The matched plot of covariate balance in bundled and non-bundled overlapped. The balance density plot after inverse probability weighted matching

did not overlap much (Figure 2). I tested the over-identification of covariate balance for IPW matching and could not reject the null hypothesis (H_0= covariates are balanced).

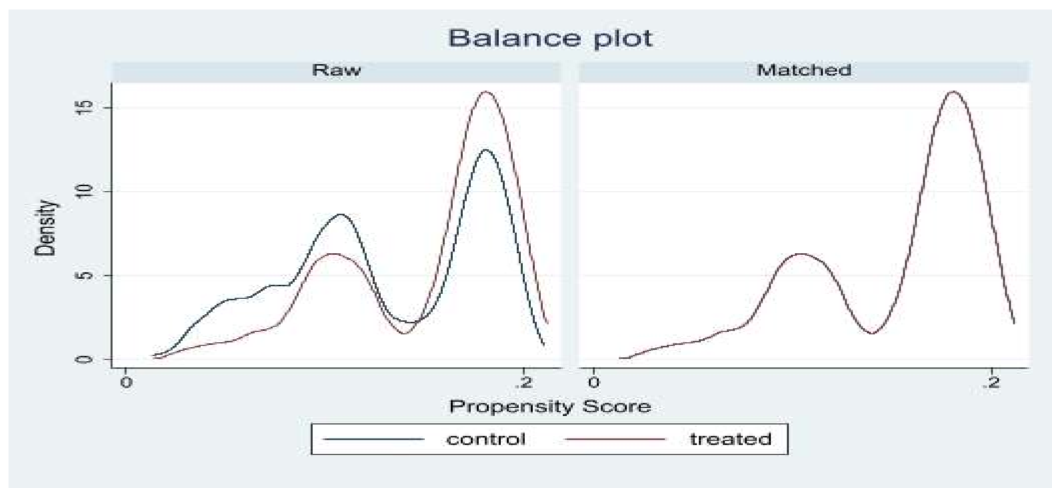

Figure 1: 70 to 1 nearest neighborhood matching balance density plot

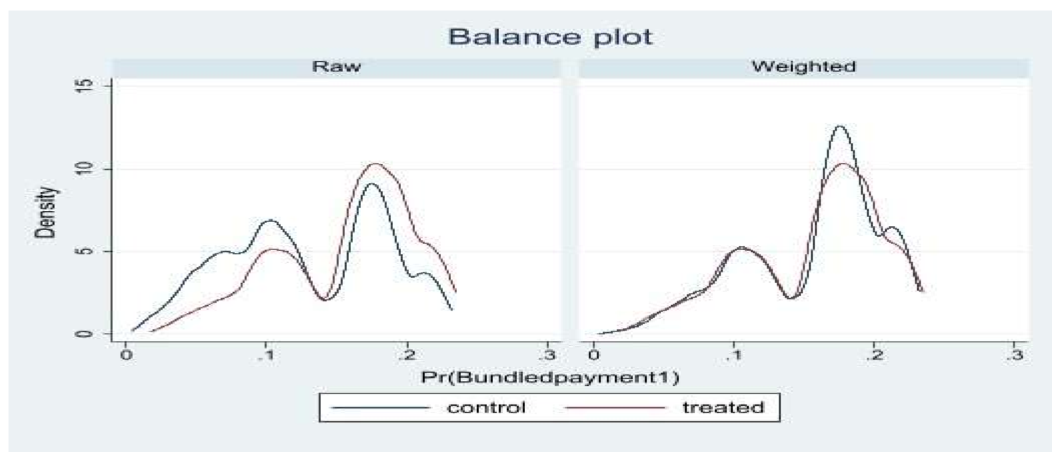

Figure 2: IPW balance density plot

Discussion

This retrospective analysis of the unplanned readmission risk examined the effect of the bundled payment program on unplanned readmission rates after THA performed between July 15, 2021, and June 30, 2023, at OrthoCarlona, in North Carolina, United States. The study included 2774 patients who underwent THA in this period. The analysis revealed that THA patients with

commercial bundled payments were at a lower risk of unplanned readmission compared to THA patients with non-bundled payments. However, the results were not statistically significant. The average effects of bundled payments were also assessed using propensity score matching (PSM). The odds of readmission were further analyzed by including the weights generated by two PSM methods followed by covariate balance analyses.

Iorio et al. (2016) found decreased length of stay, increased discharge to home, and stable readmission rates after joint replacement surgery in Medicare patients after bundled payment was implemented (Iorio et al., 2016). Additionally, Williams et al. (2017) found that the implementation of a bundle program resulted in a reduction of the 90-day readmission rate, up to 10% cost reduction, and improved length of stay (Williams et al., 2017). These two studies suggest that Bundled payments under Medicare may reduce the risk of unplanned readmission after joint replacement surgery. However, a study by Gold et al. in 2022 showed that after opting out of the bundle payment program and reverting to the fee for service model at their institution, and found no difference in both 90-day complications and 90-day readmissions between pre and post-bundle groups (Gold et al., 2022). Jones et. Aa. (2001) found that age could not be the only limiting factor when prescribing a THA for a patient, but gender and comorbid conditions should be also considered (Jones, Voaklander, Johnston, & Suarez-Almazor, 2001). The utilization of THA among younger patients has increased in recent years (Kurtz et al., 2009). Though age, along with some other factors (such as gender, race, comorbidity, etc.), is a well-established factor associated with readmission after THA (Weinberg, Kraay, Fitzgerald, Sidagam, & Wera, 2017), a significantly higher risk of readmission due to revision surgery after THA was found among patients aged 50-55 years than the patients aged 60 years and older as younger patients carry the implants many more years than older patients (Bayliss et al., 2017). In a recent study,

significantly improved health-related outcomes were found in younger patients (age 50-79 years) than in older patients (above 80 years) after THA was found (Jones et al., 2001).

The association of commercial bundled payment programs with the risk of readmission after THA among working-age patients of different age groups was not researched. Though the implementation of bundled payment was expected to reduce cost and improve quality, the evidence for the effectiveness of bundled payment for commercial payors is lacking. An initiative to study the effect of commercial bundled payment in 2010 failed due to several barriers originating from administration, state legislation, and technology (Ridgely, de Vries, Bozic, & Hussey, 2014).

My study results assessing the risk of unplanned readmission after THA among working-age patients using commercial bundled payment compared to non-bundled payment, although in the expected direction, were not statistically significant. I found that the commercial bundled payment reduced the risk of unplanned readmission when adjusted for age, gender, race, BMI, diabetes, and smoking status in the working-age population. Moreover, the reproducibility of the results was validated by using two different propensity score-matching methods following the multivariate logistic regression, and the best model was identified. Due to the unavailability of the data, the unplanned readmission in this research was not grouped by 30 days and 90 days. Instead of that, the overall risk of unplanned readmission was assessed.

There were several limitations in this study. I used retrospective data downloaded from electronic medical records. The bundled payment group was not large enough to generalize the data to the US Population, but using electronic medical records is more reflective of the US population than clinical trials, where a large portion of the population is excluded or under-represented. However, statistical significance was not achieved, and the results could not be

explained completely by the low sample size alone. There was a risk of type II error, which meant there may be a true difference between the bundled and non-bundled payment groups, that could not be measured due to missing population characteristics that were unavailable in the data. Insurance companies typically have such data available that they use to offer bundled payment services to patients. I did not have access to the insurers' proprietary data. Using insurance-level data along with the electronic health record might give more insights into the risk of unplanned readmission and capture the true difference between the two groups.

Moreover, my research population was not randomly selected. The bundled payment group was especially highly selective. The physicians decided the patients' eligibility for bundled payment depending on the patient's clinical characteristics through surgical optimization, and not all the insurers were interested in supporting commercial bundled billing. Bundled payment generally requires an upfront cost that some eligible patients may not be able to afford. Previous study reported higher unplanned readmission risk in older population (Malkani et al., 2017). There were chances of confounding effects arising from different outcome expectations leading to unplanned readmission for revision after THA from different age groups. However, the interaction of age and bundled payment in my study was not statistically significant.

The propensity score method is used to control for confounding and study the treatment effect (Patorno, Grotta, Bellocco, & Schneeweiss, 2013). To offset those limitations, I used propensity score matching that minimized the baseline differences between the two payment groups of patients and helped to limit the selection bias generated from the retrospective study design. Previously, Medicaid patients with THA were assessed for the success of the Bundled payment program using propensity score matching and it found that the Bundled payment program was unsuitable for Medicaid patients due to patient selection and access to care considering the high

healthcare cost (P Maxwell Courtney, Edmiston, Batko, & Levine, 2017). Primary THA and conversion THA outcomes (30 days) were also compared for the importance of risk adjustment under Bundled payment using propensity score matching (McLawhorn et al., 2018). Propensity score matching is a well-accepted approach to minimize the baseline differences and selection bias (Deb et al., 2016) . However, since the bundled payment group was highly selective, i.e., patient eligibility was assessed by using surgical optimization, it was not possible to completely account for the unmeasured confounding and selection bias.

This research may help policymakers rethink their policies to extend the bundled payment utilization for working-age patients who need THA. Future research for a better understanding of the risk of unplanned readmission should include more clinical characteristics of the patients, such as the comorbidity index and other confounders.

Conclusion

The result indicates the bundled payment program lowered the unplanned readmission risk in the working-age population. However, the results were not statistically significant. The analysis using larger data, with comorbidities and other confounders in the future, would give more insight into approaches for implementing commercial bundled payment. The insurance level data might be used to find potential confounding factors that were unavailable in the electronic health records to investigate the association of unplanned readmission risks with using commercial bundled payment. Investigating the 30-day and 90-day unplanned readmission risk in the future is important to understand the time requirement for treatment under bundled payment. In-depth unplanned readmission risk assessments for different age groups using patient-reported outcome surveys in the future may shed light on understanding the age-related outcome expectation and potential requirement of changes in the utilization of bundled payment policy. This research may

suggest that policymakers and providers improve the policies to make commercial bundled payment more available for working-age patients to achieve lower readmission risk among working-age patients.

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CHAPTER 3: ESTIMATING THE READMISSION RATE FOR TOTAL HIP ARTHROPLASTY (THA) PATIENTS LESS THAN 65 YEARS OLD UNDER COMMERCIALLY AVAILABLE BUNDLE PAYMENT

Introduction

Readmission rate is one of the most important and commonly used indicators of healthcare quality and is used to evaluate the outcomes of joint replacement surgery or joint arthroplasty (Çetin Aslan & Ağırbaş, 2020). Implementation of a rapid recovery protocol after THA has reduced readmission and reoperation rates by 36% (Stambough, Nunley, Curry, Steger-May, & Clohisy, 2015) within the first three months after surgery (den Hartog, Mathijssen, & Vehmeijer, 2013). The Hospital Readmissions Reduction Program (HRRP) was introduced in 2012, under the Affordable Care Act (ACA). In 2015, THA was included in the program. According to the Medicare Payment Advisory Committee, a large portion of readmission occurs within 30 days of discharge, largely due to avoidable causes (Miller et al., 2015a, 2015b), such as postoperative complications, improper care after discharge, and poor medication adherence. Consequently, 10-15% of readmissions were preventable (Mittal, Wang, Goben, & Boyd, 2018). Unplanned readmission is an unfortunate event and increases the total cost of care (Çetin Aslan & Ağırbaş, 2020; Schairer et al., 2014). Thus, unplanned readmission after index THA is considered the most important indicator of the quality of care (Çetin Aslan & Ağırbaş, 2020). Reducing readmission is important to policymakers and physicians because of its potential to improve care quality and reduce costs (Ramkumar et al., 2015). The American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) supported using 90-day readmission because patients may need follow-up treatment after discharge or extended stay at the hospital. The readmission rate after Unilateral THA was compared with Bilateral THA in a previous study and no significant difference in 30-day and 1-year readmission was found (Loppini et al., 2021).

For an episode of treatment like THA, which includes surgery, post-surgical therapies, and evaluation, a 90-day readmission rate is a better option than a 30-day readmission rate to measure the quality of care (Lucas & Pawlik, 2014). Most of the previous research articles documented 90-day readmission (Ramkumar et al., 2015; Schairer et al., 2014). However, CMS determined 30-day readmission after hospital discharge as a high-risk period without any strong evidence (James et al., 2023). Private insurers are also inclined to use 30- and 90-day readmission as a potential measure of the quality of care (Ramkumar et al., 2015).

Increasing age was found to be a significant risk factor for all-cause readmission after THA (Ali et al., 2017). Younger people (0-64years) are less likely to be readmitted than older people (above 65 years) after joint replacement surgery (Çetin Aslan & Ağırbaş, 2020). After implementing HRRP by CMS, the unplanned readmission rate in Medicare patients fell noticeably. In 2015, a study assessing the trend of unplanned readmission rate from 2009 to 2013 found that the decrease in unplanned readmission rate was steeper after THA in the group 65 years old or above (more than 1.5%) compared to the group 50-64 years old (approximately 0.1 to 0.4%) (Cary et al., 2018; Leigh Purvis, 2015). From 2009 to 2014, the overall 30-day unplanned readmission rate after THA decreased but the 30-day unplanned readmission rate after THA in the age group 18- 44 years increased by 0.5%. It was suspected that obesity was a potential cause of increased readmission after THA in younger patients (Cary et al., 2018). Further analysis is required to understand the unplanned readmission rate after index THA for younger patients below 65 years (Cary et al., 2018; Leigh Purvis, 2015). Most of the previous studies on readmission rates after THA concentrated on patients 65 years old or above. As the utilization of THA is also increasing among osteoarthritic patients below 65 years, more investigation of readmission rates for this age group is required.

Bundled payment is an alternative to the fee-for-service payment system (Whitcomb et al., 2015). To increase access to expensive treatment like THA, the Affordable Care Act and the Centers for Medicare & Medicaid Services (CMS) implemented a bundled payment pilot program in 2011 (Whitcomb et al., 2015). In fee-for-service providers receive payments for individual episodes of treatment which leads to fragmented billing for separate providers causing increased cost and the likelihood of poor communication between the providers, compromising the overall health outcome and the quality of the care. In contrast, the bundled payments are episode-based payments representing the projected cost reimbursement over the episode of care and encourage physicians, hospitals, and other healthcare providers to work together to deliver better patient care during and after discharge. Bundled payment programs reduce the sky-rising care price by moving healthcare delivery away from the fee-for-service payment system toward a value-based approach by providing more coordinated care (Gruessner, November 10, 2015). CMS' shift toward bundling payment for acute care episodes incentivizes hospitals to reduce readmission rates after joint replacement surgery, like THA. Previous work revealed a 13% overall readmission rate after THA in Medicare patients included in bundled payment (Clair et al., 2016). From 2011 to 2014 unplanned readmission after THA decreased by 6% among Medicare patients and cost by 10% (Iorio et al., 2016). The post-hospital cost, and length of stay after THA were decreased for Medicare patients included in the bundled payment (Whitcomb et al., 2015). The readmission rate after THA among Medicare patients was highly driven by infections (Zawadzki et al., 2017). A recent study reported a 5.6% readmission rate after THA in patients under Medicare (Bido, Torres, Kaidi, Rodriguez, & Rodriguez, 2024). Under bundled payment, the 30-day readmission rate was significantly lower (RR=0.73, 95% CI=0.63-0.85, p-

value<0.001) in the patients who underwent outpatient THA than in inpatient THA (LaValva et al., 2024).

The intention of reducing cost and providing quality care under bundled payment implemented by CMS for Medicare beneficiaries was a success. However, evidence is lacking for a similar assessment of the commercially available bundled payment (Christopher M Whaley et al., 2021). The commercially available bundle payment for the working-age population (18-64 years) adds another layer of interest as it is an approach to shifting from Fee-for-service to cutting costs while maintaining the quality of care (Gruessner, November 10, 2015). Previous studies for patients below 65 years old with commercial bundled payment were not successful due to several administrative, regulatory, and technical difficulties along with a small sample size (Ridgely et al., 2014; Tom Williams, 2013; Whitcomb et al., 2015).

I hypothesized that post-THA unplanned readmission incident rates and incident rate ratio among working-age patients (aged 18-64 years) are lower among patients with bundled payment programs than non-bundled payments adjusted for age, gender, race, pre-existing conditions such as diabetes, smoking habit, and being overweight.

Methods

Data source:

I conducted the secondary analysis by using the data, downloaded from the electronic health record of one of the leading independent academic orthopedic care centers serving the southeast region of the US, OrthoCarolina. The patients' primary demographics, date of admission, CPT codes, procedure description, ICD-10 codes, and diagnoses were obtained from the electronic data warehouse Epic, using SQL query and EPIC Slicer Dicer query by using the date range: from July 15, 2021, to June 30, 2023.

Variables:

Dependent variable

Unplanned Readmission: The number of readmissions was calculated as the number of times a patient was readmitted for any unplanned reason after the index THA. Unplanned readmission was defined as any readmission caused by surgical failures, infections, and accidents. Planned admissions after index THA were excluded. The unplanned readmission rate was calculated as the incidence rate, the ratio of unplanned readmissions versus the population at risk of unplanned readmissions, and expressed as per 1000 population.

Independent variables

Bundle payment: The variable was derived as "Yes" or "No" depending on, whether the patient was included in a commercially available bundle payment program (Yes/No or trt= 0/1).

Confounders: Based on the empirical literature, the following variables were used as potential confounders in the multivariable analysis.

Patients' demographics:

Gender: This categorical variable was downloaded from the electronic system and was recorded as identified at the time of birth and binary coded (Female=0, Male=1) for analysis

Race: Patients' races were downloaded from the electronic system as entered by the patients and recoded as Black, White, and Other. The race was dummy-coded for analysis.

Body mass index (BMI): BMI was downloaded from the electronic system and was categorized as normal or healthy when BMI was <25, overweight when BMI was 25 to <30, and obese when BMI was 30 or higher (The Centers for Disease Control and Prevention, June 3, 2022).

Diabetes: This variable was extracted from the EPIC record as a categorical response: "Yes" (coded as 1) or "No" (coded as 0).

Smoking status: In this research, smoking status was extracted from the self-declared responses such as former, current, never, etc. For the analysis, this variable was dummy-coded.

Effect modifier

Age: Patients' ages were calculated as the difference between the date of birth and the date of primary admission for THA (CPT code: 27130).

Statistical analysis:

Descriptive analysis: The sociodemographic and clinical characteristics of the dataset were explored by the chi^2 test compared between the two payment groups.

Negative binomial regression: All orthopedic cause unplanned readmissions were evaluated as count data and the data was expected to be positively skewed and dispersed. Thus, the data were analyzed by multivariate negative binomial regression. The analysis included bundled payment as an independent variable adjusted for age, gender, race, BMI, diabetes, and smoking status. The exposure of interest in this study was the payment groups. A marginal effect analysis was performed to assess the predicted incidence rate in readmission by using a commercial bundled payment program.

The incidence rate ratio and 95% CI were also calculated.

Results:

Descriptive analysis: From 15th July 2021 to 30th June 2023, in OrthoCarolina 2774 patients underwent THA surgery, and 70 patients had unplanned readmission after THA. The mean age of the patient population was 55 years (bundled payment group: 55.36(+/-7.8) and non-bundled payment group: 55.85(+/-6.4)). Among them, 370 were under commercial bundled payment programs and the rest were not. Under the bundled payment program, 46.8% of patients, and under the non-bundled payment program 47.0% of patients were female. Among the patients

under the non-bundled payment program, 75.4% were white, 18.2% were black and 6.4% were of other race, and under the bundled payment program 88.6% were white, 8.6% were black and 2.7% were of other race (the differences in race is statistically significant, $p<0.005$). The distribution of normal, overweight, and obese in the non-bundled payment group is 14.2%, 27.7%, 57.4%, and in bundled payment group is 14.3%,33.8%, and 51.1%, respectively. In the non-bundled payment group, 86.52% of patients were not diabetic and in the bundled payment group, 93.24% were not diabetic (with a statistically significant difference, $p=0.001$). Among the non-bundled payment group, 64.27% were never smokers, 8.74% were current smokers and 26.41% were former smokers, and among the bundled payment group 78.11% were never smokers, 2.97% were current smokers and 18.92% were former smokers, with the statistically significant difference ($p<0.005$) (Table 1).

Table 1: Data description, stratified by payment programs, i.e. non-bundled payment and bundled payment.

Demographic and clinical characteristics	Non-bundled payment	Bundled payment	p-value
Total number of patients (%)	2404(86.6%)	370(13.34%)	
Mean Age (+/- SD)	55.85(+/-6.4)	55.36(+/-7.8)	0.25
Gender (%)			
Female	47.05	46.76	0.92
Male	52.95	53.24	
Race (%)			
White	75.37	88.65	<0.005
Black	18.22	8.65	
Other	6.41	2.7	
Body Mass Index (Kg/m2) (%)			
Normal (<25)	14.23	14.32	0.08
Overweight (25 - <30)	27.66	33.78	
Obese (30 and higher)	57.4	51.08	
Missing	0.71	0.81	
Diabetes (%)			
No	86.52	93.24	0.001
Yes	13.06	6.75	
Missing	0.42	0	
Smoking Status (%)			
Never	64.27	78.11	<0.005
Current	8.74	2.97	
Former	26.41	18.92	
Missing	0.58	0	

Negative Binomial regression: How implementing a commercial bundled payment program changed the readmission rate was assessed by negative binomial marginal effect analysis. Table 2 shows the unadjusted predicted incidence rate of unplanned readmission, among working-age patients using bundle payment was 24.32 per 1000 patients (95% CI= 8.62, 40.02; p-value=0.002) and using non-bundled payment was 29.95 per 1000 patients (95% CI= 21.72,38.17; p-value<0.005).

Table 2: Unadjusted and adjusted predicted incidence rate of unplanned readmission per 1000 working-age patients under bundled payment and non-bundled payment

	Unadjusted		Adjusted	
Payment group	**Incidence Rate (95% CI)**	**p-value**	**Incidence Rate (95% CI)**	**p-value**
Bundled	24.32 (8.62, 40.02)	0.002	21.98(7.74,36.22)	0.002
Non-bundled	29.95 (21.72,38.17)	<0.005	29.48(21.29,37.67)	<0.005

Note: IR: Incidence rate; Multivariate analysis was adjusted for age, gender, race, BMI, diabetes, and smoking status

Table 3 represents the results of univariate and multivariate negative binomial regression, showing the unadjusted and adjusted incidence rate ratio (IRR) of unplanned readmission rates between non-bundled and bundled payment groups of patients who underwent THA. The unadjusted incidence rate of unplanned readmission after THA in the bundled payment group was 19% lower than the unplanned readmission after THA in the non-bundled payment group (unadjusted IRR (95%CI) = 0.81(0.40,1.63); p-value=0.56). The adjusted incidence rate ratio of unplanned readmission after THA in the bundled payment group was 26% lower than the unplanned readmission after THA in the non-bundled payment group (adjusted IRR (95%CI) = 0.74(0.37,1.52); p-value=0.42). Higher incidence rate ratio of readmissions were also observed in the patients who were white (unadjusted IRR(95%CI)= 1.49 (0.76,2.93); p-value=0.24), overweight (unadjusted IRR(95%CI)= 1.2 (0.48,3.02); p-value=0.7), obese (unadjusted IRR(95%CI)= 1.18 (0.51,2.7); p-value=0.69), and current smokers (unadjusted IRR(95%CI)= 1.07(0.41,2.78); p-value=0.89).

Table 3: Unadjusted and adjusted effect of bundled payment on the incidence rate ratio of unplanned readmission after THA

Negative Binomial Regression				
Readmission Count	**Univariate**		**Multivariate**	
	IRR(95%CI)	**p-value**	**IRR(95%CI)**	**p-value**
Payment				
Non-bundled	Baseline	Baseline	Baseline	Baseline
Bundled	0.81 (0.40,1.63)	0.56	0.74 (0.37,1.52)	0.42

Note: multivariate analysis was adjusted for age, gender, race, BMI, diabetes, and smoking status

Discussion:

The retrospective analysis of the readmission count data examines the effect of the bundled payment program on unplanned readmission rates after THA performed between July 15, 2021, and June 30, 2023, at OrthoCarlona, in North Carolina, United States. THA patients with commercial bundled payments had a significantly lower incidence rate of unplanned readmission compared to the non-bundled payment group. Furthermore, the unadjusted and adjusted incidence rate ratios of unplanned readmission among working-age patients were lower in the bundled payment group compared to the non-bundled payment group. However, the results were not statistically significant likely due to the small sample size. Despite the non-significant results, the findings were in the expected direction as observed for Medicare patients.

These findings align with Medicare's implementation of bundled payments, which resulted in a 13% unplanned readmission rate after THA (Clair et al., 2016). For Medicare patients, post-operative infections drove the readmission rate (Zawadzki et al., 2017). In recent year, Bido et al. reported a 5.6% readmission rate after THA in patients under Medicare (Bido et al., 2024).

Under bundled payment, the 30-day readmission rate ratio for outpatient THA was significantly lower (RR=0.73, 95% CI=0.63-0.85, p-value<0.001) than inpatient THA (LaValva et al., 2024), consistent with my findings To my knowledge, this research is the only completed work analyzing the effectiveness of commercial bundled payment for working-age patients.

The previous studies assessing the effectiveness of commercial bundled payment was not completed due to administrative, governmental, and technical difficulties (Ridgely et al., 2014). My study revealed that commercial bundled payment is associated with reduced unplanned readmission rates.

This study has several limitations. First, this study includes patients from only one orthopedic healthcare unit. Therefore, the result may not be generalizable beyond the orthopedic health care system. Secondly, statistical significance was not achieved. Not only the sample size was small, but the bundled payment group was also highly selective. Moreover, the data did not cover all the comorbidities and patients' other demographic characteristics. The bundled payment claims require upfront one-time out-of-pocket payment, which may refrain people from using bundled payment even though they may be eligible. Besides that, not all insurance companies participated in the bundled payment program, causing the eligible patients to be out of the bundled payment group. There were possibilities of other comorbid conditions that led the patients to be readmitted. But the information was missing in the data. These factors may increase the chance of type II errors which might result in false negative findings, i.e., erroneously concluding there is no statistically significant effect when there is actually one. Insurance companies have more access to such information that might fill up the gaps in the data. Thus, using insurers' data possibly can overcome these limitations in future research.

Furthermore, the small sample size of the patients included in the bundled payment group limited

me to assessing 30-day and 90-day readmission rates separately; instead, I was only able to assess the presence or absence of unplanned readmissions.

Conclusion

Commercial bundled payment programs for THA patients were associated with a lower, albeit nonsignificant, unplanned readmission rate after THA compared to the patients under non-bundled payment programs. Investigating the effect of commercial bundled payment for working-age patents on larger data is required. Future research including the insurance company data may give more insight into the utilization of commercial bundled payment by removing the chances of type-II error of unmeasured confounders, like comorbidities, economic conditions, insurance coverage, etc. This study indicated that policymakers and healthcare institutes may need to reform and investigate the commercial bundled payment for working-age patients to increase the implementation and achieve better outcomes.

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CHAPTER 4: THE COST-EFFECTIVENESS OF USING COMMERCIALLY AVAILABLE BUNDLED PAYMENTS FOR TOTAL HIP ARTHROPLASTY (THA) AMONG PATIENTS LESS THAN 65 YEARS OLD

Introduction

The Centers for Disease Control and Prevention (CDC) reported that in 2023, about 21.4% of people who were 18 years and older in the US had arthritis (Centers for Disease Control and Prevention, 2023a) and had a higher rate of work disability than adults without arthritis (K. A. Theis, Roblin, Helmick, & Luo, 2018; K. A. Theis et al., 2019). Total Hip Arthroplasty (THA), or Total Hip Replacement (THR), is a common elective surgical procedure for end-stage osteoarthritis patients (Springer et al., 2017; Wylde et al., 2014). The annual number of THA cases in the US is 370,000 and is projected to be as high as 635,000 by 2030 (Turan et al., 2023). According to the American Academy of Orthopedic Surgeons, in 2023, about 28% of THA patients were below 55 years old (American Academy of Orthopaedic Surgeons, 2023). By 2030, more than half of the patients using THA will be less than 65 years old (Soleimani et al., 2023).

THA reduces pain and disabilities (Lavernia et al., 2011), improves the quality of patients' lives (Jameson et al., 2015), and is cost-effective (Jameson et al., 2015). The survival rate of THA was 86% at 15 years, 79% at 20 years, and 78% at 25 years (Sodhi & Mont, 2019). Over the last two decades, the utilization of THA has increased exponentially worldwide due to the high success rate and low mortality and morbidity risk (Daigle et al., 2012). About 70% of the working-age patients could return to work after THA (Soleimani et al., 2023).

THA is a highly effective surgical procedure for treating osteoarthritis but is costly (Daigle et al., 2012). The main drivers of the cost of THA are the length of stay at the hospital, the status at

the time of discharge, and readmission. Additionally, adverse outcomes may be caused by poor management of post-surgical care (Asche et al., 2019).

Osteoarthritis was the most expensive condition for patients with private insurance. Hospitalization and treatment for osteoarthritis account for more than $6.2 billion in hospital costs (Centers for Disease Control and Prevention, 2021b). In the US, total joint replacement surgery costs between $30,000 and $112,000 (American Association of Hip and Knee Surgeons). The average cost of the THA implant comprised up to 87% of the total surgical cost (Gardezi et al., 2021).

Surgery costs can vary depending on the location, size, and scope of the facility, contractual agreement of implants, medication, and other services (American Association of Hip and Knee Surgeons). Pricing agreements between suppliers and hospitals are often opaque, and physician reimbursement is not directly related to the price of the materials used for the treatment. This opacity made physicians lose control over the rising cost of THA surgery (Gardezi et al., 2021). Under fee-for-service, providers are paid for individual courses of treatments, which results in increased costs due to the fragmented billing for separate providers. Individual courses of treatment from separate providers increase the possibility of poor communication between the providers, leading to compromised overall health outcomes and quality of care.

Bundled payment program helps reduce the high cost of care by moving healthcare delivery away from the fee-for-service payment system and provides more coordinated care, where the providers work as a team (Gruessner, November 10, 2015). The Centers for Medicare & Medicaid Services (CMS) implemented a bundled payment pilot program in 2011 as part of the Affordable Care Act to increase access and shift away from fee-for-service reimbursement (Christopher M. Whaley, 2021; Whitcomb et al., 2015). The bundled payments program aims to

deliver better patient care during and after discharge by encouraging physicians, hospitals, and other healthcare providers to work together as a team to reduce costs and improve outcomes. Bundled care is an episode-based payment, representing the projected cost reimbursement over the episode of care (Whitcomb et al., 2015). It covers all treatment costs, including surgery, medication, MRI, CT scan, and hospital stay for a particular or defined episode of treatment for a patient (Gruessner, November 10, 2015). The hospital or the provider group assumes the clinical responsibilities and the cost associated with managing the episode to provide quality treatment to the patient (Manner, 2019).

The hospital readmission rate is frequently used to measure quality of care (Clair et al., 2016). A review of the effect of bundled payment for total joint arthroplasty (TJA) among Medicare patients revealed that the program effectively reduced the cost of care, largely by reducing the length of stay, readmission, and rehabilitation (Siddiqi et al., 2017). Readmission after THA could increase the average cost of care by $36,038 (Clair et al., 2016). Patients with bundled payments under Medicare received a higher quality of care in terms of significantly shorter lengths of stay (4.02 days vs 5.27 days, p=0.001) and lower index hospitalization cost (Mean = $17,754, SD=+/-$2741 vs Mean = $183,16, SD=+/- $4732, p= 0.030) compared to non-bundled patients under Medicare (P. M. Courtney et al., 2016). Approximately 10% of the relative cost of surgery can be reduced by bundled payment (Iorio et al., 2016; Christopher M. Whaley, 2021). Bundled payment has gained importance as an approach to lower and streamline all the costs utilized in an episode of care, such as THA, among policymakers, hospital owners, and insurers (P. M. Courtney et al., 2016; Tom Williams, 2013). The initiative under the value-based program, like bundled payment for THA in Medicare and similar programs provided by commercial insurance, is for hospitals to deliver quality care at a lower cost without

compromising the outcomes (Asche et al., 2019). A bundled payment program is a good fit for elective surgeries, which are expensive and have predictable outcomes, such as THA (Manner, 2019). Some commercial health insurance providers have voluntarily adopted bundled payment programs to provide quality care at a lower cost (Asche et al., 2019; Tom Williams, 2013).

The implementation of bundled payment was more difficult than anticipated. Various private healthcare sector initiatives to utilize bundled payment were successful in including only a few insurers, patients, and hospitals (Tom Williams, 2013). Therefore, there is little and sometimes conflicting pieces of evidence present about the cost-effectiveness of the bundled payment adopted by commercial health insurance providers (Christopher M. Whaley, 2021; Christopher M Whaley et al., 2021). For example, Whitcomb et al., (2015), in their study on designing and implementing bundled payment, did not find a cost difference before and after implementing the bundled payment program at THA at Baystate Health in western Massachusetts (Whitcomb et al., 2015). An initiative to study the effectiveness of the commercial bundled payment for orthopedic surgery failed due to several issues that arose from administrative and state regulatory barriers and disagreements (Ridgely et al., 2014).

The Incremental Cost Effectiveness Ratio (ICER) (Burnham, Meta, Lizzio, Makhni, & Bozic, 2017) measures incremental gain and is commonly used to compare two or more strategies for performing the same task in healthcare. ICER is defined as the ratio of the difference in total cost and the difference in outcome measures. The outcome measures can be any clinically meaningful outcomes, such as survival time, quality-adjusted life year, or symptoms-reduced days where larger values indicate better outcomes (Bang & Zhao, 2012).

For my research, I hypothesized that,

1. using the commercial bundled payment for THA, the working-age (18-64 years old) patients have a longer time before unplanned readmission, that is, the time between index THA and any unplanned readmission after index THA compared to the regular payment.
2. the THA under commercial bundled payment is cost-effective, as measured by ICER, for working-age patients (18-64 years old) compared to the regular payment.

Methods

Data Source: OrthoCarolina is a well-known leading independent academic orthopedic care center serving the southeast region of the US. I retrieved the data from their electronic health records (from July 15, 2021, to June 30, 2023). Current Procedural Terminology (CPT) codes, procedure descriptions, and ICD-10 codes were used to identify the patients who utilized THA. The charges for the services on the THA service date and the unplanned readmission date for each patient were obtained from the Epic electronic data warehouse.

Variables:

Dependent variable

Total cost: The total cost was calculated from cost-to-charg-ratio or CCR. The CCR is the ratio of total charge to total expense. The Cost was calculated as the gross charge multiplied by CCR (American Hospital Association, 2019). The CCR was used to calculate the costs of each service given to the patients based on the charges of the services on the days of hospital encounter for THA and unplanned readmission. The CCR for OrthoCarolina was calculated as 0.44, which was validated for its accuracy (96%). The validation calculation is attached as Appendix No. 3.1. The cost of each encounter was calculated as the summation of all costs due to any services on the hospital encounter for THA and unplanned readmission. The episode of the THA encounter

started from the initial THA procedure to follow-up. In the case of an event of readmission, the cost during readmission was added to the cost of the initial encounter.

Time before unplanned readmission: The time before unplanned readmission was the number of days counted as the difference between the dates of services of the initial hospital encounter or admission for THA (Start date) and the next encounter of any unplanned readmission (Stop date), where applicable. The data end date of June 30, 2023, was used as the stop date, in the cases of no unplanned readmission.

Independent variables:

Bundled payment: The bundled payment variable was coded as 1 (Yes) if the patient was included in a commercially available bundled payment program, or 0 (No) if the patient was not included in the bundled payment program.

Confounders:

Age: Patient age was calculated as the differences between patients' birth dates and service dates for THA in years.

Gender: The gender identified at birth was dummy-coded, 1=Male, 0=Female.

Race: Patients self-identified as white, black, or other, and dummy-coded for the analysis.

Body Mass Index (BMI): BMI was downloaded from the electronic system, which was the ratio of patients' weight in kilograms or pounds divided by the square of height in meters or feet. For the analysis, the entries were categorized as: normal or healthy when BMI was <25, overweight when BMI was 25 to <30, and obese when BMI was 30 or higher (The Centers for Disease Control and Prevention, June 3, 2022)

Diabetes: The patients' information on diabetes from electronic health records was coded as 1= Yes, 0 otherwise.

Smoking status: The self-declared responses on smoking status were classified as former, current, or never.

Statistical analysis

Descriptive analysis: T-test and Chi2 test were used to compare the patients' characteristics in the two groups of payment programs. The total costs of hospital encounters were compared between the working-age patients under commercially available bundled payment and non-bundled payment programs. The total cost was calculated as the treatment cost for primary THA and for readmission, where applicable.

Regression analysis: Univariate and multivariate linear regression analyses were performed to estimate the difference in total cost of bundled and non-bundled payment programs considering the potential confounders such as age, gender, race, BMI, Diabetes, and smoking status.

Incremental cost-effectiveness ratio (ICER): The patient's time before unplanned readmission (as defined earlier) was used to calculate the ICER. The time difference before readmission between the bundled payment group and the non-bundled payment group was calculated as the incremental effect. The difference between the total cost of care, including the cost on the day for THA and the day of readmission between bundled and non-bundled payment groups, was calculated as incremental cost. The ratio of the incremental cost and the incremental effect was calculated as ICER (Khan, 2015).

Cost-effectiveness acceptability curve (CEAC): A mean-centered 95% CI ellipse was plotted to identify the cost-effectiveness of using bundled payment after bootstrapping; the bootstrap dataset was implanted by 50 replications of the dataset used in this study (Fenwick, O'Brien, & Briggs, 2004; Khan, 2015).

Utilization of cost-effectiveness threshold for identifying the cost-effectiveness: In 1973, Health economists coined the term cost-effectiveness threshold and defined it as a ratio of total cost and a measure of health gain. This threshold is meant to compare with the ICER (Soarez & Novaes, 2017; Weinstein & Zeckhauser, 1973). The gross domestic product (GDP)-based threshold is commonly used to compare with the ICER. The World Health Organization (WHO) recommended a 1 to 3x GDP per capita rule, which says if ICER is between 1xGDP per capita and 3xGDP per capita the intervention is cost-effective. An ICER below 1xGDP per capita is considered highly cost-effective and an ICER above 3xGDP per capita indicates cost inefficiency (Kazibwe et al., 2022). In 2019, the Institute for Clinical and Economic Review conducted a seminar to identify the operational cost-effectiveness threshold to be used in decision making in health care. The health economists around the world participated and decided on a range between $50,000-$100,000 as a cost-effectiveness threshold for the US (Institute for Clinical and Economic Review, 2019). The recent GDP per capita in 2023 in the US was $65,020 (Trading Economics, 2024). To narrow it down to match closely with reality, Woods et al. (2016) and Ochalek et al. (2018) recommended using half GDP per capita as the cost-effectiveness threshold value, which would be approximately $25,000 (Chi et al., 2020).

Results

Descriptive analysis: In OrthoCarolina, 2773 patients underwent THA surgery between July 15, 2021, and June 30, 2023; of whom only 370 were under the commercial bundled payment program. The average age of patients was 55.37 years and 55.85 years under non-bundled and bundled payment groups respectively. About 47% of the patients under the bundled payment program were female. The majority of the patients under the bundled payment program were white (88.6%); 6.4% were black, and 2.7% were from other races. In the bundled payment

group, normal, overweight, and obese were 14.3%, 33.8%, and 51.1%, respectively. In the bundled payment group, 6.8 were diabetic compared to 13.1% in non-bundled payment group (p=0.001). In the bundled payment group, 78.1% were never smokers, 2.9% were current smokers, and 18.9% were former smokers compared to 64.3%, 8.7%, and 26.4% in the non-bundled payment group, respectively (p-value=0.005) (Table 1)

Table 1. Stratified description of covariates by payment program

Demographic and clinical characteristics	Non- bundled payment	Bundled payment	p- value
Total number of patients (%)	2403(86.66%)	370(13.34%)	
Mean Age (+/- SD)	55.9(+/-6.4)	55.4(+/-7.8)	0.25
Gender (%)			
Female	47.0	46.8	0.92
Male	52.9	53.2	
Race (%)			
White	75.4	88.6	<0.005
Black	18.2	8.6	
Other	6.4	2.7	
Body Mass Index (Kg/m2) (%)			
Normal (<25)	14.2	14.3	0.08
Overweight (25 - <30)	27.7	33.8	
Obese (30 and higher)	57.4	51.1	
Missing	0.7	0.8	
Diabetes (%)			
No	86.5	93.2	0.001
Yes	13.1	6.7	
Missing	0.4	0	
Smoking Status (%)			
Never	64.3	78.1	<0.005
Current	8.7	2.9	
Former	26.4	18.9	
Missing	0.6	0	
Geometric Mean Total Cost (95% CI)	1266.4 (1255.1, 1277.9)	2112.1 (1876.8, 2377.9)	
Geometric Mean time before unplanned readmission (95% CI)	231.0 (221.6, 240.8)	243 (218.1, 272.5)	

Univariate and multivariate regression analyses were performed to assess the effect of bundled payment on total cost. The univariate analysis revealed that the total cost increased significantly by $3460 (SE=+/- $141, p-value<0.005) among those using bundled payment compared to those in non-bundled payment. The estimate did not change much after adjusting for potential confounders. (Table 2).

Table 2: Univariate and multivariate analysis to assess the effect of bundled payment on the total cost

Total Cost	Univariate			Multivariate		
	Coeff (SE)	**95% CI**	**p-value**	**Coeff (+/- SE)**	**95% CI**	**p-value**
Payment Program						
Non-bundled Payment	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Bundled Payment	3460.48 (+/-140.96)	3184.08, 3736.88	<0.005	3491.12 (+/-143.59)	3209.56, 3772.67	<0.005

Note: the multivariate analysis was adjusted for the confounders, age group, gender, race, BMI, diabetes, and smoking status

The Univariate regression analysis showed the patients using bundled payment, had on average 18.55 (SE=+/-11.6, P-value=0.110) additional days before readmission, 12.87 (SE=+/-12.99, P-value=0.322) additional days when adjusted for potential confounders (Table 3).

Table 3: Univariate and multivariate analysis to assess the effect of bundled payment on the time before unplanned readmission, i.e. the readmission days

Time before unplanned readmission	Univariate			Multivariate		
	Coeff (+/- SE)	**95% CI**	**p-value**	**Coeff (+/- SE)**	**95% CI**	**p-value**
Payment Program						
Non-bundled Payment	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Bundled Payment	18.55 (+/11.60)	-4.19, 41.29	0.110	12.87 (+/12.99)	-12.62, 38.36	0.322

Note: the multivariate analysis was adjusted for the confounders, age group, gender, race, BMI, diabetes, smoking status and Total Cost

The average cost of treatment in the bundled payment group was higher compared to the non-bundled payment group. The patients in the bundled payment group had on average 345 days before any readmission compared to 327 days in the non-bundled payment group. The cost-effectiveness analysis yielded an ICER of $186; the cost spent to increase the time before unplanned readmission by one day (Table 4).

Table 4: Comparing the mean cost, time before unplanned readmission, and ICER

Payment Program	**Average Cost ($)**	**Effect (**time in days before unplanned readmission**)**	**Incremental Cost ($)**	**Incremental effect (**time before unplanned readmission**)**	**ICER ($)**
Non- Bundled payment	1311.62	327.03	3460.48	18.55	186.51
Bundled payment	4772.10	345.58			

Note: ICER = Incremental cost/ Incremental effect, Incremental cost = difference between average cost in bundled payment and non-bundled payment.

Figure 1 shows a scatterplot of the Cost-Effectiveness Acceptability Curve (CEAC). The mean-centered 95% CI ellipse fell mostly in the north-east quadrant and slightly in the north-west quadrant. That indicated CEAC cut the y-axis at 0 which means none of the density involves cost-savings, but most of the density involves health gains (more than 75%) as the CEAC asymptotes to a value less than 1 (Fenwick et al., 2004). The mean was in the north-east quadrant. So, the analysis concluded that implementing the commercial bundled payment for working-age THA patients was more expensive and mostly effective than the non-bundled payment in all bootstrap runs (50 reps). A 95% confidence ellipse and the mean were also plotted in the scatter plot. The ICER was below the cost-effectiveness threshold range of $25,000 as suggested by Woods et al. (2016) and Ochalek et al. (2018), indicated that using the commercial

bundled payment for the working-age patients who underwent THA was very effective even though it was costlier than the non-bundled payment.

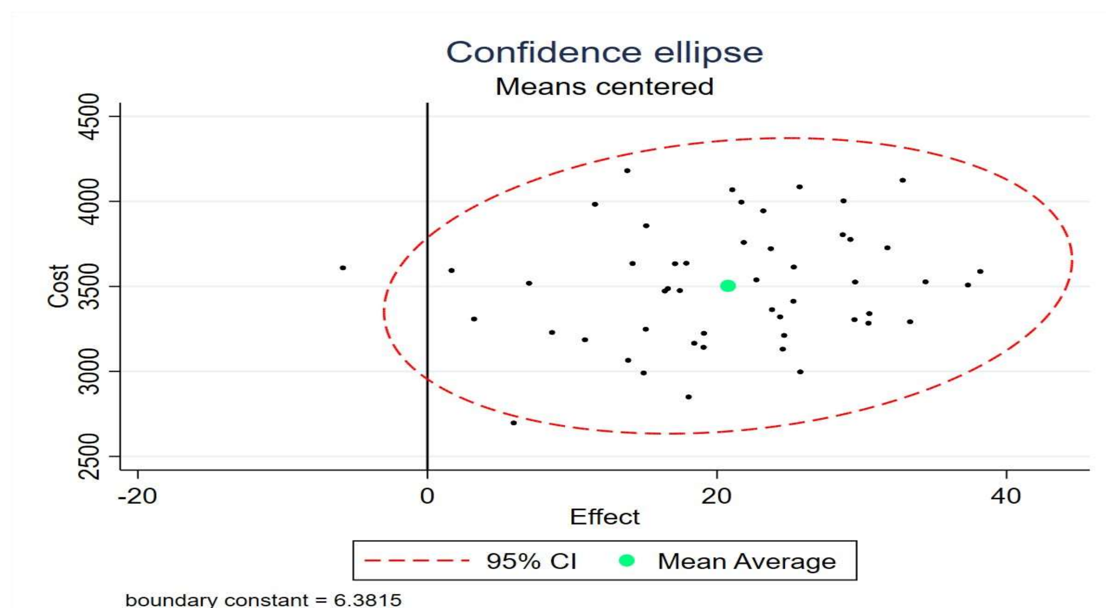

Figure 1: Scatterplot of cost-effectiveness bootstrapped dataset (50 plications) with 95% confidence ellipse and the mean
Note: Cost was total cost and Effect was the time before unplanned readmission

Discussion

My overall objective of this study was to assess the cost-effectiveness of the commercial bundled payment for the working-age bundled patients who underwent THA. My first hypothesis was that the patients under the bundled payment program had a longer duration before unplanned readmission after THA than patients under non-bundled payment. My findings were consistent with the hypothesis that the patients who underwent THA and used bundled payment had longer periods of time before an event of unplanned readmission after THA compared to patients without bundled payment, however, the finding was not statistically significant. In a previous study, bundled payment for THA was associated with a higher quality of care, in terms of significantly shorter lengths of stay compared to the patients without bundled payment (P. M.

Courtney et al., 2016). Siddiqi et al. in their clinical review article investing the effectiveness of bundled payment as an alternative payment model for joint arthroplasty, concluded that the bundled payment program effectively reduced the cost of care, largely by reducing the length of stay, readmission, and rehabilitation (Siddiqi et al., 2017). My study was limited to a smaller group of patients using commercial bundled payment. Additionally, the patients who used commercial bundled payment were selected by surgical optimization to get better outcomes. All the eligible patients may not be included in the bundled payment group as not all the insurers participate in the bundled payment program. Moreover, some eligible patients might not be able to afford to pay upfront one-time out-of-pocket cost to be included in the bundled program. Moreover, data on some confounders such as the comorbidity index, employment, etc., possibly associated with the outcomes of using bundled payment were not available. Using insurance companies' proprietary data, that likely contain information on these missing confounders can give more insight into the association of readmission days using commercially available bundled payment.

Unlike previous studies, this study found significantly higher costs associated with commercial bundled payment, though the quality of care improved. Earlier studies found reduced total cost achieved by using bundled payment for THA compared to non-bundled payment for Medicare patients (P. M. Courtney et al., 2016; Siddiqi et al., 2017). Iorio et al. in 2016, and Christopher M. Whaley in 2021 claimed 10% of the relative cost reduction was achievable by bundled payment for surgery in Medicare patients (Iorio et al., 2016; Christopher M. Whaley, 2021). The discrepant findings could be because the researchers studied bundled payment in Medicare patients who get the pre-determined amount for an episode of care from Medicare which may not be the case with private health insurers. Surprisingly, the study comparing the cost and quality of

THA between the patients (younger than 65 years old) before and after implementing bundled payment found no difference in total costs but was limited by low enrollment, administrative level barriers, and exclusion of any post-hospital care (Whitcomb et al., 2015). Along with the hospitalization cost and the cost of surgery, several other costs may contribute to the higher costs for patients with private insurance. In 2021, Gardezi et al. found that 87% of the total surgical cost came from the average cost of the implant of THA. The complex pricing agreement between a supplier and the hospital made the physician lose control over the rising cost of THA surgery even though they were concerned about the high price (Gardezi et al., 2021). According to the American Association of Hip and Knee Surgeons, the location, size, and scope of the facility, the contractual agreement of implants, medication, and other services can cause a higher cost of surgery (American Association of Hip and Knee Surgeons). The similar constraints of pricing agreements and other hidden factors limited us from identifying the contributing factors that caused higher expenses for the bundled patients. The total cost involved the expenses of the readmission day specifically, other expenses for the extended treatment after the day of readmission, required physiotherapy, and medications, which were excluded. That may cause a cost difference, too. Additionally, the effect of bundled payment on the total cost of an episode of care was not successfully measured due to missing information in the data, such as comorbidity index and employment status of a patient. Researching insurance data along with the electronic health record may give full strength to analyzing the total cost of an episode of care. My second hypothesis was to assess the incremental cost-effectiveness of the commercial bundled payment for working-age patients who underwent THA. I found that the commercial bundled payment is effective, though it is costlier compared to non-bundled payment for working-age bundled patients who underwent THA. In this research, I performed an incremental

cost-effectiveness analysis to assess the cost-effectiveness of the bundled payment compared to the non-bundled payment. Several hospitals and some commercial health insurance providers targeted to deliver quality care at a lower cost without compromising the outcomes by adopting similar surgical bundled payment programs (Asche et al., 2019; Tom Williams, 2013). However, implementing commercial bundled payment was more difficult, and only a few insurers, patients, and hospitals were willing to participate (Tom Williams, 2013). In 2014, Ridgely et al. reported the study on the effectiveness of the commercial bundled payment for orthopedic surgery failed due to administrative and state regulatory level barriers and disagreements (Ridgely et al., 2014). OrthoCarolina has established a bundled payment program, collaborating with private insurers for THA. This retrospective study using the electronic health record from OrthoCarolina, successfully assessed the cost-effectiveness of the commercial bundled payment for working-age patients who underwent THA. To my knowledge, this study is a unique study exploring ICER for the commercial bundled payment compared to non-bundled payment for the patients who went for THA. ICER is the decision-making tool widely used to determine if the intervention should be accepted or rejected when the total cost is high but provides a better outcome. This study may help policymakers and healthcare institutes revise the commercial bundled payment and pricing agreements to reduce the total cost for THA, keeping the improved quality intact.

Conclusion

Commercial bundled payment for working-age patients who underwent THA was highly effective, though costlier than the non-bundled payment. The better outcome in terms of increased days before unplanned readmission was observed in the bundled payment group. However, it was not statistically significant. There were chances of statistical errors arising from the unmeasured missing confounders, which might be the cause of statistical insignificance

associated with increased days before unplanned readmission and significantly higher cost in the bundled payment group. There is scope for strengthening future research by using insurance companies' data, which has more information. Orthopedic healthcare centers may achieve better cost adjustment providing accessibility to THA by improving the pricing agreements between the supplier and the healthcare institutes. In general, as bundled payment is coordinated care, revising the contractual agreement for health care supplies, and including them as part of coordinated care may help reduce costs. Policymakers, insurers, and healthcare institutes may get an indication to examine their policies for implementing bundled care to increase the accessibility of THA for working-age patients. Further analysis to explore the cost-contributing factors is required to understand the adjustments we need to align the efficacy of commercial bundled payment as bundled payment under Medicare for the patients who opt for THA.

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CHAPTER 5: CONCLUSIONS

Research Findings

This study used the analysis of the retrospective data downloaded from the electronic health record of one of the leading independent academic orthopedic care centers, OrthoCarolina, serving the southeast region of the U.S. The data was de-identified and reviewed by the Institutional Review Board (IRB) of the University of North Carolina, Charlotte, to protect data privacy. I investigated the readmission risk and readmission rate after Total Hip Arthroplasty (THA) among working-age patients using commercial bundled payment compared with non-bundled or fee-for-service payment. Additionally, I examined the cost-effectiveness of the commercial bundled payment for THA among working-age patients compared with non-bundled or fee-for-service payment. In my study, I found lower unplanned readmission risk and unplanned readmission rate in patients using commercial bundled payment compared to non-bundled payment. A higher number of days between THA and unplanned readmission among patients using commercial bundled payment compared to non-bundled payment was also found. From the study, I concluded that the commercial bundled payment for THA was more cost-effective than non-bundled payment among working-age patients. Unlike the previous research on Medicare bundled payment for THA, the total cost of care in commercial bundled payment for THA was significantly higher than the non-bundled payment.

The findings indicated better health outcome was gained by using commercial bundled payment for THA in the working-age population. However, despite being consistent with the findings from other researchers, the results were not statistically significant. The bundled payment group was small, and the data was only retrieved from a specific orthopedic healthcare center. This retrospective study may not be generalizable to the US population. However, a randomized clinical trial study was not feasible because the bundled payment group was selected based on

surgical optimization, insurers' participation, and patients' willingness to be involved in the bundled payment program. Rather, using electronic medical records was more reflective of the US population as in clinical trials, there is a high chance of under-representation of a large portion.

Besides the small sample size, the patient’s eligibility to be included in the commercial bundled payment was very selective, that is by surgical optimization. As all the insurers did not participate in the bundled payment program, and not all patients may be able to afford an upfront one-time out-of-pocket cost, some eligible patients may be left out of the commercial bundled payment group. There were possibilities of other unmeasured confounders, such as comorbidity index, employment, etc., associated with the outcomes, but these were unavailable in the data. Furthermore, the complex agreement between healthcare and the supplier was beyond the purview of the attending physicians and was not identifiable from the electronic medical records. The total cost was calculated based on the charges associated with the hospital admission days for THA and readmission, which might not be cover the true total cost of care. The outcomes and the total costs between the two patient groups were difficult to compare without knowing the missing confounders, including patients’ characteristics such as the comorbidity index. Thus, cost-effectiveness was better in assessing the effectiveness of commercial bundled payment as it was an aggregated measure of the cost and health outcome. The cost-effectiveness indicated the success of the commercial bundled payment initiative, but the significantly higher cost compared to the non-bundled commercial bundled payment group left the goal of cost reduction unachieved.

Implications

The smaller group of patients, who were selected by using surgical optimization using the commercial-bundled payment, and complex pricing agreements between the supplier and the healthcare institutes limited the study to fully assess the effect of commercial bundled payment over non-bundled payment for THA among working-age patients. Unlike the previous approaches, which failed due to complexities at managerial, legal, and implementation levels, this study gave clear messages to policymakers, practice managers, healthcare institutes, and researchers about the effectiveness of commercial bundled payment programs.

This research could prompt policymakers to expand the use of commercial bundled payments for working-age patients undergoing THA. Revising the contractual agreements for healthcare supplies for THA and included within this coordinated care framework of commercial bundled payment, might open a door for controlling cost and maintaining affordability in the era of skyrocketing healthcare pricing.

Future studies involving additional patient clinical characteristics, such as the comorbidity index, and using the insurance company's data may help to capture missing information on potential confounders which may be required for a better understanding of the risk and rate of unplanned readmissions after THA among working-age patients. Analyzing unplanned readmissions by the number of days may provide insights into the treatment duration necessary for inclusion in bundled payment models. Additionally, investigating cost-contributing factors, and researching using insurance company data may give more insights and will help align the effectiveness of commercial bundled payments with Medicare's bundled payment models for THA patients.

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APPENDICES

Chapter 2

Table 2.1: Comparison of demographic and clinical characteristics of patients (THA) who had unplanned readmission after THA and no readmission at all

Patients' characteristics	Unplanned Readmission		
	No	Yes	p-value
Mean Age (+/- SD)	55.39(+/-0.15)	56.51(+/-0.75)	0.227
Gender (n/%)			
Female	1270 (46.9%)	34 (48.6%)	0.791
Male	1434 (53.0%)	36 (51.4%)	
Race (n/%)			
White	2083 (77.0%)	57 (81.4%)	0.673
Black	460 (17.0%)	10 (14.3%)	
Other	161 (5.9%)	3 (4.3%)	
Body Mass Index (Kg/m2) (n/%)			
Normal (<25)	387 (14.3%)	8 (11.4%)	0.738
Overweight (25 - <30)	771 (28.5%)	19 (27.1%)	
Obese (30 and higher)	1526 (56.4%)	43 (61.4%)	
Missing	20 (0.7%)	0	
Diabetes (n/%)			
No	2365 (87.5%)	60 (85.71%)	0.313

Yes	330 (12.2%)	9 (12.9%)	
Missing	9 (0.3%)	1 (1.4%)	
Smoking Status (n/%)			
Never	1781 (65.9%)	53 (75.7%)	0.256
Current	215 (7.9%)	6 (8.6%)	
Former	694 (25.7%)	11 (15.7%)	
Missing	14 (0.5%)	0	
Bundled payment (n/%)			
No	2343 (86.6%)	61 (87.1%)	0.905
Yes	361 (13.3%)	9 (12.9%)	

Table 2.2: Unadjusted and adjusted logistic regression

Unplanned Readmission	Univariate		Multivariate	
	OR (95%CI)	p-value	OR (95%CI)	p-value
Payment Program				
Non-bundled Payment	Baseline	Baseline	Baseline	Baseline
Bundled Payment	0.96(0.47,1.94)	0.905	0.90(0.44,1.85)	0.781
Age	1.02(0.99,1.06)	0.227	1.02(0.98,1.06)	0.254
Gender				
Female	Baseline	Baseline	Baseline	Baseline
Male	0.94(0.58,1.50)	0.791	0.94(0.58,1.06)	0.807
Race				
White	1.26(0.64,2.48)	0.507	1.23(0.62,2.5)	0.55
Black	Baseline	Baseline	Baseline	Baseline
Other	0.86(0.23,3.15)	0.817	0.94(0.25,3.48)	0.923
Body Mass Index (Kg/m2)				
Normal (<25)	Baseline	Baseline	Baseline	Baseline
Overweight (25 - <30)	1.19(0.51,2.74)	0.68	1.23(0.52,2.87)	0.628
Obese (30 and higher)	1.36(0.63,2.9)	0.426	1.39(0.643.06)	0.402
Diabetes				

No	Baseline	Baseline	Baseline	Baseline
Yes	1.07(0.53,2.19)	0.842	1.01(0.49,2.09)	0.977
Smoking Status				
Never	Baseline	Baseline	Baseline	Baseline
Current	0.94(0.39,2.20)	0.883	0.83(0.33,2.11)	0.692
Former	0.53(0.28,1.03)	0.06	0.522(0.27,1.01)	0.053

Table 2.3: Covariate balance after 1:70 nearest neighbor matching

Covariate	**Standardized differences**		**Variance ratio**	
	Raw	**Matched**	**Raw**	**Matched**
Age	0.075	0.02	0.67	0.97
BMI	-0.09	-0.03	0.98	1
Gender	0.01	-0.03	1	1
Race	0.32	-0.01	0.55	0.99
Smoking Status	-0.25	-0.01	0.81	1
Diabetes	-0.21	0	0.56	1

Table 2.4: Covariate balance summary after IPW matching

Covariate	Standardized Differences		Variance Ratio	
	Raw	Weighted	Raw	Weighted
Age	0.08	-0.002	0.68	0.75
Gender (Male)	0.01	-0.000	1	1
Race				
White	0.33	-0.000	0.55	1
Other	-0.16	0.000	0.47	1
Body Mass Index (Kg/m2)				
Overweight (25 - <30)	0.13	0.002	1.12	1
Obese (30 and up)	-0.13	-0.004	1.03	1
Diabetes (Yes)	-0.21	-0.002	0.56	0.99
Smoking Status				
Current	-0.24	0.001	0.34	1
Former	-0.18	0.001	0.79	1

Table 2.5: Over-identification of covariate balance

H0: Covariates are balanced	
chi2(10)	6.26
Prob > chi2	0.793
Result: we cannot reject H0	

2.6: STATA code used in Chapter 2

```
version 17
clear
*****Data Loading****
cd "G:\My Drive\Dissertation research data\Final data\Research Data"
capture log close
set more off
log using Bundled.log, replace
import excel "G:\My Drive\Dissertation research data\Final data\Research Data\THA-unplanned-readmission.xlsx", sheet("data-compilation") firstrow
**** Knowing the data*****
summarize
table
describe
codebook THAID THADOSID THAServicedate UnplannedReadmissionDate UnplannedReadmissionDays UnplannedReadmission PlannedReadmissionDate PlannedReadmissionDays Age Gender Race Diabetc SmokingStatus BMI BundledPayment
**** Coding dichotomous dependent variables
****Unplanned Readmission
codebook UnplannedReadmission
encode UnplannedReadmission, gen (UnplannedReadmission_temp)
tab UnplannedReadmission_temp, nol
```

recode UnplannedReadmission_temp (2=1 "Yes") (1=0 "No"), gen

(UnplannedReadmission_new) label(UnplannedReadmission_lbl)

tab UnplannedReadmission_new

tab UnplannedReadmission_new, nol

drop UnplannedReadmission_temp

********Planned Readmission**

codebook PlannedReadmission

encode PlannedReadmission, gen (PlannedReadmission_temp)

tab PlannedReadmission_temp, nol

recode PlannedReadmission_temp (2=1 "Yes") (1=0 "No"), gen (PlannedReadmission_new)

label(PlannedReadmission_lbl)

tab PlannedReadmission_new

tab PlannedReadmission_new, nol

drop PlannedReadmission_temp

****** Coding categorical independent variable**

****Bundle payment and Non bundled payment**

tab BundledPayment, nol

codebook BundledPayment

encode BundledPayment, gen (Bundledpayment1_temp)

tab Bundledpayment1_temp, nol

recode Bundledpayment1_temp(1=0) (2=1), gen (Bundledpayment1)

tab Bundledpayment1

tab Bundledpayment1, miss

****Race Black, White, Other**

```
tab Race
codebook Race
encode Race, gen (Race_temp)
tab Race_temp, nol
recode Race_temp (1=1 "Black") (2=2 "Other") (3=3 "White"), gen (Race1) label(Race1_lbl)
tab Race1, nol
tab Race1
drop Race_temp
```

**** Smoking Habit**

```
tab SmokingStatus
codebook SmokingStatus
encode SmokingStatus, gen (Smokinghabit_temp)
tab Smokinghabit_temp, nol
recode Smokinghabit_temp (1=2 "Current") (2=3 "Former") (3=1 "Never"), gen
(SmokingStatus1) label(Smokingstatus_lbl)
tab SmokingStatus1, nol
tab SmokingStatus1, miss
drop Smokinghabit_temp
```

**** Gender**

```
tab Gender
codebook Gender
encode Gender, gen (Gender1_temp)
```

recode Gender1_temp (2=1 "Male") (1=0 "Female"), gen (Gender1) label(Gender1_lbl)

tab Gender1, nol

tab Gender1

codebook Gender1

**** Diabetic**

codebook Diabetc

encode Diabetc, gen (Diabetic_temp)

tab Diabetic_temp,nol

recode Diabetic_temp (2=1 "Yes") (1=0 "No"), gen (Diabetes) label(Diabetes_lbl)

tab Diabetes, nol

tab Diabetes

codebook Diabetes

**** Body Mass Index (Dummy Coding)**

codebook BMI

gen BMInew=BMI

replace BMInew=1 if BMI<25 & BMI<.

replace BMInew=2 if (BMI>=25 & BMI<30) & BMI<.

replace BMInew=3 if BMI>=30 & BMI<.

tab BMInew

label define BMInew 1 "1.Normal" 2 "2.Overweight" 3 "3.Obese"

label values BMInew BMInew

tab BMInew

****** Data summary**

summarize Age

tab UnplannedReadmission_new

tab PlannedReadmission_new

tab Bundledpayment1

tab Gender1, miss

tab Race1, miss

tab BMInew, miss

tab Diabetes, miss

tab SmokingStatus1, miss

*******Stratifying by Bundled Payment*******

bysort Bundledpayment1: tab1 UnplannedReadmission_new PlannedReadmission_new

ttest Age, by (Bundledpayment1)

tab Gender1 Bundledpayment1 , col chi2

tab Race1 Bundledpayment1 , col chi2 miss

tab BMInew Bundledpayment1 , col chi2 miss

tab Diabetes Bundledpayment1 , col chi2 miss

tab SmokingStatus1 Bundledpayment1 , col chi2 miss

*******Stratifying by Unplanned Readmision*******

ttest Age, by (UnplannedReadmission_new)

tab Gender1 UnplannedReadmission_new, col chi2

tab Race1 UnplannedReadmission_new, col chi2 miss

tab BMInew UnplannedReadmission_new, col chi2 miss

tab Diabetes UnplannedReadmission_new, col chi2 miss

tab SmokingStatus1 UnplannedReadmission_new , col chi2 miss

tab Bundledpayment1 UnplannedReadmission_new , col chi2 miss

***********Causal Analysis***Logistic regression***********

******Univariate******

logistic UnplannedReadmission_new Bundledpayment1 , or

logistic UnplannedReadmission_new Age, or

logistic UnplannedReadmission_new i.Gender1 , or

logistic UnplannedReadmission_new i.Race1 , or

logistic UnplannedReadmission_new i.BMInew , or

logistic UnplannedReadmission_new i.Diabetes , or

logistic UnplannedReadmission_new i.SmokingStatus1, or

*******Multivariate*****

logistic UnplannedReadmission_new i.Bundledpayment1 Age i.Gender1 i.Race1 i.BMInew i.Diabetes i.SmokingStatus1, or

*******Propensity score matching **********

*******Step 1: predict probability of being in the bundlepayment group*******

logistic Bundledpayment1 Age i.BMInew i.Diabetes i.Gender1 i.SmokingStatus1 i.Race1, robust

predict pscore

twoway (kdensity pscore if Bundledpayment1==1, fcolor(blue)) kdensity pscore if Bundledpayment1==0, fcolor(red)

*******Step 2: 70:1 Matching*****try 1:k match**

ssc install psmatch2

```
psmatch2 Bundledpayment1 Age i.BMInew i.Gender1  i.Race1 i.SmokingStatus1 i.Diabetes,
outcome(UnplannedReadmission_new) neighbor(70) common logit
teffects psmatch (UnplannedReadmission_new) (Bundledpayment1 Age BMInew  Gender1
Race1 SmokingStatus1  Diabetes), atet gen(match) //Table 3
predict ps0 ps1, ps //predicted propensity score for each group
predict y0 y1, po //potential outcome estimated for each observation
predict te //treatment effect estimated fro each group
tebalance summarize
tebalance density
logistic UnplannedReadmission_new Bundledpayment1  [pweight=_weight], or
logistic UnplannedReadmission_new Bundledpayment1 Age i.BMInew i.Diabetes i.Gender1
i.SmokingStatus1 i.Race1 [pweight=_weight], or
******IPW *******
logistic Bundledpayment1 Age i.BMInew i.Gender1  i.Race1 i.SmokingStatus1 i.Diabetes
predict p
gen iptw=1/p if Bundledpayment1==1
replace iptw=1/(1-p) if Bundledpayment1==0
sum iptw
teffects ipw (UnplannedReadmission_new) (Bundledpayment1 Age i.BMInew i.Gender1
i.Race1 i.SmokingStatus1 i.Diabetes), atet //Table 3
tebalance summarize
tebalance overid
tebalance density p
```

```
logistic UnplannedReadmission_new Bundledpayment1 Age i.BMInew i.Diabetes i.Gender1
i.SmokingStatus1 i.Race1 [pweight=iptw], or
```

Chapter 3

3.1 Unadjusted and adjusted incidence rate ratio of unplanned readmission

	IRR (95%CI)	p-value	IRR (95%CI)	p-value
Payment Program				
Non-bundled Payment	Baseline	Baseline	Baseline	Baseline
Bundled Payment	0.81(0.40,1.63)	0.56	0.74(0.37,1.52)	0.42
Age	1.02(0.99,1.06)	0.235		
Gender				
Female	Baseline	Baseline	Baseline	Baseline
Male	0.95(0.57,1.58)	0.86	1.03(0.63,1.68)	0.9
Race				
White	1.49(0.76,2.93)	0.25	1.40(0.71,2.76)	0.33
Black	Baseline	Baseline	Baseline	Baseline
Other	0.86(0.24,3.08)	0.82	0.89(0.25,3.2)	0.86
Body Mass Index (Kg/m2)				
Normal (<25)	Baseline	Baseline	Baseline	Baseline
Overweight (25 - <30)	1.2(0.48,3.02)	0.7	1.21(0.5,2.94)	0.68
Obese (30 and higher)	1.18(0.51,2.7)	0.69	1.14(0.50,2.58)	0.76
Diabetes				
No	Baseline	Baseline	Baseline	Baseline
Yes	0.93(0.46,1.88)	0.85	0.94(0.47,1.90)	0.87
Smoking Status				

Never	Baseline	Baseline	Baseline	Baseline
Current	1.07(0.41,2.78)	0.89	0.69(0.27,1.72)	0.42
Former	0.46(0.24,0.89)	0.02	0.45(0.23,0.87)	0.018

3.2 STATA code used for Chapter 3

```
version 17

clear

cd "G:\My Drive\Dissertation research data\Final data\Research Data"

capture log close

set more off

log using Bundled.log, replace

import excel "G:\My Drive\Dissertation research data\Final data\Research Data\Readmission
count.xlsx", sheet("combine") firstrow

**** Knowing the data*****

summarize

table

describe

codebook THAID Age Gender Race Diabetc SmokingStatus BMI BundledPayment
ReadmissionCount

**** Coding categorical independent variable

**Bundle payment and non bundled payment

tab BundledPayment, nol

codebook BundledPayment
```

```
encode BundledPayment, gen (Bundledpayment1_temp)
tab Bundledpayment1_temp, nol
recode Bundledpayment1_temp(1=0) (2=1), gen (Bundledpayment1)
tab Bundledpayment1
tab Bundledpayment1, miss
```

****Race Black, White, Other**

```
 tab Race
 codebook Race
 encode Race, gen (Race_temp)
 tab Race_temp, nol
 recode Race_temp (1=1 "Black")(2=2 "Other") (3=3 "White"), gen (Race1) label(Race1_lbl)
 tab Race1, nol
 tab Race1
 drop Race_temp
```

**** Smoking Habit**

```
 tab SmokingStatus
 codebook SmokingStatus
 encode SmokingStatus, gen (Smokinghabit_temp)
 tab Smokinghabit_temp, nol
 recode Smokinghabit_temp (1=2 "Current") (2=3 "Former") (3=1 "Never"), gen
(SmokingStatus1) label(Smokingstatus_lbl)
 tab SmokingStatus1, nol
 tab SmokingStatus1, miss
```

```
drop Smokinghabit_temp
** Gender
tab Gender
codebook Gender
encode Gender, gen (Gender1_temp)
recode Gender1_temp (2=1 "Male") (1=0 "Female"), gen (Gender1) label(Gender1_lbl)
tab Gender1, nol
tab Gender1
codebook Gender1
** Diabetic
codebook Diabetc
encode Diabetc, gen (Diabetic_temp)
tab Diabetic_temp,nol
recode Diabetic_temp (2=1 "Yes") (1=0 "No"), gen (Diabetes) label(Diabetes_lbl)
tab Diabetes, nol
tab Diabetes
codebook Diabetes
** Body Mass Index (Dummy Coding)
codebook BMI
gen BMInew=BMI
replace BMInew=1 if BMI<25 & BMI<.
replace BMInew=2 if (BMI>=25 & BMI<30) & BMI<.
replace BMInew=3 if BMI>=30 & BMI<.
```

```
tab BMInew

label define BMInew 1 "1.Normal" 2 "2.Overweight" 3 "3.Obese"

label values BMInew BMInew

tab BMInew
```

****** Data summary**

```
summarize Age BMI

tab Bundledpayment1
```

******description by payment program: ttest and chi2 test******

*******stratifying by Bundledpayment*******

```
bysort Bundledpayment1: tab1 BMInew Diabetes Gender1 SmokingStatus1 Race1

summarize ReadmissionCount

sum Age, d

ttest Age, by (Bundledpayment1)

tab Gender1 Bundledpayment1 , col chi2

tab Race1 Bundledpayment1   , col chi2 miss

tab BMInew Bundledpayment1  , col chi2 miss

tab Diabetes Bundledpayment1  , col chi2 miss

tab SmokingStatus1 Bundledpayment1  , col chi2 miss
```

*******Negative binomial regression*****Incidence rate******

****Univariate****

```
nbreg ReadmissionCount i.Bundledpayment1, ir robust

margins i.Bundledpayment1, predict(ir)vce(unconditional)
```

****Multivariate****

nbreg ReadmissionCount i.Bundledpayment1 Age i.Race1 i.SmokingStatus1 i.Gender1 i.Diabetes i.BMInew, ir robust

margins i.Bundledpayment1, predict(ir)vce(unconditional)

******Incidence rate ratio*******

***********Univariate*******

nbreg ReadmissionCount i.Bundledpayment1, irr robust

nbreg ReadmissionCount i.Age, irr robust

nbreg ReadmissionCount i.Gender1, irr robust

nbreg ReadmissionCount i.Race1, irr robust

nbreg ReadmissionCount i.BMInew, irr robust

nbreg ReadmissionCount i.Diabetes, irr robust

nbreg ReadmissionCount i.SmokingStatus1, irr robust

*******Multivariate******

nbreg ReadmissionCount i.Bundledpayment1 Age i.Race1 i.SmokingStatus1 i.Gender1 i.Diabetes i.BMInew, irr robust

Chapter 4

4.1 Cost-to-charge ratio and data validation:

Cost-to-charge or CCR is the ratio of total charge to total expense. The Cost can be calculated as the gross charge multiplied by CCR (American Hospital Association, 2019). In OrthoCarolina, the hospital-wide CCR is 42% (calculated from OrthoCarolina's Financial statement and the total charge)

Date Range	Total cost	Total Charge	CCR
Jan-Jun, 2023	$149,247,636	$370458472	0.40
Jan-Jun, 2022	$298,777,244	$716,777,079	0.42

The total cost is the summation of all the expenses for care, including personnel expenses, operating expenses, and physician expenses. For the commercial bundled payment patient, the expenses are reduced to 50% of the fee-for-service expense, which is specific to OrthoCarolina. The national average charge compared to Medicare's allowable cost is 3.4 and the mode is 2.4 (Bai & Anderson, 2015). The hospital markup is calculated as ratios of charges over Medicare-allowable costs (Bai & Anderson, 2015).

CCR= cost/charge

The national average hospital Mark-up = 3.4, Mode=2.4

OrthoCarolina's total expense of care is estimated as 50% higher than the Medicare-allowable costs. So, OrthoCarolina's total cost / Medicare-allowable costs=1.5

Then, CCR for OrthoCarolina = 1.5/3.4 = 44%, Error rate = 0.045, Accuracy 96% -98% approximately.

4.2 Univariate and multivariate regression analysis: effect of bundled payment on the total cost

	Univariate analysis			Multivariate analysis		
	Coeff(+/-SE)	(95%CI)	p-value	Coeff(+/-SE)	(95%CI)	p-value
Payment Program						
Non-bundled Payment	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Bundled Payment	3460.48(+/- 140.96)	3184.08, 3736.88	<0.005	3491.12(+/- 143.59)	3209.56, 3772.68	<0.005
Age	18.74(+/- 6.94)	5.13, 32.35	0.007	16.19(+/- 6.41)	3.61, 28.76	0.012
Gender						
Female	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Male	-6.37(+/- 105.97)	-214.16, 201.42	0.952	-7.33(+/- 97.95)	-199.41, 184.75	0.94
Race						
White	165.06(+/- 141.85)	-113.08, 443.19	0.245	-142.72(+/- 131.38)	-400.33, 114.90	0.277
Black	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Other	-76.28(+/- 252.53)	-571.44, 418.88	0.763	1.27(+/- 238.18)	-465.76, 468.29	0.996
Body Mass Index (Kg/m2)						

Normal (<25)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Overweight (25 - <30)	11.11(+/- 172.35)	-326.85, 349.07	0.949	-72.32(+/- 157.93)	-381.72, 237.09	0.647
Obese (30 and higher)	139.58(+/- 157.47)	-169.19, 448.36	0.375	192.05(+/- 146.26)	-94.74,478.85	0.189
Diabetes						
No	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Yes	-286.99(+/- 161.62)	-603.90, 29.92	0.076	-150.45(+/- 150.1)	-444.93,144.04	0.317
Smoking Status						
Never	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Current	-544.32(+/- 198.44)	-933.43,-155.21	0.006	-168.90(+/- 182.46)	-526.69,188.88	0.335
Former	-280.02(+/- 123.51)	-522.19, -37.85	0.023	-86.54(+/- 112)	-307.49,134.42	0.443

4.3. Univariate and multivariate regression analysis: effect of bundled payment on the time before unplanned readmission

Survival	Univariate			Multivariate		
	Coeff (+/- SE)	**95% CI**	**p-value**	**Coeff (+/- SE)**	**95% CI**	**p-value**
Payment Program						
Non-bundled Payment	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Bundled Payment	18.55 (+/- 11.60)	- 4.19,41.29	0.110	12.87(+/- 12.99)	-12.62,38.36	0.322
Age	0.62(+/0.52)	- 0.40,1.63)	0.235	0.62(+/-0.53)	-0.41,1.65	0.240
Gender						
Female	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Male	-2.06 (+/-7.90)	-17.57, 13.43	0.794	0.58(+/-8.04)	-16.35, 15.19	0.942
Race						
White	-6.19 (+/- 10.58)	-26.95, 14.56	0.558	-10.63(+/- 10.79)	-31.78, 10.52	0.325
Black	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Other	-16.94(+/- 18.84)	-53.89, 20.02	0.369	-13.64(+/- 19.55)	-51.98, 24.70	0.486
Body Mass Index (Kg/m2)						
Normal (<25)	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline

Overweight (25 - <30)	-5.16(+/-12.81)	-30.28, 19.96	0.687	-5.83(+/- 12.96)	-31.24, 19.57	0.653
Obese (30 and higher)	-0.45(+/-11.70)	-23.41, 22.50	0.969	0.41(+/-12.01)	-23.14,23.97	0.973
Diabetes						
No	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Yes	-20.00(+/- 12.04)	-43.62, 3.61	0.097	-21.59(+/- 12.33)	-45.77,2.59	0.080
Smoking Status						
Never	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Current	-5.99(+/-14.78)	-34.98, 22.99	0.685	-1.83(+/- 14.98)	-31.22,27.54	0.902
Former	15.70(9.20)	-2.34, 33.74	0.088	17.15(+/-9.25)	-0.98,35.29	0.064
Total Cost	0.003(+/- 0.001)	-4.29e-08, 0.006	0.050	0.002(+/- 0.002)	-0.001,0.005	0.194

4.4 STATA code used for Chapter 4

```
version 17

clear

cd "G:\My Drive\Dissertation research data\Final data\Research Data"

capture log close

set more off

log using Bundled.log, replace
```

```
import excel "G:\My Drive\Dissertation research data\Final data\Research Data\THA-unplanned-surv-cost.xlsx", sheet("Charge") firstrow
```

****** Knowing the data*******

```
summarize
table
describe
```

****** Coding dichotomous dependent variables**

******Unplanned Readmission**

```
codebook UnplannedReadmission
encode UnplannedReadmission, gen (UnplannedReadmission_temp)
tab UnplannedReadmission_temp, nol
recode UnplannedReadmission_temp (2=1 "Yes") (1=0 "No"), gen (UnplannedReadmission_new) label(UnplannedReadmission_lbl)
tab UnplannedReadmission_new
tab UnplannedReadmission_new, nol
drop UnplannedReadmission_temp
```

****** Coding categorical independent variable**

****Bundle payment ******

```
tab BundledPayment, nol
codebook BundledPayment
encode BundledPayment, gen (Bundledpayment1_temp)
tab Bundledpayment1_temp, nol
recode Bundledpayment1_temp(1=0) (2=1), gen (Bundledpayment1)
```

tab Bundledpayment1

tab Bundledpayment1, miss

****Race Black, White, Other**

tab Race

codebook Race

encode Race, gen (Race_temp)

tab Race_temp, nol

recode Race_temp (1=1 "Black")(2=2 "Other") (3=3 "White"), gen (Race1) label(Race1_lbl)

tab Race1, nol

tab Race1

drop Race_temp

**** Smoking Habit**

tab SmokingStatus

codebook SmokingStatus

encode SmokingStatus, gen (Smokinghabit_temp)

tab Smokinghabit_temp, nol

recode Smokinghabit_temp (1=2 "Current") (2=3 "Former") (3=1 "Never"), gen

(SmokingStatus1) label(Smokingstatus_lbl)

tab SmokingStatus1, nol

tab SmokingStatus1, miss

drop Smokinghabit_temp

**** Gender**

tab Gender

```
codebook Gender
encode Gender, gen (Gender1_temp)
recode Gender1_temp (2=1 "Male") (1=0 "Female"), gen (Gender1) label(Gender1_lbl)
tab Gender1, nol
tab Gender1
codebook Gender1
```

**** Diabetic**

```
codebook Diabetc
encode Diabetc, gen (Diabetic_temp)
tab Diabetic_temp,nol
recode Diabetic_temp (2=1 "Yes") (1=0 "No"), gen (Diabetes) label(Diabetes_lbl)
tab Diabetes, nol
tab Diabetes
codebook Diabetes
```

**** Body Mass Index (Dummy Coding)**

```
codebook BMI
gen BMInew=BMI
replace BMInew=1 if BMI<25 & BMI<.
replace BMInew=2 if (BMI>=25 & BMI<30) & BMI<.
replace BMInew=3 if BMI>=30 & BMI<.
tab BMInew
label define BMInew 1 "1.Normal" 2 "2.Overweight" 3 "3.Obese"
label values BMInew BMInew
```

tab BMInew

****** Data summary**

*******stratifying by Bundled payment*******

bysort Bundledpayment1: tab1 Agenew BMInew Diabetes Gender1 SmokingStatus1 Race1

histogram Totalcost

ttest Totalcost, by (Bundledpayment1)

generate logcost= ln(Totalcost)

histogram logcost

sum logcost, detail

ttest logcost, by (Bundledpayment1)

****** Report the Geometric Mean****

bys Bundledpayment1: ameans Totalcost Surv

bys Bundledpayment1: ameans logcost Surv

ttest Age, by (Bundledpayment1)

ttest Surv, by (Bundledpayment1)

tab Gender1 Bundledpayment1 , col chi2

tab Race1 Bundledpayment1 , col chi2 miss

tab BMInew Bundledpayment1 , col chi2 miss

tab Diabetes Bundledpayment1 , col chi2 miss

tab SmokingStatus1 Bundledpayment1 , col chi2 miss

*********Regression*******

*****Univariate for Total Cost****

regress Totalcost i.Bundledpayment1

regress Totalcost i.Agenew

regress Totalcost Age

regress Totalcost Gender1

regress Totalcost i.Race1

regress Totalcost i.BMInew

regress Totalcost i.Diabetes

regress Totalcost i.SmokingStatus1

*****Multivariate for Total Cost *****

regress Totalcost i.Bundledpayment1 Age i.Gender1 i.Race1 i.BMInew i.Diabetes i.SmokingStatus1

*******Univariate for Time Before Readmission *******

regress Surv i.Bundledpayment1

regress Surv i.Agenew

regress Surv Gender1

regress Surv i.Race1

regress Surv i.BMInew

regress Surv i.Diabetes

regress Surv i.SmokingStatus1

regress Surv Totalcost

*******Multivariate for Time Before Readmission *******

regress Surv i.Bundledpayment1 Totalcost Age i.Gender1 i.Race1 i.BMInew i.Diabetes i.SmokingStatus1

*********Incremental Cost Effectiveness Ratio (ICER)******bene: highest score of effect is** beneficial; detr: detrimental to health like mortality

```
heabs Totalcost Surv, intervention(Bundledpayment1) response(bene) w2p(0)
bootstrap cost1=r(cost1) effect1=r(outcome1) NB1=r(NB1) NB1Lo=r(loCINB1) NB1Up=r(upCINB1), saving (dummysurv, replace) reps(50) seed(24): heabs Totalcost Surv, w2p(0) intervention(Bundledpayment1) response(bene)
use dummysurv.dta, clear
heapbs, lci(NB1Lo) uci(NB1Up) ref(-3460.482) inb(NB1) draw cost(cost1) effect(effect1) graphregion(color(white))
```