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# Reasons for Ninety-Day Emergency Visits and Readmissions After Elective Total Joint Arthroplasty: Results From a US Integrated Healthcare System

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ABSTRACT

*Background:* Previous studies evaluating reasons for 30-day readmissions following total joint arthroplasty (TJA) may underestimate hospital-based utilization of healthcare resources during a patient's episode-of-care. We sought to identify common reasons for 90-day emergency department (ED) visits and hospital readmissions following primary elective unilateral TJA.
*Methods:* Patients from July 1, 2012 through June 30, 2015 having primary elective TJA and at least one 90-day postoperative ED-only visit and/or readmission for any reason were identified using the Kaiser Permanente Total Joint Replacement Registry. Chart reviews for ED visits/readmissions included 13 surgical and 11 medical reasons. The 2344 total hips and 5520 total knees were analyzed separately.
*Results:* Incidence of at least one ED visit following total hip arthroplasty (THA) was 13.4% and 4.5% for readmissions. The most frequent reasons for ED visits were swelling (15.6%) and pain (12.8%); the most frequent reasons for readmissions were infection (12.5%) and unrelated elective procedures (9.0%). The incidence of at least one ED visit following total knee arthroplasty (TKA) was 13.8%, and the incidence of readmission was 5.5%. The most frequent reasons for ED visits were pain (15.8%) and swelling (15.6%); the most common readmission reasons were gastrointestinal (19.1%) and manipulation under anesthesia (9.4%).
*Conclusion:* Swelling and pain related to the procedure were the most frequent reasons for 90-day ED visits after both THA and TKA. Readmissions were most commonly due to infection or unrelated procedures for THA and gastrointestinal or manipulation under anesthesia for TKA. Modifications to discharge protocols may help prevent or alleviate these issues, avoiding unnecessary hospital returns.


The demand for total joint arthroplasty (TJA) continues to rise, with surgical rates that outpace the number of orthopedic surgeons [1]. Projected estimates suggest an increase in the United States (US) of approximately 35% for total hip arthroplasty (THA) from 378,089 in 2015 to 511,837 in 2020, and an estimated 48% increase in total knee arthroplasty (TKA) from 926,527 in 2015 to 1,375,574 in 2020 [2]. The increasing demand for TJA will similarly make financial demands on healthcare delivery systems. In 2010, 1.05 million joint arthroplasties were performed with a total approximate cost of $19,000 per joint for a total of $20 billion in healthcare expenditure [3]. The anticipated rise in surgical volume makes it imperative for surgeons to control costs within the episode-of-care, while maintaining a high standard of quality and patient satisfaction.

In the US, the Centers for Medicare and Medicaid Services initiated the Bundled Payments for Care Improvement Initiative (BPCI), with the proposed goals of controlling costs while rewarding quality of care. Under model 2 of the BPCI, the episode of TJA includes the inpatient stay in an acute care hospital plus the postacute care and all related services up to 90 days after hospital discharge [4]. This bundle includes all hospital and outpatient care,

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including any related readmissions. Hospital admissions in this patient population have been shown to be high at baseline, and to increase further in the 365 days after the arthroplasty procedure. Bohm et al [5] found the frequency of admissions in the preoperative year to increase in the 1-year postoperative period for both elective THA (12.9%-14.8%) and elective TKA (10.2%-15.5%) patients, representing a 15% and 52% increase, respectively, illustrating both the importance and challenge of finding ways to decrease hospital readmissions.

The current emphasis on readmission following TJA in the US is understandable given the risk in penalty of up to 3% of annual hospital Medicare payments for excessive readmissions under the Affordable Care Act. However, this focus on readmission underestimates hospital-based utilization of healthcare resources [6]. It is estimated that 5.6%-13.9% of hospital discharges following TJA present to the emergency department (ED) only within 30 days of discharge [7,8]. An accurate assessment of the impact to our healthcare system must therefore also include ED visits.

The combined demands of an increasing number of patients undergoing TJA and increasing pressures for cost containment make it imperative to address all aspects of patients' recovery and resource utilization. The goal of this study is to identify reasons for visits to the ED and for readmissions in the first 90 days following THA and TKA separately. In evaluating the reasons for events, we hope to establish baseline numbers for future comparison and guide preventative efforts.

## Materials and Methods

### *Study Setting and Population*

We conducted a descriptive study including patients who underwent an elective primary unilateral THA or TKA at 3 high-volume Southern California hospitals within our integrated healthcare system between July 1, 2012 and June 30, 2015 and subsequently had at least one event within 90 days of the primary procedure. An event was defined as an ED-only visit and/or a readmission. Only patients with an event to a hospital within our integrated healthcare system were included since ED visit and readmission information from outside hospitals was not available in the electronic health record (EHR). Events where the patient left without being seen, and care not documented in the EHR were excluded. Patients younger than the age of 18 and those who underwent a same-day bilateral TJA or revision surgery were excluded.

### *Data Collection*

TJA patients from the 3 participating medical centers were identified using the Kaiser Permanente Total Joint Replacement Registry (TJRR). Detailed information on TJRR coverage, data collection procedures, and quality assurance has been detailed previously [9,10]. Information extracted from the TJRR included patient characteristics (age, gender, and American Society of Anesthesiologists [ASA] classification) and primary procedure characteristics (diagnosis, date of procedure, and in-hospital length of stay [LOS]).

The institutional EHR was used to identify events within 90 days of the TJA and the reasons for events. ED-only visits occurring within the 90-day time frame were identified as an “Emergency” admission to the hospital, while readmissions were identified as an “Inpatient” stay. For readmissions, the admit source was classified as either through the ED or outside the ED. The reasons for events were reviewed and classified by orthopedic surgeon investigators. The surgeon reviewers classified the primary cause of each 90-day event using 24 prespecified reasons for return. These reasons were either surgically related or medically related (Table 1). Surgical-related causes included cellulitis, constipation, deep infection, deep vein thrombosis (DVT), dislocation, hematoma drainage,

**Table 1**
Prespecified ED Visit and Readmission Cause Categories.

| Relation to the Surgical Procedure | Primary Cause Category | Category Inclusion Examples |
|---|---|---|
| Surgical | Cellulitis | |
| | Constipation | |
| | Deep infection | |
| | Deep vein thrombosis | |
| | Dislocation | |
| | Hematoma/drainage | |
| | Manipulation under anesthesia | |
| | Pain related to the primary procedure | Operative leg pain, including med refills |
| | Pulmonary embolism | |
| | Serous drainage | |
| | Swelling of the operative extremity | Ecchymosis, edema, incisional concerns, patient or family concern about swelling, wound appearance |
| | Wound dehiscence | |
| | Other related to the primary procedure | Neuropraxia |
| Medical | Cardiovascular | Anemia, chest pain, hypertension, hypotension, vascular |
| | Elective procedure unrelated to the primary procedure | Elective TJA for the opposite side |
| | Endocrine | Diabetes mellitus, thyroid disorders |
| | Fever of unknown origin | |
| | Gastrointestinal not including constipation | Cholecystitis, diarrhea, gastrointestinal bleed, small bowel obstruction, sore throat |
| | Genitourinary | Dehydration/dizziness, electrolytes, fluids, hematuria, renal failure, retention, urinary tract infection |
| | Neurological | Altered mental status, headache, migraine, stroke, syncope, transient ischemic attack, vertigo |
| | Pain unrelated to the primary procedure | Nonoperative leg musculoskeletal pain/injury, operative leg pain away from surgical site (eg, calf pain, compression hose issues) |
| | Pulmonary | Cough, hematemesis, pneumonia, shortness of breath |
| | Other medical unrelated to the primary procedure | Allergic reaction, anxiety, failure to thrive/cope, general health concerns, medication reaction/overdose |
| | Other musculoskeletal complaints | Ankle sprain, back pain, cervicalgia, chest wall pain |

**Table 2**
Demographic and Surgical Characteristics of THA and TKA Patients who Returned to the ED or were Readmitted Within 90 Days Following the Primary Procedure.

| Characteristic | THA | | TKA | |
|---|---|---|---|---|
| | ED Visit, n, (%) | Readmission, n, (%) | ED Visit, n, (%) | Readmission, n (%) |
| Total N | 366 | 144 | 931 | 277 |
| Age (y), median (IQR) | 68 (59-76) | 67 (59.5-76) | 68 (62-74) | 69 (62-78) |
| Gender | | | | |
| Female | 210 (57.4) | 77 (53.5) | 576 (61.9) | 167 (60.3) |
| Male | 156 (42.6) | 67 (46.5) | 355 (38.1) | 110 (39.7) |
| ASA score | | | | |
| 1-2 | 264 (72.1) | 89 (61.8) | 704 (75.6) | 181 (65.6) |
| 3-4 | 102 (27.9) | 55 (38.2) | 227 (24.4) | 95 (34.4) |
| Length of stay (h), median (IQR) | 48 (48-72) | 51.3 (48-72) | 48 (48-72) | 51.9 (48-72) |
| Discharge to ED/readmission (d), median (IQR) | 11 (3-39) | 33 (13-65) | 12 (4-34) | 36 (10-66) |
| Readmission source | | | | |
| ED | – | 88 (61.1) | – | 192 (69.3) |
| Outside of the ED | – | 56 (38.9) | – | 85 (30.7) |

Missing: knee: ASA score (readmission n = 1, %).
IQR, interquartile range.

manipulation under anesthesia (MUA), pain related to the primary procedure (related pain), pulmonary embolism, serous drainage, swelling of the operative extremity, wound dehiscence, and other related to the primary procedure. Medical-related causes included cardiovascular, elective surgical procedure unrelated to the primary procedure, endocrine, fever of unknown origin, gastrointestinal (GI) not including constipation, genitourinary (GU), neurological, pain unrelated to the procedure (unrelated pain), pulmonary, other medical unrelated to the primary procedure, and other musculoskeletal complaints.

*Statistical Analysis*

Crude incidence of at least one ED-only visit or of at least one readmission in the 90-day episode-of-care following the primary procedure was calculated as the proportion of at least one 90-day event following the primary procedure over the total eligible population from the 3 participating sites. Descriptive statistics including frequencies, proportions, means, standard deviations, medians, interquartile ranges, and ranges were computed using the R Statistical Computing Environment. Primary causes for ED-only visits and readmissions were presented both according to events that occurred within 90 days of the primary procedure and within the 30 days following the primary procedure and stratified according to surgical-related causes or medical-related causes. Results were presented for THA and TKA procedures separately.

*Ethics*

Institutional review board approval was obtained prior to the beginning of the study. No outside funding was obtained for the performance of this study.

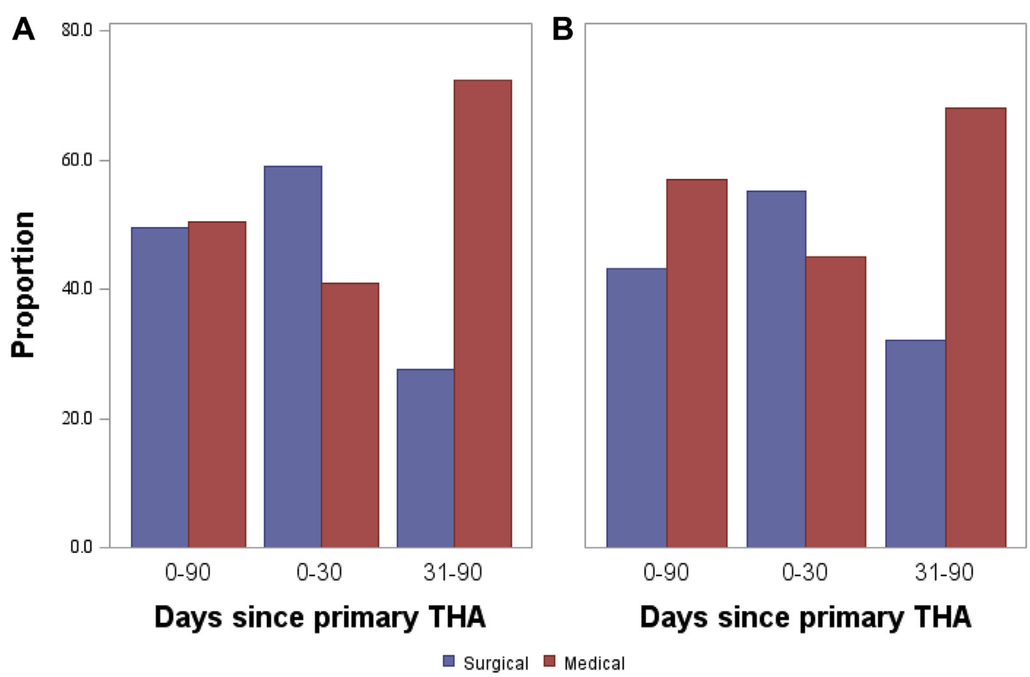


**Fig. 1.** Proportion of (A) ED-only visits and (B) readmissions following elective primary unilateral THA due to surgical or medical primary causes. Blue bars represent surgical cause and red bars represent medical cause. Proportions are stratified according to timing of the event: 90 days overall, within 30 days, and 31-90 days following the primary THA.

## Results

### *Study Sample*

There were 2344 THAs and 5520 TKAs performed at the 3 sites during the study period. About 13.4% of all THAs and 13.8% of all TKAs had at least one 90-day ED-only visit following the primary procedure. Incidence of at least one 90-day readmission following the primary procedure was 4.5% for THA and 5.5% for TKA. The final study sample consisted of 510 and 1208 ninety-day events following THA and TKA, respectively. Of the 510 THA events, 366 (71.8%) were ED-only visits and 144 (28.2%) were readmissions; 88 (61.1%) of THA readmissions were through the ED. Of the 1208 TKA events, there were 931 (77.1%) ED-only visits and 277 (22.9%) readmissions, with 192 (69.3%) of the readmissions readmitted through the ED.

Of the THA patients, the median age was 67-68 years, and the majority were female and had an ASA less than 3 (Table 2). Of the TKA patients, the median age was 68-69 years and were predominantly female with an ASA less than 3 (Table 2). For both THA and TKA ED-only visit groups, the median LOS following the primary procedure was 48 hours, while the median LOS for the readmission groups was over 51 hours. Median time from discharge to return to the ED following THA and TKA was 11 and 12 days, respectively, and from discharge to readmission was 33 and 36 days, respectively.

### *Total Hip Arthroplasty*

Of the 366 ED-only visits following THA, 254 (69.4%) occurred within 30 days of the primary procedure. The majority of ED visits within the first 30 days were due to surgical-related causes, although in the 31-day to 90-day time period the majority were due to medical causes (Fig. 1A). In the first 90 days after primary THA, the top 3 surgically related reasons for ED-only visits included the following: 1, swelling of the operative extremity; 2, related pain; and 3, constipation (Table 3). These were the same top 3 reasons within the first 30 days. The top 3 medically related reasons for 90-day ED-only visit following THA included the following: 1, other musculoskeletal complaints; 2, GU; and 3, GI and other unrelated medical cause (tie). Within the first 30 days only, the top reasons were similar, although GU rather than other musculoskeletal complaints was the predominant reason for readmission.

Readmission events following THA were less frequent than ED events. After primary THA, there were 69 (47.9%) readmissions within 30 days and 75 (52.1%) readmissions in the 31-day to 90-day period. Similar to ED-only visits, the majority of readmissions within the first 30 days were due to surgical-related causes while most were due to medical causes in the 31-day to 90-day time period (Fig. 1B). The top surgically related reasons for 90-day readmissions included the following: 1, deep infection; and 2, dislocation and other related surgical cause (tie) (Table 3). Deep infection was also the top surgical reason within the first 30 days. Top 3 medically related reasons for 90-day readmissions included the following: 1, unrelated elective procedure; 2, cardiovascular; and 3, GI and pulmonary (tie). Within the first 30 days only, cardiovascular was the main medical reason for readmission. There were no elective procedures within the first 30 days.

### *Total Knee Arthroplasty*

There were 667 (71.6%), 30-day ED-only events and 264 (28.4%) in the 31-day to 90-day period following primary TKA. Although the majority of ED-only visits within the first 30 days were almost evenly distributed between surgical and medical-related causes, in the 31-day to 90-day time period the majority were due to medical primary causes (Fig. 2A). The top 3 surgically related reasons for both 90-day and 30-day ED-only visits after primary TKA were the same as THA: 1, related pain; 2, swelling of the operative extremity; and 3, constipation (Table 4). Looking at medically related reasons, the top reasons for ED-only visits in the first 90 days following TKA included the following: 1, GI; 2, other musculoskeletal complaint; and 3, other unrelated medical cause. GI and other unrelated medical cause were also top medical reasons within the first 30 days.

Similar to THA, readmission events were less frequent than ED events following TKA. Of the 277 readmissions following TKA, 123 (44.4%) occurred within 30 days of the primary procedure. The majority of readmissions following primary TKA were due to

**Table 3**
Primary Cause for ED-Only Visit and Readmission Following Primary THA.

| Primary Cause | 0-90 D, n (%) | 0-30 D, n (%) |
|---|---|---|
| ED visit | | |
| Total | 366 (100.0) | 254 (100.0) |
| Surgical | | |
| Swelling | 57 (15.6) | 50 (19.7) |
| Pain related to the primary | 47 (12.8) | 44 (17.3) |
| Constipation | 18 (4.9) | 18 (7.1) |
| Dislocation | 15 (4.1) | 7 (2.8) |
| Cellulitis | 14 (3.8) | 9 (3.5) |
| Serous drainage | 8 (2.2) | 6 (2.4) |
| Deep vein thrombosis | 7 (1.9) | 4 (1.6) |
| Hematoma drainage | 6 (1.6) | 6 (2.4) |
| Other related to the primary | 5 (1.4) | 4 (1.6) |
| Wound dehiscence | 4 (1.1) | 2 (0.8) |
| Manipulation under anesthesia | 0 (0.0) | 0 (0.0) |
| Pulmonary embolism | 0 (0.0) | 0 (0.0) |
| Deep infection | 0 (0.0) | 0 (0.0) |
| Medical | | |
| Other musculoskeletal complaints | 31 (8.5) | 15 (5.9) |
| Genitourinary | 30 (8.2) | 22 (8.7) |
| Gastrointestinal not including constipation | 25 (6.8) | 10 (3.9) |
| Other medical unrelated to the primary | 25 (6.8) | 15 (5.9) |
| Cardiovascular | 18 (4.9) | 12 (4.7) |
| Pulmonary | 18 (4.9) | 8 (3.1) |
| Neurological | 17 (4.6) | 6 (2.4) |
| Pain unrelated to the primary | 14 (3.8) | 10 (3.9) |
| Fever of unknown origin | 6 (1.6) | 5 (2.0) |
| Endocrine | 1 (0.3) | 1 (0.4) |
| Elective procedure unrelated to the primary | 0 (0.0) | 0 (0.0) |
| Readmission | | |
| Total | 144 (100.0) | 69 (100.0) |
| Surgical | | |
| Deep infection | 18 (12.5) | 8 (11.6) |
| Dislocation | 10 (6.9) | 3 (4.3) |
| Other related to the primary | 10 (6.9) | 5 (7.2) |
| Cellulitis | 7 (4.9) | 7 (10.1) |
| Serous drainage | 6 (4.2) | 5 (7.2) |
| Hematoma drainage | 4 (2.8) | 4 (5.8) |
| Deep vein thrombosis | 3 (2.1) | 3 (4.3) |
| Pain related to the primary | 2 (1.4) | 2 (2.9) |
| Pulmonary embolism | 2 (1.4) | 1 (1.4) |
| Constipation | 0 (0.0) | 0 (0.0) |
| Manipulation under anesthesia | 0 (0.0) | 0 (0.0) |
| Swelling | 0 (0.0) | 0 (0.0) |
| Wound dehiscence | 0 (0.0) | 0 (0.0) |
| Medical | | |
| Elective procedure unrelated to the primary | 13 (9.0) | 0 (0.0) |
| Cardiovascular | 12 (8.3) | 7 (10.1) |
| Gastrointestinal not including constipation | 10 (6.9) | 4 (5.8) |
| Pulmonary | 10 (6.9) | 4 (5.8) |
| Other medical unrelated to the primary | 9 (6.3) | 2 (2.9) |
| Other musculoskeletal complaints | 9 (6.3) | 0 (0.0) |
| Neurological | 8 (5.6) | 5 (7.2) |
| Genitourinary | 7 (4.9) | 5 (7.2) |
| Fever of unknown origin | 4 (2.8) | 4 (5.8) |
| Endocrine | 0 (0.0) | 0 (0.0) |
| Pain unrelated to the primary | 0 (0.0) | 0 (0.0) |

Stratified by surgical or medical-related causes then ordered from most to least frequently occurring during the first 90 d postoperatively.

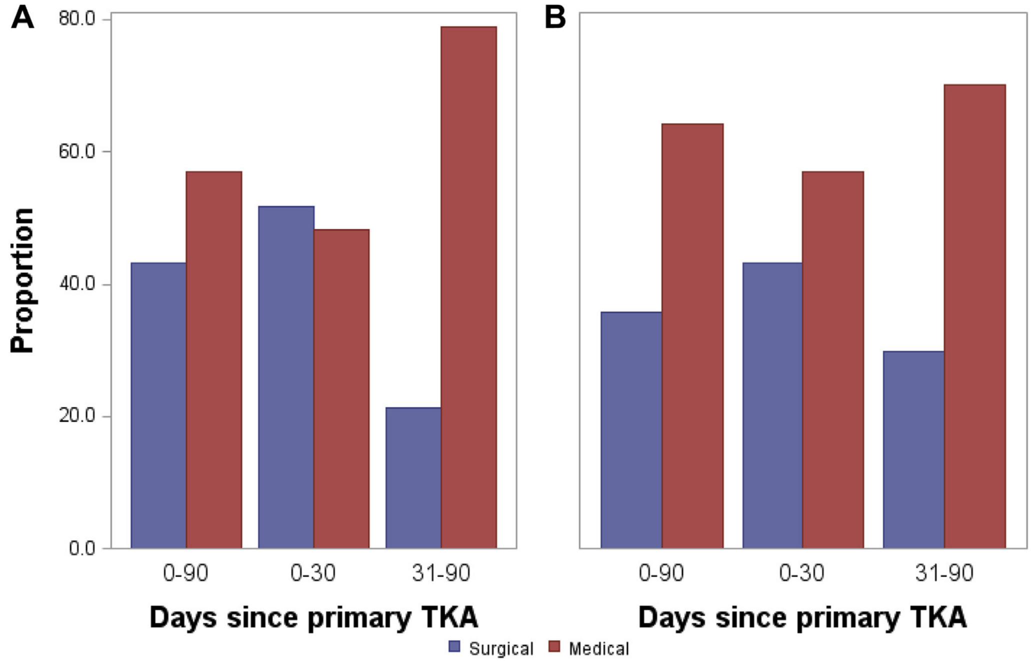


**Fig. 2.** Proportion of (A) ED-only visits and (B) readmissions following elective primary unilateral TKA due to surgical or medical primary causes. Blue bars represent surgical cause and red bars represent medical cause. Proportions are stratified according to timing of the event: 90 days overall, within 30 days, and 31-90 days following the primary TKA.

medical causes in both the 0-day to 30-day and 31-day to 90-day time periods (Fig. 2B). The top 3 surgically related reasons for readmissions in the 90 days after primary TKA included the following: 1, MUA; 2, cellulitis; and 3, deep infection (Table 4). Cellulitis was the main reason for readmission within the first 30 days, while there were no readmissions for MUA. The top medically related readmission reasons in the 90 days following TKA included the following: 1, GI; 2, cardiovascular; and 3, neurological. GI and cardiovascular were also top medical reasons within the first 30 days.

## Discussion

ED visits and readmissions increase the overall cost per episode, utilize hospital resources, place an undue burden on patients and families in the immediate postoperative period, and can have a negative impact on recovery. Attempts to decrease ED visits and readmissions depend on understanding the causes for these visits. For both THA and TKA, we found ED-only visits were more common in the first 30 days postoperative, while readmissions were more common in the 31-day to 90-day period. With the exception of readmissions following TKA, surgically related reasons tended to predominate within the first 30 days, but medically related reasons were more common overall. Pain and swelling were the most common reasons for ED-only visits for both THA and TKA, while infectious reasons were the most common for readmissions.

Similar to prior reports, ED-only visits were more common than readmissions [7,8,11]. Rossman et al [7] reported an ED visit rate of 12%, in line with our 90-day rate. Although Trimba et al [8] found ED visits to be more commonly associated to the surgical procedure, we found medical causes to be the primary reason. This discrepancy may be due to differences in the postoperative time period of interest: surgical reasons predominated in our study sample within the first 30 days, but medical reasons were the primary when looking over the entire 90 days postoperative. Rossman et al [7] found over half of postoperative TKA patients were seen in the ED only without being readmitted, indicating an overuse of the ED for routine issues. Likewise, only 19% and 17% of ED visits in our study resulted in an admission following THA and TKA, respectively. Readmission rates reported here were similar to previous reports [7,12–14] with the majority due to medical causes, in agreement with Trimba et al [8]. Although our sample included elective procedures unrelated to the primary procedure as a medically related cause, even after the exclusion of this group, medical causes were still the primary reason for 90-day readmissions.

Pain and swelling were the most common reasons overall for ED-only visits following both THA and TKA, consistent with prior studies evaluating 30-day [8,11] and 90-day [7] ED visits following primary TJA. The frequency of these reasons in the postoperative period is striking. Patients presenting with pain and swelling are typically screened to rule out DVT. Looking at our TJRR data, 0 of the 104 (0.0%) THA and 2 of the 292 (0.7%) TKA patients presenting to the ED for pain and swelling were later diagnosed with a DVT (data not shown), illustrating the importance of establishing patient expectations, prevention, and proper triage by all personnel involved in the care pathway.

Infectious related causes (deep infection and cellulitis) were the most common reasons overall and the top surgical reasons for readmission following THA. These findings are consistent with prior studies investigating reasons for 30-day [8,15,16] and 90-day [7,12] readmissions in TJA patients, underscoring the importance of infection control measures.

Prior studies are conflicting regarding readmissions due to dislocations following THA. Vorhies et al [17] reported dislocations to be infrequent, while Trimba et al [8] and Schairer et al [13] found dislocations to be a leading reason for readmission. In our study sample, dislocations were a leading surgical-related cause of 90-day, but not 30-day, readmissions for primary THA patients.

Similar to our findings regarding MUA, Schairer et al [18] found arthrofibrosis to be the leading surgical cause of 90-day readmissions, although the study sample also included revision TKA. Zmistowski et al [12] also reported stiffness to be the second leading cause of 90-day readmission following TKA.

**Table 4**
Primary Cause for ED-Only Visit and Readmission Following Primary TKA.

| Primary Cause | 0-90 D, n (%) | 0-30 D, n (%) |
|---|---|---|
| ED visit | | |
| Total | 931 (100.0) | 667 (100.0) |
| Surgical | | |
| Pain related to the primary | 147 (15.8) | 116 (17.4) |
| Swelling | 145 (15.6) | 135 (20.2) |
| Constipation | 58 (6.2) | 52 (7.8) |
| Cellulitis | 24 (2.6) | 19 (2.8) |
| Hematoma drainage | 11 (1.2) | 10 (1.5) |
| Deep vein thrombosis | 7 (0.8) | 6 (0.9) |
| Serous drainage | 7 (0.8) | 6 (0.9) |
| Wound dehiscence | 2 (0.2) | 1 (0.1) |
| Dislocation | 0 (0.0) | 0 (0.0) |
| Manipulation under anesthesia | 0 (0.0) | 0 (0.0) |
| Pulmonary embolism | 0 (0.0) | 0 (0.0) |
| Deep infection | 0 (0.0) | 0 (0.0) |
| Other related to the primary | 0 (0.0) | 0 (0.0) |
| Medical | | |
| Gastrointestinal not including constipation | 114 (12.2) | 62 (9.3) |
| Other musculoskeletal complaints | 85 (9.1) | 33 (4.9) |
| Other medical unrelated to the primary | 74 (7.9) | 49 (7.3) |
| Cardiovascular | 58 (6.2) | 39 (5.8) |
| Genitourinary | 56 (6.0) | 34 (5.1) |
| Neurological | 46 (4.9) | 30 (4.5) |
| Pain unrelated to the primary | 43 (4.6) | 35 (5.2) |
| Pulmonary | 38 (4.1) | 27 (4.0) |
| Fever of unknown origin | 13 (1.4) | 12 (1.8) |
| Endocrine | 3 (0.3) | 1 (0.1) |
| Elective procedure unrelated to the primary | 0 (0.0) | 0 (0.0) |
| Readmission | | |
| Total | 277 (100.0) | 123 (100.0) |
| Surgical | | |
| Manipulation under anesthesia | 26 (9.4) | 0 (0.0) |
| Cellulitis | 23 (8.3) | 22 (17.9) |
| Deep infection | 18 (6.5) | 8 (6.5) |
| Pulmonary embolism | 14 (5.1) | 10 (8.1) |
| Hematoma drainage | 5 (1.8) | 5 (4.1) |
| Wound dehiscence | 5 (1.8) | 3 (2.4) |
| Other related to the primary | 3 (1.1) | 1 (0.8) |
| Serous drainage | 3 (1.1) | 2 (1.6) |
| Pain related to the primary | 1 (0.4) | 1 (0.8) |
| Swelling | 1 (0.4) | 1 (0.8) |
| Constipation | 0 (0.0) | 0 (0.0) |
| Deep vein thrombosis | 0 (0.0) | 0 (0.0) |
| Dislocation | 0 (0.0) | 0 (0.0) |
| Medical | | |
| Gastrointestinal not including constipation | 53 (19.1) | 20 (16.3) |
| Cardiovascular | 23 (8.3) | 11 (8.9) |
| Neurological | 22 (7.9) | 8 (6.5) |
| Elective procedure unrelated to the primary | 21 (7.6) | 1 (0.8) |
| Genitourinary | 20 (7.2) | 11 (8.9) |
| Pulmonary | 16 (5.8) | 5 (4.1) |
| Other musculoskeletal complaints | 11 (4.0) | 4 (3.3) |
| Other medical unrelated to the primary | 7 (2.5) | 5 (4.1) |
| Fever of unknown origin | 4 (1.4) | 4 (3.3) |
| Endocrine | 1 (0.4) | 1 (0.8) |
| Pain unrelated to the primary | 0 (0.0) | 0 (0.0) |

Stratified by surgical or medical-related causes then ordered from most to least frequently occurring during the first 90 d postoperatively.

Jordan et al [19] showed targeted interventions can have a dramatic effect in reducing readmission after TJA. With an interest in addressing preventable reasons of unplanned events, we have instituted a number of changes to the care protocols within our integrated healthcare system. Preoperatively, patient screening and optimization protocols were updated and patient education materials now include detailed instructions on prevention and home treatment of swelling, pain, and constipation. Patient-specific pain medication protocols were adopted, with the goal of using the minimal amount of narcotic medication for the shortest amount of time possible. Intraoperatively, anesthesia protocols were revised to now routinely use spinal and regional using nerve blocks. The pharmacy added an improved local pain cocktail to our formulary and Foley catheters are used more sparingly. Postoperatively, physical therapy makes first contact with patients in the recovery room. Expanded home care teams allow earlier and more frequent patient contacts after discharge. In addition, a proactive nursing follow-up phone call now occurs within the first 2 days after discharge to reinforce discharge instructions and provide answers to common postoperative questions. Our nursing call centers in the healthcare system were given more specific instructions and triage algorithms. Future studies will seek to evaluate the effectiveness of these efforts.

This study has several limitations. First, this study is descriptive in nature, lacking a comparison group to evaluate factors such as LOS, discharge disposition, inpatient vs outpatient surgery, or patient risk factors as variables and risk for ED visits and readmissions. Second, we did not include urgent care or other medical provider visits; this report focuses only on understanding reasons for ED-only visits and readmissions. The EHR captures all ED visits and readmissions to any hospital within our integrated healthcare system; ED visits to outside hospitals are not captured. However, we expect the frequency of this occurring to be low since most patients return to facilities within our integrated healthcare system. Finally, ED-only visits for cellulitis were difficult to confirm retrospectively; there is potential for misclassification of actual superficial infection vs simple redness.

Study strengths include stratification by medical and surgical causes, as well as 30-day and 90-day reasons to comprehensively understand the full postoperative window under BPCI. Furthermore, all ED visits and readmissions were comprehensively chart reviewed by an experienced orthopedic surgeon to discern the most accurate reason for the patient contact. In this manner, we were able to increase the accuracy of the diagnosis, as compared to prior studies relying only on International Classifications of Disease, 9th Revision, Clinical Modification codes. Total joint patients at the 3 participating medical centers shared similar preoperative, intraoperative, and postoperative protocols, which were thought to be a representative sample of what would be commonly found in the general TJA population of the US. Patients are typically discharged to home and followed by home health services for the first 2-3 weeks after discharge, with the first follow-up visit to the operating surgeon in the third week.

## Conclusions

Total joint surgeons and the hospitals in which these procedures are performed are tasked with maintaining a high quality of care while keeping a keen focus on cost containment. Reimbursement models under the BPCI make this effort even more imperative. Postoperative care events negatively affect both quality and cost metrics, and understanding the reasons for these events will help to guide efforts to prevent them. This study identified the reasons for ED visits and readmissions in the 90-day period after primary elective TJA in an integrated healthcare setting over a 3-year period at 3 total joint centers. Since then, changes to our care protocols have been made and the effects of these changes will be evaluated in future studies.

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# Development of a reference chart to monitor postoperative swelling following total knee arthroplasty

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ORIGINAL ARTICLE

# Development of a reference chart to monitor postoperative swelling following total knee arthroplasty

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**ABSTRACT**
**Title:** Development of a reference chart to monitor postoperative swelling following total knee arthroplasty.
**Purpose:** Lower extremity swelling is a feature of total knee arthroplasty. Until recently, clinicians lacked tools to accurately measure swelling in clinical settings, but bioelectrical impedance assessment has shown promise in this regard. The purpose of this study was to develop a reference chart of lower extremity swelling following total knee arthroplasty.
**Method:** Fifty-six participants (54% male, mean age = 64 years) were followed for the first 7 weeks following total knee arthroplasty, during which frequent lower extremity bioelectrical impedance assessments were performed. Using Generalized Additive Models for Location Scale and Shape, a reference chart for swelling was developed with bioelectrical impedance assessment data from the first 40 patients enrolled in the study (223 observations) and preliminarily tested for performance in the remaining 16 patients' data (96 observations).
**Results:** The reference chart illustrates approximately 10% per day increase for the first 3 days following surgery. Peak swelling occurs 6–8 days following surgery; the 10th percentile demonstrates a peak of 25%, whereas the 90th percentile peaks at 47%. In the test data, this reference chart demonstrated accurate coverage at each estimated centile.
**Conclusion:** The reference chart provides a novel framework for monitoring swelling following total knee arthroplasty and may augment clinical decisions to improve postoperative swelling management.

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**KEYWORDS**
Total knee arthroplasty; swelling; reference chart; bioelectrical impedance assessment; monitoring; generalized additive models for location scale and shape

**➤ IMPLICATIONS FOR REHABILITATION**

- The use of bioelectrical impedance assessment provides an accurate and easily implemented approach for rehabilitation professionals to measure swelling.
- The reference chart provided allows for monitoring of patient recovery of swelling following total knee arthroplasty.
- Precise depictions of where a patient's swelling is in reference to others will improve clinical decision making at the individual level.

## Introduction

Total knee arthroplasty is the most common inpatient elective surgery, at over 700,000 procedures per year in the United States [1]. Although it is widely regarded as effective at reducing pain and improving quality of life in patients with end-stage knee osteoarthritis [2,3], total knee arthroplasty results in an immediate and profound loss of knee extensor strength [4–6]. This early postoperative strength loss is driven by a deficit in voluntary activation [5–7], which limits rehabilitation potential and ultimately exacerbates long-term weakness [8], predisposing patients to reduced physical functioning relative to their healthy peers [9]. Lower extremity swelling likely contributes to postoperative weakness through altered neuromuscular excitability and inhibition of voluntary activation of the extensor mechanism [10–13]. Clinically, the relationship between swelling and knee extensor strength has been shown in people following total knee arthroplasty, indicating a need for improved approaches to managing swelling following the surgery [14,15].

To date, clinical assessment of lower extremity swelling after total knee arthroplasty has been limited by the available measures. Circumferential measures are highly imprecise and influenced greatly by bandaging and dressings early after surgery, and volumetric methods are difficult to perform and present a possible infection risk [16,17]. Recently, bioelectrical impedance assessment has emerged as a safe, easy and accurate method by which to assess lower extremity swelling [18]. Moreover, swelling measured using bioelectrical impedance assessment has demonstrated relationships with poor physical functioning and reduced strength following total knee arthroplasty [15]. Therefore, bioelectrical impedance assessment holds promise as a clinical tool for monitoring postoperative swelling, to assist patients and providers in limiting the swelling response and maximizing the potential for strength and functional recovery.

The purpose of this study was to develop and preliminarily validate a reference chart for lower extremity bioelectrical impedance assessment, following total knee arthroplasty, to provide an intuitive framework for clinical monitoring of postoperative

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Step 1) Have the patient lie supine for ~10 minutes and begin with the uninvolved limb
Step 2) Place the electrodes as shown
1) 20 cm proximal to the superior patellar pole over the midline of the thigh
2) 10 cm proximal to the superior patellar pole over the midline of the thigh
3) On a point midway between the medial and lateral malleolus
4) 10 cm distal to the midway point between the malleoli over the 2nd ray
Step 3) Attach electrode leads as shown
Step 4) Turn on the device, wait ~ 5 seconds, and record the value
Step 5) Perform the same technique on the involved limb
Step 6) Use the formula to calculate percent swelling: **(1-(Inv. Bioelectrical impedance assessment/Uninv. Bioelectrical impedance assessment))*100**

**Figure 1.** Instructions and set-up example for using bioelectrical impedance assessment in the measurement of swelling.

swelling at the level of the individual patient. To be useful in practice, individual-level bioelectrical impedance assessment values should have context; they should be examined relative to what is expected, considering the magnitude and variability typically observed in bioelectrical impedance assessment over time. By this approach, patients and providers can quickly garner whether a patient's lower extremity swelling appears relatively controlled or not, and real-time adjustment of treatment plans may be possible (e.g., by varying the dose of lower extremity elevation or limb compression, etc.) [19,20]. Thus, the overall goal of this study was to produce a clinically implementable tool for monitoring post-total knee arthroplasty swelling, to serve as a mechanism for improving postoperative care and optimizing patient functioning.

## Methods

### *Study design and participants*

Data used in this analysis were collected as part of a longitudinal, observational study conducted at the University of Colorado Denver, Anschutz Medical Campus. Swelling measurements were collected from 56 people undergoing surgery by one of three surgeons at the University of Colorado Hospital, both prior to surgery and at seven different points over the first 7 weeks post-total knee arthroplasty. The timing of assessments was pseudorandomized in an attempt to maximize coverage over the first 7 weeks following surgery. This time frame was chosen to capture the rapid postoperative increase and subsequent decrease that is typically observed with post-total knee arthroplasty swelling [21]. All outcomes were collected by the same team of four researchers trained in all testing methods, and data was stored in Research Electronic Data Capture (REDCap), a secure web-based software [22]. Patients enrolled in the study participated in routine postoperative physical therapy that did not include specific management for swelling, other than instructions to elevate the surgical leg when sitting or lying. Inclusion criteria for the study were as follows: undergoing a primary, unilateral total knee arthroplasty for osteoarthritis and aged between 50 and 90 y/o. Exclusions included neurological conditions or unstable orthopedic conditions limiting participation, history of orthopedic surgery or trauma within one year of study enrollment, or diagnosis of a condition known to result in lower extremity edema. All study procedures were approved by the Colorado Multiple Institution Review Board (COMIRB #15-1419).

### *Procedures*

Lower extremity swelling was measured using bioelectrical impedance assessment. This approach has been validated for the measurement of swelling in patients with upper extremity lymphedema [16] and in patients following total knee arthroplasty [18,21,23]. All measurements were taken using an RJL systems Quantum II body composition analyzer© (Clinton Township, MI) and recorded in Ohms. Two electrodes were placed over the second ray on the dorsum of the foot separated by 10 cm and two were placed on the thigh, 10 and 20 cm proximal to the superior pole of the patella (Figure 1). Swelling values are presented as percentage difference in the involved limb to the uninvolved limb using the formula: (1-(involved bioelectrical impedance assessment/uninvolved bioelectrical impedance assessment))*100. By normalizing to the uninvolved limb, bioelectrical impedance assessments accounted for differences in body composition between subjects, allowing for the accurate measurement of changes in fluid status between the limbs [16].

### *Statistical analysis*

To build and preliminarily validate the reference chart, the full dataset was divided temporally (based on surgical date) into development and test sets according to a 70%/30% split, as previously described [24]. This approach allowed us to build the reference chart with the first 40 participants (223 observations; surgical dates: December 2015–December 2016) and test its performance with the remaining 16 participants (96 observations; surgical dates: December 2016–May 2017). This provides a more rigorous preliminary test performance of the chart than a random sampling approach.

**Table 1.** Descriptive variables for development and test data.

| | Development | Test | *p* value |
|---|---|---|---|
| *N* (obs.) | 40 (223) | 16 (96) | – |
| Age (mean; SD) | 64.75;9.07 | 63.3;9.9 | 0.52 |
| Sex (% male) | 55% | 44% | 0.1 |
| BMI (mean; SD) | 32.5;5.5 | 30.0;5.2 | 0.08 |
| Pre-total knee arthroplasty swelling % (mean; SD) | 1.01;7.93 | <1;6.86 | 0.82 |

*T*-test was used to compare proportions and chi-square was used to compare frequency counts (i.e., sex). Significance was set at $p < 0.05$

In the development set, the median, variance, skewness, and kurtosis of bioelectrical impedance assessments were found to vary over time following surgery. Therefore, we chose a modeling approach that would accommodate a high level of flexibility in these parameters. Generalized Additive Models for Location, Scale and Shape (R statistical computing) [25] is commonly used for such applications and is the recommended method for building clinical reference charts such as the World Health Organization (WHO) growth standards [26]. Within Generalized Additive Models for Location Scale and Shape, a variety of distributional families are available to enable the construction of increasingly flexible models, and we chose to examine the performance of three such families.

The normal distribution family modeled the median and variance of bioelectrical impedance assessments over time, the Box-Cox Cole and Green distribution modeled the median, variance, and skewness over time, and the Box-Cox Power Exponential distribution modeled the median, variance, skewness and kurtosis over time [27]. The flexibility was adjusted by optimizing the number of smoothing spline knots and power transformation of time using the "find.hyper" function in the Generalized Additive Models for Location Scale and Shape package. The overall model fit was compared across these three distributional families using the Schwarz Bayesian Criterion as a numerical guide and by examining the accuracy of centile coverage (i.e., comparing the percentage of realized observations captured below each of the specified centiles). The performance of the best fitting model was then examined in the test set data. The actual percentage of observations below each of the specified centiles was compared to the expected value using *z*-tests for proportions.

## Results

Demographic information for the development and test sets are provided in Table 1. A total of 217 people were screened for enrollment in the study; 37 declined and 124 were excluded due to neurological conditions (7), history of orthopedic surgery or trauma within one year of study enrollment (35), or diagnosis of a condition known to result in lower extremity edema (39), not receiving total knee arthroplasty for osteoarthritis (5), and 38 did not live in the area. No significant differences were seen in sex frequency distributions, mean age and BMI, or mean levels of pre-operative lower extremity bioelectrical impedance assessment values. A total of 319 bioelectrical impedance assessments were performed over the first 52 days following surgery.

### *Reference chart development and test performance*

Using the "find.hyper" function in Generalized Additive Models for Location Scale and Shape, the number of smoothing spline knots for each parameter was optimized (Table 2), and the power transformation of time was set at 0.01, reflecting a rapid increase in swelling in the initial days following surgery. These characteristics were then used to build three reference charts according to the selected distributional families and the resultant Schwarz Bayesian Criterion values and centile coverages were assessed (Table 2). Each of the distributional families displayed similar and acceptable coverage, although the normal distribution model was found to have the lowest Schwarz Bayesian Criterion (Figure 2). This model also appeared to be most parsimonious (with fewer overall degrees of freedom). Thus, the reference chart constructed with the normal distribution family was selected for preliminary test performance in the test set, where it also demonstrated satisfactory performance; none of the specified centiles demonstrated coverage significantly different from the expected proportions (Figure 2).

### *Reference chart for lower extremity bioelectrical impedance assessment following total knee arthroplasty*

The clinical reference chart for post-total knee arthroplasty swelling is provided in Figure 3. The underlying model captures a period of rapid increase and subsequent decrease in swelling, across all centiles, occurring over approximately the first 15 days post-total knee arthroplasty. This is followed by an attenuation in the rate of decline of swelling from days ∼15–50 following surgery. At the later time-points (∼7 weeks), the 10th percentile indicates ∼10% swelling of the involved limb relative to the uninvolved limb, while the 90th percentile indicates values greater than 35% of the uninvolved limb. The reference chart provided in Figure 3 can be used to monitor individual patient swelling over the first 7 weeks following total knee arthroplasty.

## Discussion

This study used a promising, clinically feasible method for measuring lower extremity swelling following total knee arthroplasty to construct a reference chart for clinical use. Across all centiles of the reference chart (10th, 25th, 50th, 75th, and 90th) a common trajectory is observed; there is a period of rapid increase in swelling immediately following surgery ∼10% per day over the first three days and the peak occurs at ∼6–8 days post-total knee arthroplasty. There is substantial variability in peak swelling; the 10th centile peaked at 25% swelling, the estimated median peaked at 35%, and the 90th centile peaked at 47%. Following the peak, all centiles demonstrated a decrease in swelling over the next ∼6 weeks. However, even at 50 days post-total knee arthroplasty all centiles demonstrated swelling values higher than the contralateral limb (10th centile =10% swelling). This finding aligns with past literature, which has shown persistent swelling to occur in a substantial proportion of patients following total knee arthroplasty (18% of satisfied patients and 36% of unsatisfied patients) [28]. Overall, this reference chart may be used to inform assessments of patients' lower extremity swelling status and to augment clinical decisions regarding the postoperative management of swelling.

The centile reference chart presented here allows for visualization of the trajectory of lower extremity swelling and its variability

**Table 2.** Schwarz Bayesian Criterion (SBC) and centile proportions for each of the tested distributions in the development set.

| Model optimized parameters df(mu) = 3, df(sigma) = 0, df(nu) = 1, df(tau) = 1 | Model DF | SBC | 10th | 25th | 50th | 75th | 90th |
|---|---|---|---|---|---|---|---|
| NO | 7 | 1700.41 | 9.87 | 26.46 | 50.67 | 74.89 | 87.44 |
| BCCG | 10 | 1714.58 | 10.31 | 27.35 | 50.22 | 75.34 | 88.79 |
| BCPE | 13 | 1724.65 | 9.42 | 25.11 | 52.02 | 75.78 | 88.34 |

Optimized model parameters are provided.
df(mu): number of degrees of freedom for the median parameter; df(sigma): number of degrees of freedom for the variance parameter; df(nu): number of degrees of freedom for the skewness parameter; df(tau): number of degrees of freedom for the kurtosis parameter; NO: Normal Distribution; BCCG : Box Cox Cole and Green; BCPE : Box-Cox Power Exponential

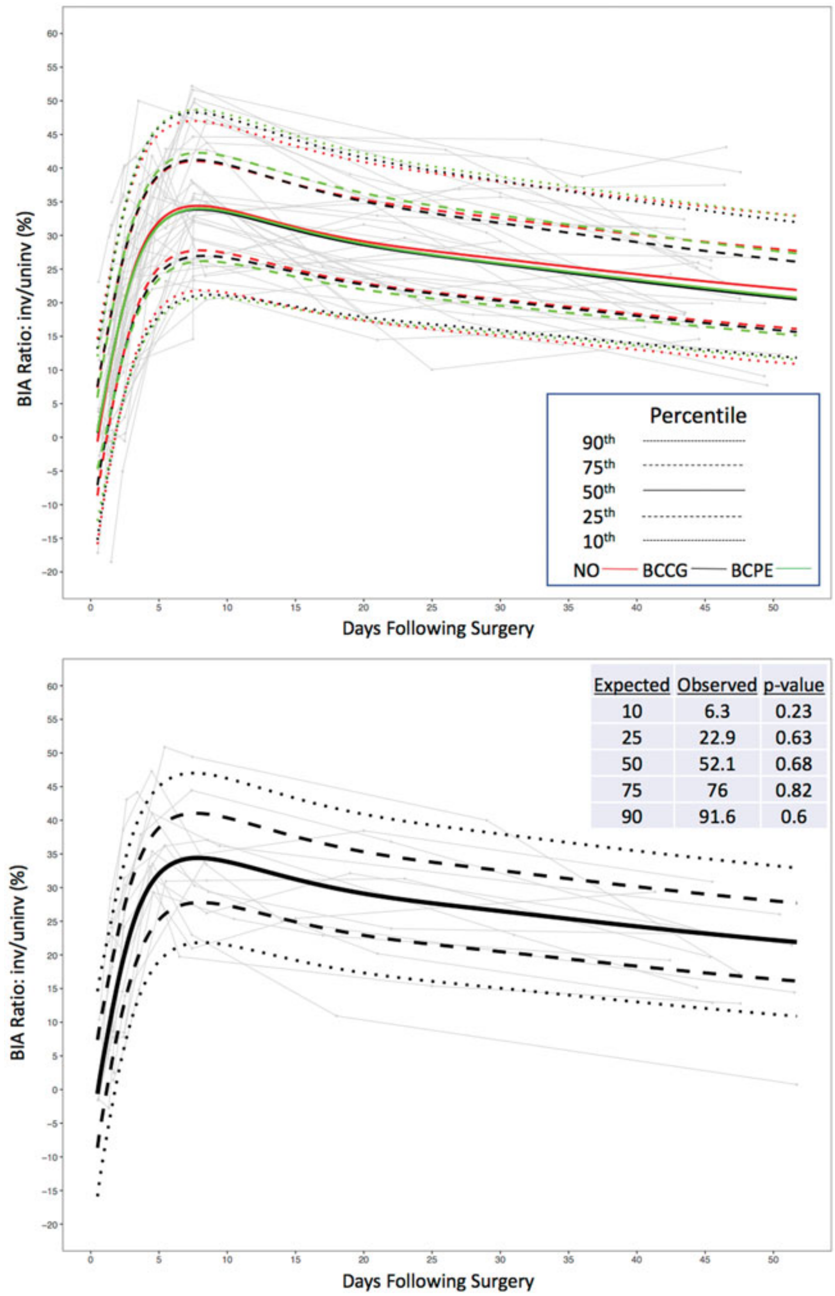


**Figure 2.** (A) Plots of NO, BCCG, and BCPE distributions on development data. (B) Final NO model displayed on test data with observed proportions of each centile and $p$ values. (Significance $p < 0.05$). NO: Normal distribution; BCCG: Box-Cox Cole and Green distribution; BCPE: Box-Cox Power Exponential.

Patient Name:___________________

Therapist Name:_________________

**Swelling Formula:**

(1-(Inv. bioelectrical impedance assessment/Uninv. bioelectrical impedance assessment))*100

Notes:

| Date | BIA Involved | BIA uninvolved | % Swelling |
|---|---|---|---|
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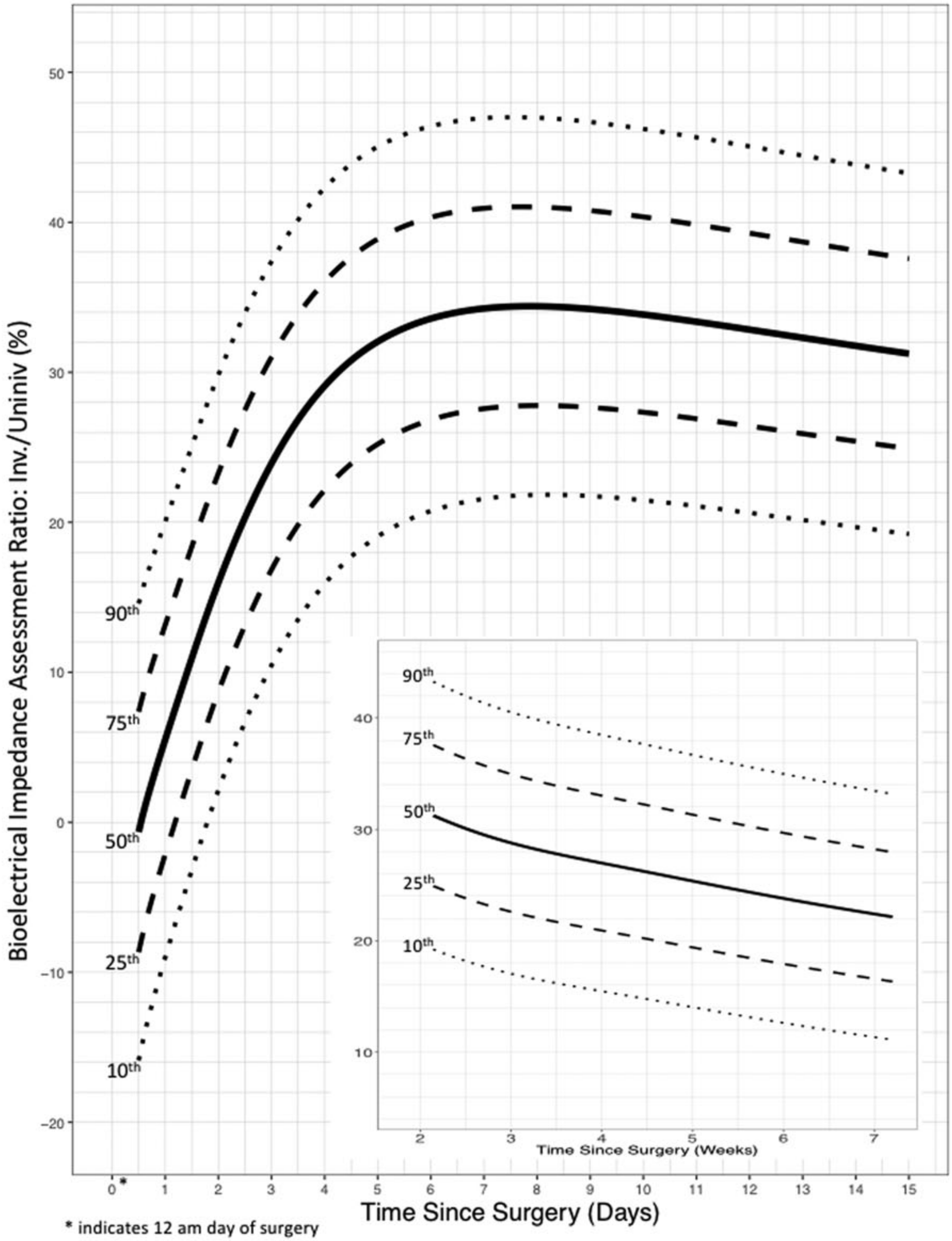


Figure 3. Reference chart of post-total knee arthroplasty swelling measured using bioelectrical impedance assessments over the first 50 post-operative days. Large pane is trajectory over the first 15 days, insert is trajectory from weeks 2–7.

following total knee arthroplasty, improving substantially on previous estimations of post-total knee arthroplasty swelling. It will help to inform clinicians and patients about the expected recovery of swelling and help inform future investigations aimed at managing the swelling at critical times during the postoperative period.

Until recently, the measurement of swelling following total knee arthroplasty was primarily done using circumferential methods or other techniques [16,29,30]. These techniques either lack the precision and reliability needed to develop useful trajectories (i.e., circumferential measures), or they are not feasibly performed in the clinic (i.e., water submersion) [16,29]. The introduction of bioelectrical impedance assessment as a measure of post-total knee arthroplasty swelling has provided a new and promising approach that improves on older techniques [16,18,21]. However, even with emerging evidence supporting the use of bioelectrical impedance assessment as an effective swelling measure, to date, no clinically useful trajectory of post-total knee arthroplasty swelling has been produced, and in most cases the best available evidence is mean and SD information available only at specified points in time [14,31]. Thus, no information exists to inform the expected recovery trajectory across all patients following total knee arthroplasty. Pua [21] used bioelectrical impedance assessment to quantify swelling after total knee arthroplasty and demonstrated the average level of swelling for patients over the first 90 days following surgery. This estimate follows a similar trajectory to that produced in the current study, demonstrating similar rapid increases in swelling early after surgery and slower declines in the days and weeks following. It also supports the current finding that swelling remains beyond 7 weeks post-total knee arthroplasty. However, the plot of post-total knee arthroplasty swelling provided by Pua only presents the sample mean and fails to provide information regarding the variability in the recovery of swelling. Thus, the expected trajectory of those patients with more or less swelling cannot be interpreted. By plotting the centiles, the current model provides information critical to determining how an individual relates to the population and allows for interpretation of expected recovery across varying levels of swelling.

Swelling has been identified by patients as critical to successful recovery and health care providers including, nurses, physicians, and physical therapist are often consulted by patients regarding the expected trajectory and duration of swelling [28,32–34]. Furthermore, lower extremity swelling is hypothesized to influence other critical elements of functional recovery and pain management following total knee arthroplasty [14,21,35]. Specifically, past evidence has shown that swelling is related to worse strength and slower walking speeds over the first 90 postoperative days [21]. Considering the impact swelling has on patients' perceptions of recovery and its potential to delay recovery of function, swelling emerges as an important target for intervention. The authors ascertain that an improved understanding of the post-total knee arthroplasty swelling trajectory will benefit clinical practice by helping with the placement of patient expectations, assisting in patient monitoring, and helping to identify targets for intervention in those patients presenting with detrimental levels of swelling.

Consider two patients, each of which have recently undergone total knee arthroplasty. Patient one is preparing to discharge from the hospital and has asked the health care providers how quickly the swelling will reach its peak, the maximum level it can be expected to reach, and when to expect a noticeable reduction? Patient two is four weeks out of surgery and participating in outpatient rehabilitation. Swelling has been a continual issue for this patient and appears to be interfering with the recovery of function. Without a clinically useable depiction of the trajectory of post-total knee arthroplasty swelling these patients and their providers are left with very little information.

The use of a reference chart to support monitoring of post-total knee arthroplasty swelling by bioelectrical impedance assessment could lead to improvements in care. The use of a reference chart would allow providers to easily convey information regarding prognosis and help to properly place patient expectations alleviating the concerns of patient one. It also allows for the easy visualization of a patient's swelling values in relation to others who have undergone the surgery. By simply plotting the swelling values on the reference chart shared decision making can be enhanced, allowing the patient and the provider to discuss swelling status and management strategies. This could assist in the development of a treatment strategy for patient two as the patient and the provider work together to develop an effective treatment plan to address ongoing swelling issues and monitor its progress over time.

## Study limitations

This study has limitations. The small sample size may make the estimation of the centiles on the periphery less precise (e.g., 10th and 90th) and could limit the ability to detect differences in the distributions. However, the outer centiles remain stable in this approach because they are estimated along with the central ones. The use of a much larger sample (say 10 times larger) may add refinement to centile shape, which may have been lost with smoothing. However, by testing the reference chart in a model performance step further supports that by restricting the flexibility in our model we do not experience large changes when applied to new data. The time points selected for swelling measurement only occurred over the first 7 weeks following surgery and do not allow for interpretation at later time points. There are also postoperative periods in the dataset where coverage of swelling measurements over time is rather sparse. Especially in these regions, generalizability to other datasets or populations of people undergoing total knee arthroplasty could be questioned. Thus, there remains a need for prospective validation of this reference chart in other datasets. However, the performance of the reference chart in a test set of data (with later surgical dates) is reassuring, and this preliminary test performance of the chart is a strength of this study. It is worth noting that the use of reference charts in monitoring child growth have not been validated in all populations, but are still used as an important clinical tool. Determining how these can be implemented in various populations and how they perform clinically becomes an implementation science question, which may be a fruitful area of future research.

## Conclusion

This study describes the development and test performance of a reference chart for lower extremity swelling following total knee arthroplasty using generalized additive models for location scale and shape. A variety of models were examined, but ultimately a relatively simple model was found to have the best statistical fit and also performed well in out-of-sample test performance of the chart. The reference chart and the instructions for measuring swelling with bioelectrical impedance assessment, provided here, will contribute to the management of swelling and will assist in patient monitoring and placement of expectations.

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# The relationship between lower extremity swelling, quadriceps strength, and functional performance following total knee arthroplasty☆

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ABSTRACT

*Background:* The relationships between swelling after total knee arthroplasty (TKA) and quadriceps strength and functional performance are poorly understood.
Therefore, the aim of this study was to examine the relationships between lower extremity swelling, measured using bioelectrical impedance assessment (SF-BIA), and quadriceps strength and timed up and go (TUG) times following TKA.

*Methods:* 53 participants (64 ± 9.5 y/o, 43% male) undergoing primary unilateral TKA were recruited for the longitudinal observational study with repeated measures.
Quantities of swelling were examined for contribution to two and six-week outcomes of strength and TUG time using hierarchical regression controlling for age, sex, and the baseline value of the dependent variable. Swelling was assessed using bioelectrical impedance assessment and quantified as the peak level of swelling and cumulative swelling (integral) over the post-TKA time window. Maximum isometric quadriceps strength (MVIC) was measured using a electromechanical dynamometer and participant functional performance measured using the TUG.

*Results:* Neither peak swelling nor cumulative swelling significantly contributed to the variance of two-week quadriceps strength. At six weeks, peak swelling significantly improved the variance in maximal quadriceps strength by an additional four percent ($p = 0.05$), while cumulative swelling did not significantly contribute. Peak swelling significantly contributed to the variance in two-week (16%) and six-week (five percent) TUG times ($p < 0.05$), but the cumulative swelling did not.

*Conclusions:* Peak swelling represents a value of post-TKA swelling that is associated with strength and function. Reducing the peak level of swelling, occurring early after surgery, may improve patient functional recovery.

*Level of evidence:* Level II — Prospective observational study.


☆ Declarations of interest: none.

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## 1. Introduction

Limiting functional decline following total knee arthroplasty (TKA) is a high priority for patients and clinicians. Functional decline following surgery is common and includes, but is not limited to, decreased walking speed [1], difficulty rising from a chair [2,3], and reduced stair climbing ability [4,5]. Poor performance on more difficult activities has also been reported in patients many years after surgery [6,7]. Functional limitations following surgery are often attributed to the significant decline in quadriceps muscle strength following surgery [8–10]. Thus, increasing quadriceps strength and improving functional mobility remain a focal point of most post-TKA rehabilitation. As a result, research aimed at improving post-TKA outcomes has focused on identifying causes of quadriceps strength loss and decline in functional performance [10–15].

One hypothesized mechanism contributing to quadriceps strength loss and decline in functional performance following TKA is lower extremity swelling [7,13,16]. Swelling occurs substantially in and around the knee joint capsule in the majority of patients following TKA. The presence of swelling after TKA is thought to reduce muscle strength by decreasing voluntary muscle activation through a process referred to as arthrogenic muscle inhibition (AMI) [7,13,17]. Arthrogenic muscle inhibition results when sensory afferent signaling increases the influence of inhibitory interneurons on motor neuron excitability [13]. The relationship between swelling and AMI of the quadriceps has been shown to occur acutely with artificially-induced effusion of the knee [7,18]. These studies provide the theoretical framework for the investigation of the relation between swelling and motor function following TKA.

While there is growing evidence to support the hypothesis that swelling may be a contributor to post-TKA quadriceps strength loss [19,20], there remains a need to further explore this relationship. This can be explored by analyzing how changes in swelling after TKA relate to quadriceps muscle strength at different points in the recovery process and by examining different measures of swelling. Furthermore, the relationship between swelling and functional performance remains poorly understood. Swelling may result in decreased functional performance by contributing to strength loss in muscles throughout the lower extremity or by causing other impairments that influence functional performance, such as knee range of motion. Thus, the relationship between swelling and functional performance should be examined independent of quadriceps strength.

The purpose of this study was to determine the relationship between swelling and strength and functional performance after TKA. We hypothesized that swelling will be significantly related to quadriceps strength and patient performance on the timed up and go (TUG) test at two and six weeks following surgery. Identification of these relationships will help inform clinicians and researchers as they design interventions to target swelling with the intent of improving patient functional performance.

## 2. Methods

### *2.1. Participants*

Data used in this analysis were collected as part of a longitudinal observational study examining post-TKA swelling and quadriceps strength, consisting of 53 participants consecutively recruited from three different orthopedic surgeons between December 2015 and April 2017. Data were collected at baseline (pre-TKA) and days zero, one, two, four, seven, two weeks, and six weeks (post-TKA). Inclusion criteria for the study included: undergoing a primary, unilateral TKA for osteoarthritis and ages 50 to 90 y/o. Exclusion criteria included: neurological conditions or unstable orthopedic conditions that limited function, history of orthopedic surgery or trauma within one year of study enrollment, or diagnosis of a condition known to result in lower extremity edema (i.e., heart failure and primary or secondary lymphedema). Informed consent was obtained from all participants. This study was approved by the Colorado Multiple Institutional Review Board (COMIRB #15-1419).

### *2.2. Outcomes assessments*

#### *2.2.1. Swelling*

Lower extremity swelling was assessed using Bioelectrical Impedance Assessment (BIA). This approach has been validated for the measurement of swelling in patients with upper extremity lymphedema [21] and in patients following TKA [22,23]. All measurements were taken using an RJL systems Quantum II body composition analyzer© (Clinton Township, MI) and recorded in Ohms. Two electrodes were placed over the second ray on the dorsum of the foot separated by 10 cm and two were placed on the thigh, 10 and 20 cm proximal to the superior pole of the patella, a similar method for measuring swelling with bioelectrical impedance spectrometry has been previously used [24]. Swelling values are recorded as a percentage difference in the involved limb to the uninvolved limb using the formula:

$$\mathrm{BIA}_{\mathrm{ratio}} = (1-(\text{involved BIA}/\text{uninvolved BIA})) * 100$$

By normalizing the uninvolved limb, the $\mathrm{BIA}_{\mathrm{ratio}}$ controls for differences in body composition (i.e., BMI) between subjects and accurately measures changes in swelling between the limbs [21].

Utilizing the $\mathrm{BIA}_{\mathrm{ratio}}$, two different quantities of the swelling response were calculated: peak level of swelling and the cumulative swelling (integral) over time. Peak swelling is represented by the maximum value in involved limb swelling recorded at any of the post-TKA assessments. This value was chosen, as the authors hypothesize that the peak level may represent the time when swelling is likely to be the most damaging to the neuromuscular system. Cumulative swelling was calculated using the “sintegral” function in the Bolstad2 package in R (Bolstad2 1.0) [25]. This function calculates the trapezoidal area under the curve. Two integral values were calculated, one for the first two weeks and a second for the full six-week post-TKA period. Because swelling values were not always collected at exactly 14 and 42 days following surgery, significant variation in the integral of the swelling measures was possible. Therefore, when examining integral swelling values in the regression models time since surgery was controlled for. When examining the univariate correlations, swelling assessments occurring at 14 ± 2 days were used for the two-week swelling value, while assessments occurring at 42 ± 2 days were used for the six-week swelling value. For those two-week and six-week assessments that occurred beyond the accepted window, imputation was performed to estimate a swelling at day 14 or 42. This was done by assuming a linear relationship between the preceding and following swelling values and calculating the point corresponding with either the 14th or 42nd post-TKA day. If swelling values were not collected within or beyond the 14th and 42nd day, imputation could not be performed and those patient records were not used in the correlations. Cumulative swelling was chosen to represent the total amount of swelling experienced over the two windows of time (days 0–14 & 0–42). Examples of cumulative swelling (integrals) are provided in Figure 1.

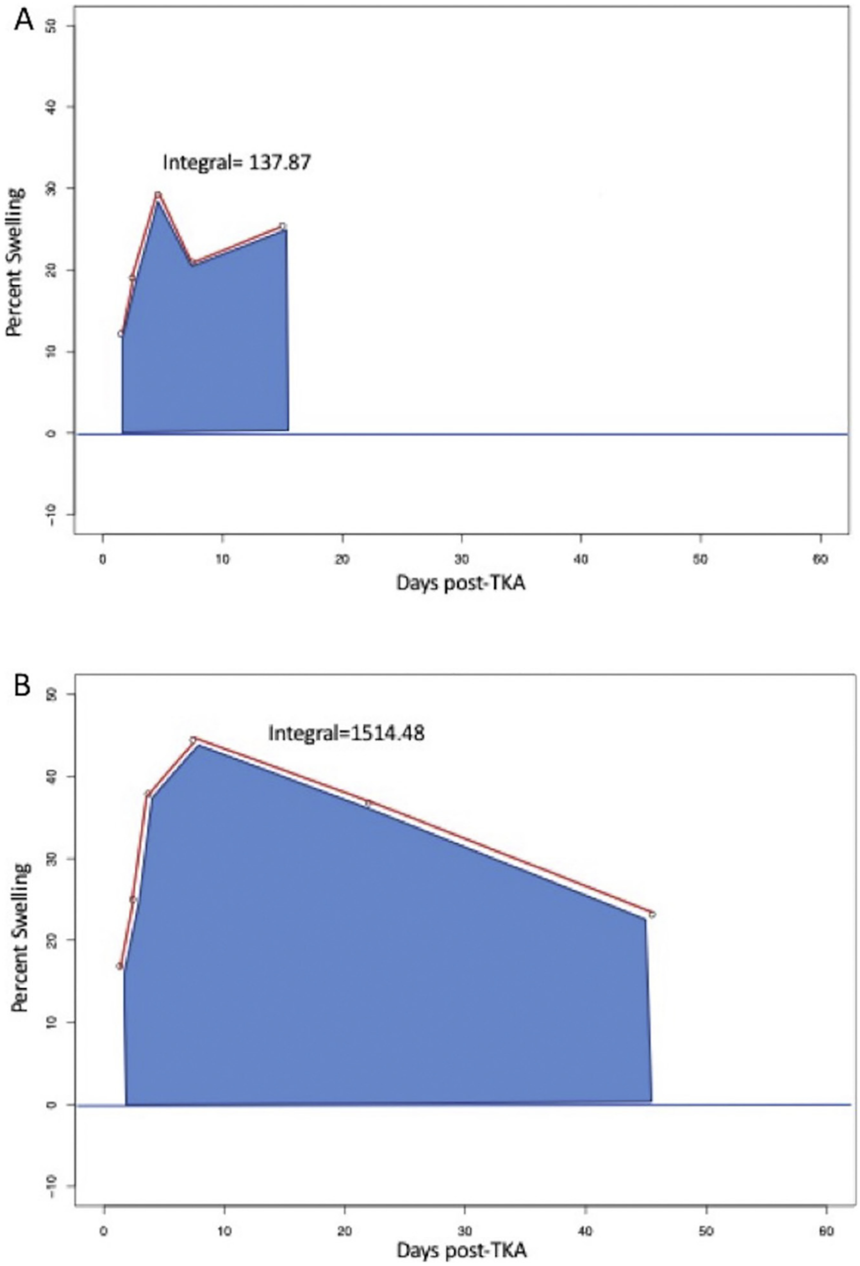


**Figure 1.** Examples of the calculation of A) Early cumulative swelling (integral of ~14 days) and B) full cumulative swelling (integral of ~42 days) using trapezoidal integration.

#### 2.2.2. Quadriceps strength assessment

Quadriceps strength was measured as a maximum voluntary isometric contraction (MVIC) and recorded in Newton-meters (N-m) using an electromechanical dynamometer (Humac Norm) with the participant seated upright and positioned in 90 degrees of hip flexion and 60° of knee flexion. Each participant performed two warm up trials followed by maximal contractions as previously described [1]. If the force values produced in the first two maximal attempts were not within five percent of one another, additional trials were performed until two trials were within five percent of each other and the highest value of the two was used for analysis.

#### 2.2.3. TUG test assessment

The TUG is a timed test of the patient ability to rise from an arm chair (seat height of 46 cm), walk three meters, turn, and return to sitting in the same chair without physical assistance [26]. TUG is a valid and reliable measure, and decreased performance on the TUG has been shown to correlate with increased risk of falls and higher rates of mortality in elderly patients [26]. This test has excellent inter-rater (Intraclass Correlation Coefficient (ICC) = 0.99) and intra-rater (ICC = 0.99) reliability, as measured in a group of older adults (mean age 80 years) [27]. In our study, participants performed the TUG test twice during each assessment, and the average of the two trials was used for analysis.

Assessments of swelling, strength, and TUG time were performed during the same sessions at each time point and were always performed in the same order, beginning with BIA measures of swelling, followed by the TUG test, and concluding with quadriceps strength assessments.

### 2.3. Calculation

General relationships between the peak and cumulative levels of swelling and the dependent variables of interest were established using Pearson product correlations at two and six weeks following surgery [28].

To estimate the effect of swelling on post-operative quadriceps strength and TUG time, hierarchical regression modeling was used. Hierarchical model building was chosen because it allows for determination of the individual contribution of the independent variable of interest to the variance in the dependent variable when controlling for other important covariates [29,30]. Step one consisted of modeling known covariates of interest (i.e., sex and age), and in the case of the swelling integral, time since surgery, on the dependent variable. In step two, pre-TKA values for the dependent variables were added to the model. In step three, the swelling value of interest is added to the model. In steps two and three, the coefficients and 95% Confidence Interval (CI) as well as the standardized coefficients were calculated for the independent variables of interest. Standardized coefficients were used to allow for easy assessment of the model contribution for each independent variable. In total, eight models were examined, one for each dependent variable regressed on each of the swelling values, at two and six weeks. Model fit was tested by examining the change in adjusted r-squared, the F-statistic, and level of model significance at each step. Model significance was defined as a p-value ≤0.05. The contribution of the independent variable to the model was examined using the variable p-value, parameter estimate, standardized coefficient, and the contribution to the adjusted r-squared.

## 3. Results

Patient characteristics as well as baseline swelling, strength, and TUG times are included in Table 1. Imputation was performed to calculate swelling values seven times and four participants did not have sufficient data for assessment of swelling, therefore, 49 participants were available for analysis. Additionally, from the 49 participants with usable swelling data two participants were unwilling to perform the TUG or strength testing at two weeks and at six weeks TUG and strength data were missing for five participants. Data missing at six weeks was a result of multiple factors including participants unable to perform the testing, testing equipment failure, and time restraints. This missing data was less than five percent of the useable data at two weeks and ~10% at six weeks.

### 3.1. Correlation between swelling, strength, and function

Pearson correlation coefficients, shown in Table 2, demonstrate that the peak swelling significantly correlated with quadriceps strength at two and six weeks, whereas cumulative swelling was only related to six-week strength. Peak swelling was significantly related to two-week TUG time, but had a weaker correlation at six weeks. Cumulative swelling was not correlated with TUG time at two or six weeks.

### 3.2. Hierarchical modeling of quadriceps strength

Table 3 presents the results of the hierarchical regression modeling for the outcome of two and six week quadriceps strength. When added as step three of the hierarchical regression, neither peak swelling or cumulative swelling were found to significantly contribute to the variance in the outcome of quadriceps strength at two weeks ($p = 0.22$ and $p = 0.98$, respectively)(Table 3). At six weeks, both full models were found to be significant, but the majority of the model variance was explained by pre-TKA strength. However, with the addition of peak swelling a significant contribution of an additional four percent of the variance was explained ($p = 0.05$), while cumulative swelling failed to reach significance at six weeks ($p = 0.47$).

**Table 1**
Demographic and baseline information for study participants.

| | |
|---|---|
| Age mean (SD) | 64.2 (9.5) |
| Sex (% female) | 57% |
| BMI mean (SD) | 31.9 (5.4) |
| Pre-TKA swelling % mean (SD) | 1.7 (6.8) |
| Pre-TKA strength (N-m) mean (SD) | |
| Involved | 105.7 (55.8) |
| Uninvolved | 125.2 (54.3) |
| TUG time (s) mean (SD) | 10.1 (2.8) |
| Comorbidity, frequency (%) | |
| HBP | 29/53 (55%) |
| Diabetes | 7/53 (13%) |
| Cancer | 4/53 (8%) |
| RA | 0/53 (0%) |

BMI — Body mass index.
TUG — Timed up and go test.
HBP — High blood pressure.
RA — Rheumatoid arthritis.

### *3.3. Hierarchical modeling of TUG time*

Table 4 presents the results of the hierarchical regression modeling for the outcome of two and six-week TUG time. Peak swelling was found to explain a significant portion of the variance in two-week TUG time ($p = 0.003$) (Figure 2). At the six-week time point, peak swelling significantly contributed to the variance in TUG time ($p = 0.04$) (Figure 2). The standardized beta coefficient for peak swelling was greater than pre-TKA TUG time at two weeks (0.45 vs 0.05), while at six weeks, the standardized beta coefficient for peak swelling was nearly equal to that of pre-TKA TUG time (0.27 vs 0.28). Cumulative swelling did not significantly contribute to two-week ($p = 0.14$) or six-week ($p = 0.47$) TUG time.

## 4. Discussion

This study was designed to examine the relationships between swelling following TKA, quadriceps strength, and functional performance. It was hypothesized that higher peak levels of swelling and greater cumulative swelling over time (integral) would be associated with lower quadriceps strength and slower TUG times. At both two and six weeks following surgery, peak swelling was found to significantly contribute to the variance in TUG time. Similarly, peak swelling significantly contributed to the variance in six-week quadriceps strength. Interestingly, cumulative swelling did not significantly contribute to the variance in two or six-week TUG time or quadriceps strength. The strength of the relationships between peak swelling and TUG time is compelling, especially at two weeks following surgery when peak swelling was a stronger predictor of functional performance than pre-TKA TUG time. While this full model only explained 20% of the variance in TUG time, 16% of the variance was explained by peak swelling, demonstrating the relative impact swelling has on functional recovery after TKA.

These findings add depth to our understanding of the swelling response after TKA by examining two different measurements of post-operative swelling. This quantitative information helps evaluate the relationship between swelling and quadriceps strength loss and examining the association of swelling to functional performance is critical to understanding the widespread impact swelling has on recovery from TKA.

The two swelling measures, peak swelling and cumulative swelling, were chosen based on physiologic rationale for influencing strength. Peak swelling represents the maximum level of recorded swelling for each participant. This value was chosen based on past literature showing continual decreases in knee extensor torque with increasing levels of knee joint effusion [31]. While the current study did not simultaneously test strength at the time of peak swelling, reductions in voluntary activation when swelling is at its highest could reduce the ability to benefit from strengthening activities. This is a result of an inability to achieve physiologic muscle overload with AMI, which could contribute to quadriceps disuse. Disuse is likely to contribute to both immediate

**Table 2**
Pearson correlation coefficients (95% CI) between swelling variables and strength outcomes.

| | Maximal strength | p-Value | TUG time | p-Value |
|---|---|---|---|---|
| *2 weeks (N = 49)* | | | | |
| Peak swelling (%) | r = −0.32 (−0.56, −0.04) | 0.02* | 0.43 (0.16, 0.65) | 0.003* |
| Cumulative swelling (integral) | r = −0.18 (−0.44, 0.13) | 0.23 | 0.26 (−0.04, 0.51) | 0.08 |
| *6 weeks (N = 48)* | | | | |
| Peak swelling (%) | r = −0.45 (−0.65, −0.17) | 0.002* | 0.25 (−0.04, 0.51) | 0.09 |
| Cumulative swelling (integral) | r = −0.33 (−0.57,-0.04) | 0.03* | 0.23 (−0.07, 0.49) | 0.12 |

TUG — Timed up and go test.
* Significant at $p < 0.05$.

**Table 3**
Hierarchical model building examining swelling measures and outcome of knee extensor strength.

| Dependent variable | Independent variables | Added Variable Statistics | | | Model Statistics | | | |
|---|---|---|---|---|---|---|---|---|
| | | Estimate (95% CI) | Standardized Coefficient | p-Value | Adj. R2 | F-statistic | df | p-Value |
| Strength (2 weeks) | | | | | | | | |
| Step 1 | Age + sex | – | | – | 0.03 | 1.66 | 2, 45 | 0.2 |
| Step 2 | Age + sex + baseline strength | 0.15 (0.006,0.29) | 0.4 | 0.04 | 0.1 | 2.65 | 3, 44 | 0.06 |
| Step 3 | Age + sex + baseline strength + peak | −0.50 (−1.31 0.34) | −0.2 | 0.22 | 0.11 | 2.40 | 4, 43 | 0.06 |
| | Age + sex + baseline strength + time since surgery + cumulative | −0.004 (−0.10 0.09) | −0.01 | 0.98 | 0.09 | 2.01 | 5, 42 | 0.09 |
| Strength (6 weeks) | | | | | | | | |
| Step 1 | Age + sex | – | | – | 0.37 | 13.88 | 2, 42 | <0.0001* |
| Step 2 | Age + sex + baseline strength | 0.38 (0.16, 0.60) | 0.54 | 0.001 | 0.5 | 15.83 | 3, 41 | <0.0001* |
| Step 3 | Age + sex + baseline strength + peak | −1.17 (−2.37, 0.02) | −0.24 | 0.05 | 0.54 | 13.71 | 4, 40 | <0.0001* |
| | Age + sex + baseline strength + time since surgery + cumulative | −0.008 (−0.04, 0.02) | −0.09 | 0.47 | 0.48 | 9.98 | 5, 39 | <0.0001* |

* Significant at $p < 0.05$; df — degrees of freedom; Adj. R2 — Adjusted r-squared.

and longer-term strength loss. Peak swelling might also reflect the magnitude of swelling at which muscle fibers experience damage. High levels of swelling have been shown to cause alterations in muscle cell water volume and internal pressure. These changes have been associated with strength loss in people following extreme endurance exercise [32]. The swelling integral was chosen as a measure of the cumulative swelling over time. The authors hypothesized that prolonged exposure to elevated levels of swelling may represent an abnormal or unhealthy response and may contribute to difficulty with recovery of strength and function. However, the lack of significant relationships between cumulative swelling and the outcomes of interest may be a result of the body's ability to accommodate to prolonged periods of elevated swelling. Unfortunately, prior lab based studies have only examined the acute influence of swelling and the impact of prolonged swelling is not yet understood.

The role of swelling in strength loss is supported by studies such as Palmeri-Smith et al. 2007 [16] and others [18,33], which demonstrated that the injection of saline into the knee results in significant AMI. These studies have shown that effusion in the knee joint capsule causes increased signaling from group II mechanoreceptors and, in large part, from group III and IV afferent fibers, which become sensitive to mechanical stimulation in the presence of swelling [34,35]. As afferent signaling increases from each of these fiber types, AMI occurs and a decline in muscle activation is observed [13,35–38]. Furthermore, studies have directly shown a reduction in quadriceps strength in the presence of artificial knee joint effusion [39–41]. In an attempt to link swelling to muscle activation in patients following TKA a couple studies have examined the influence swelling has on strength in this patient population [19,20]. Pua et al. 2015 [20] used methods similar to those used in the current study to examine the

**Table 4**
Hierarchical model building examining swelling measures and outcome of TUG time.

| Dependent variable | Independent variables | Added variable statistics | | | Model statistics | | | |
|---|---|---|---|---|---|---|---|---|
| | | Estimate (95% CI) | Standardized Coefficient | p-value | Adj. R2 | F-statistic | df | p-value |
| TUG time (2 weeks) | | | | | | | | |
| Step 1 | Age + sex | – | – | – | 0.07 | 2.399 | 2, 45 | 0.1 |
| Step 2 | Age + sex + baseline TUG time | 0.07 (−0.4,0.5) | 0.05 | 0.7 | 0.04 | 1.329 | 3, 44 | 0.2 |
| Step 3 | Age + sex + baseline TUG + Peak | 0.23 (0.07,0.40) | 0.45 | 0.003 | 0.2 | 3.757 | 4, 43 | 0.01* |
| | Age + sex + baseline TUG + time since surgery + cumulative | 0.01 (−0.005,0.03) | 0.22 | 0.14 | 0.06 | 1.578 | 5, 42 | 0.18 |
| TUG time (6 weeks) | | | | | | | | |
| Step 1 | Age + sex | – | | – | 0.25 | 8.172 | 2, 42 | 0.001* |
| Step 2 | Age + sex + baseline TUG | 0.2 (0.02,0.39) | 0.28 | 0.03 | 0.31 | 7.546 | 3, 41 | 0.0003* |
| Step 3 | Age + sex + baseline TUG time + Peak | 0.07 (0.002,0.14) | 0.27 | 0.04 | 0.36 | 7.2 | 4, 40 | 0.0002* |
| | Age + sex + baseline TUG + time since surgery + cumulative | 0.002 (−0.006,0.02) | 0.17 | 0.48 | 0.28 | 4.462 | 5, 39 | 0.002* |

* Significant at $p < 0.05$; TUG — timed up and go test.

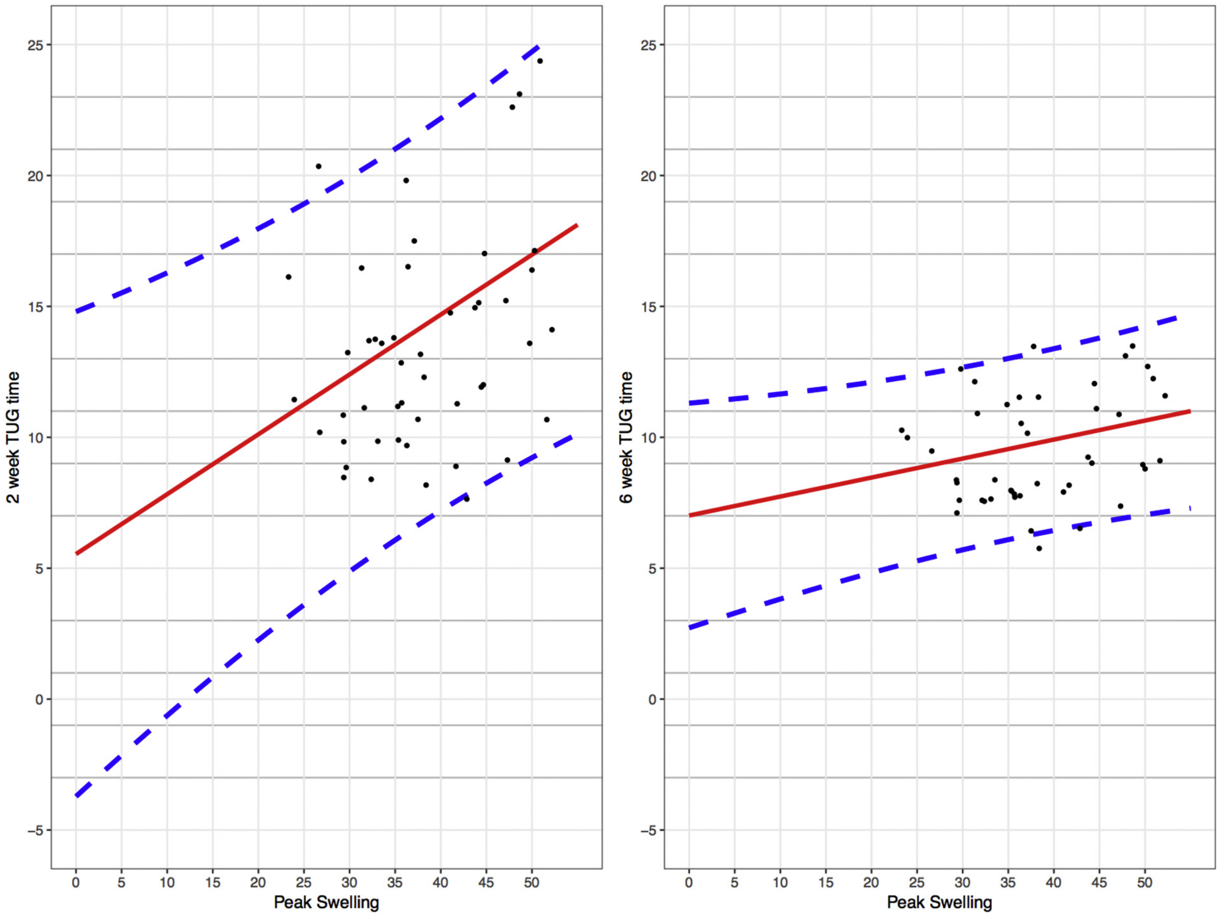


**Figure 2.** Relationship between peak swelling and A) two-week TUG time and B) six-week TUG time from the linear model when controlling for baseline TUG time, age, and sex.

relationship between swelling after TKA and quadriceps strength. In this study, swelling over the first 90 days after TKA, measured using BIA, was found to be significantly related to quadriceps strength over the same 90 days. Specifically, differences between those participants in the highest percentile of swelling and those in the lowest over the entire 90 days, when controlling for age, sex, pre-TKA strength, and pain, were found.

Findings from the current study echo those shown by Pua, but add further insight into the relation of swelling after TKA and quadriceps strength, specifically, by examining swelling levels as the peak acute level of swelling and the cumulative level of swelling. When added to the model, peak swelling reached significance ($p = 0.05$), demonstrating the incremental decline in six-week strength that occurs with increasing levels in peak swelling. Furthermore, in the previous work a dichotomy of the people with the highest and lowest levels of swelling was used. In this study swelling differences were viewed continuously allowing us to provide estimates of the affect incremental increases in peak swelling have on strength. Specifically, for each percentage point increase in peak swelling, a reduction of nearly 0.25 N-m in six-week strength occurred when controlling for age, sex, and pre-TKA quadriceps strength. Additionally, the standardized beta coefficient for peak swelling is of clinical consideration, as it is nearly half the magnitude of that of pre-TKA quadriceps strength (−0.27 vs. 0.54), suggesting that swelling contributes to post-TKA quadriceps strength loss in a clinically meaningful way. However, the authors note the need to be cautious in the interpretation of the standardized coefficient, with the positive skew in quadriceps strength this result has potential for over estimation. These findings add to the findings by Pua, demonstrating the individual contribution of peak swelling to the variance in quadriceps strength, above that explained by pre-operative strength, which is known to be the strongest predictor of post-TKA strength [9]. Reducing peak swelling may also be more clinically feasible than attempting to reduce mean swelling over the first 90 post-TKA days, as was the measure of swelling used by Pua.

Perhaps the most compelling finding from the current study was the strong contributions peak swelling made to TUG times at two and six weeks. Particularly, the finding that peak swelling was a significant predictor of two-week TUG performance, while pre-TKA TUG time was not. The TUG is a commonly used performance measure for determining patient's mobility status after TKA [42], and it is strongly correlated with patient independence [26]. It is also known to correlate with quadriceps strength following

TKA [8]. Despite a weaker relation between swelling and strength, a strong relation between swelling and TUG time supports the hypothesis that swelling is associated with recovery beyond reducing maximal quadriceps strength.

Swelling may result in strength declines in different muscles aside from the quadriceps that are also critical to performance-based outcomes. Declines in muscle strength of the plantar flexors, hip extensors, and hip abductors could be influenced by swelling occurring throughout the limb and detected by BIA. Each of these muscle groups contributes to functional mobility and is likely to contribute to TUG test performance [43–45]. The plantar flexor muscles have been found to experience significant strength loss following TKA [46], which is likely driven by decreased activation or disuse. The influence activation plays in plantar flexor strength has been demonstrated in patients after immobilization from ankle fracture [47,48]. Therefore, the significant declines in plantar flexor strength, observed following TKA, could be associated with declines in activation caused by swelling in different lower extremity compartments (e.g., calf and ankle). Swelling in and around the plantar flexor muscles has also been shown to result in fiber swelling and decreased force producing ability [32]. In a similar way, swelling throughout the lower extremity could contribute to the decline in strength of hip extensors and abductors, shown to occur following TKA and known to contribute to functional performance [45,49,50]. While evidence exists to support strength loss throughout the lower extremity following TKA [46], linking this loss to swelling will require investigations of these muscle, but will benefit from measuring swelling using BIA, which captures swelling throughout the entire limb.

Secondary hypotheses are that swelling impairs the quadriceps muscles by reducing submaximal force steadiness [51], rate of torque development, [52] and/or eccentric control [53], all of which may be impacted following surgery and may impair functional performance. Swelling may also alter functional recovery by contributing to factors such as limited joint mobility [8], decreased proprioception [54], or increased pain [55]. Specifically, early after surgery decreased ROM has been shown to correlate with slower TUG times [8]. Future work should examine these relationships and test whether they may mediate or moderate the relationship between swelling and functional performance.

This study has limitations that require further examination. The time points for strength assessment were chosen because the authors believed they would provide both an early and later assessment of strength outcomes and would capture swelling when it was greatest and most likely to contribute to strength loss. However, the lack of strong relationships between swelling and strength may be partially explained by the chosen time points that also did not account for time of day of swelling assessment. Two weeks following surgery patients are likely to be influenced by a number of factors that can lead to decreased strength or an inability to accurately perform strength assessments. These factors include pain, fatigue, stiffness, and fear of movement. Unfortunately, this study was not designed to examine all of these factors. Additionally, by using the linear interpolation method for calculating missing swelling values there is a potential that in some cases swelling may have been under estimated, potentially influencing the observed relationship between cumulative swelling and the outcomes. Secondarily, this analysis was limited by a small sample, reducing the number of covariates from what had been used previously [20]. Lastly, bioelectrical impedance assessment is a reliable and precise way of measuring swelling, but this measure captures changes across the entire lower extremity. This could lead to inaccurate representation of the swelling in the knee joint capsule—the location where swelling is most likely to contribute to AMI of the quadriceps and may explain the small affect detected between swelling and strength.

## 5. Conclusion

Total knee arthroplasty is the most commonly performed elective orthopedic surgery in the United States, and improving outcomes following TKA remains an important priority for clinicians and patients. While the post-TKA recovery is complex and associated with a number of factors, findings from past studies and this current study indicate that managing swelling following TKA may lend itself to improved outcomes. Specifically, this study has shown a strong relationship between peak swelling and TUG times at both two and six weeks following surgery. Peak swelling provides an ideal clinical target for management due to its time course and explicit value. Recent evidence suggests that peak swelling typically occurs between days six and 10 following surgery [56]. Intervention approaches designed to target peak swelling during this window may improve patient functional performance during the early and longer term following surgery.

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## Conflict of interest statement

None of the authors report any conflicts of interest related to the submitted work titled "THE RELATIONSHIP BETWEEN SWELLING, QUADRICEPS STRENGTH, AND FUNCTIONAL PERFORMANCE FOLLOWING TOTAL KNEE ARTHROPLASTY".

This study was approved by and followed all ethical standards of the Colorado Multiple Institutional Review Board (COMIRB #15-1419).

## Ethical statement

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Health Policy & Economics

# Emergency Department Visits Within Thirty Days of Discharge After Primary Total Hip Arthroplasty: A Hidden Quality Measure

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ABSTRACT

*Background:* Thirty-day hospital readmissions following total hip arthroplasty (THA) have received increasing scrutiny by policy makers and hospitals. Emergency department (ED) visits may not necessarily result in an inpatient readmission but can be a measure of performance and can incur costs to the health system. The purpose of this study is to describe the following: (1) the frequency and subsequent disposition; (2) patient characteristics; (3) reasons; and (4) potential risk factors for ED visits that did not result in a readmission within 30 days of discharge after THA.

*Methods:* All primary THAs performed at a large healthcare system between 2013 and 2015 were identified. Patients who received unplanned hospital services for complications within 30 days following surgery were identified and analyzed. A multiple regression analysis was utilized to identify risk factors predisposing for returning to the ED without readmission.

*Results:* From a total of 6270 primary THAs, 440 patients (7%) had an unplanned return to the hospital within 30 days. Of those, 227 (3.6%) patients presented to the ED and were not readmitted. Higher percentage of African Americans was noted among patients who returned to the ED versus those who did not (20.2% vs 9.8%, $P < .01$). The most common medical diagnoses were nonspecific medical symptoms (24.8%) followed by minor gastrointestinal problems (10.5%). The most common surgery-related diagnoses were pain and swelling (35%), followed by wound complications (12%) and hip dislocations (7.3%). Nearly 50% of wound complications and 40% of hip dislocations were managed and discharged from the ED without a readmission. Both African Americans (odds ratio 2.28, 95% confidence interval 1.55-3.36) and home discharge (odds ratio 1.90, 95% confidence interval 1.28-2.82) were independent risk factors for return to the ED without readmission.

*Conclusion:* ED visits that do not result in hospital readmissions, many of which may be due to serious complications, are more frequent than inpatient readmission. This is extremely relevant to policy makers and quality metrics, especially as comprehensive and bundled payment initiatives become more prevalent.



Thirty-day hospital readmissions following inpatient hospitalization have received increasing scrutiny by the Centers of Medicare and Medicaid Services, policy makers, and hospitals. With recent healthcare reimbursement models and the paradigm shift from "volume-based care" to "value-based care," hospital readmission rates became a key performance metric for payment through the Hospital Readmission Reduction Program, which penalizes hospitals with higher than expected readmission rates [1]. However, readmission measures are all defined as admission episodes to an inpatient floor within a specified time interval from the primary discharge, and do not take into account emergency department (ED) visits or observation stays. The Hospital Readmission Reduction Program has been followed by the implementation of the Bundled Payments for Care Improvement initiative [2,3], with a single global fee for all services related to the index episode [4–7]. This includes subsequent ED care in addition to inpatient readmission.

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Total hip arthroplasty (THA) patients may present to the ED shortly after hospital discharge for a number of complications, including wound problems, periprosthetic joint infections, prosthetic hip dislocations, periprosthetic fractures, and medical problems [8–10]. Some of these complications can be potentially managed and discharged from the ED, without being captured as a quality or performance metric. For instance, a trial of local wound care or vacuum dressing and oral antibiotics can be utilized for a draining surgical site. Additionally, a dislocated THA can be successfully reduced under conscious sedation without the need for inpatient readmission. Hence, identifying these ED visits is crucial as some of these may be avoidable, and thus are a measure of performance. Furthermore, under the Bundled Payments for Care Improvement initiative, these ED visits are a financial burden to the healthcare system.

The frequency and cost of ED visits after hospital discharge and their effect on patient outcomes and satisfaction are largely unknown, as there is paucity of literature describing them after THA. Therefore, the purpose of this study is to investigate the following: (1) the frequency and subsequent disposition; (2) patient characteristics; (3) reasons; and (4) potential risk factors for ED visits that did not result in an inpatient readmission within 30 days of discharge after primary THA.

## Methods

### Data Acquisition

Following approval by our Institutional Review Board, we queried the electronic databases of a large hospital healthcare system for all patients who underwent primary THA between January 1, 2013 and December 31, 2015, which encompassed 11 hospitals in a single state. Our system included 3 academic and 8 community hospitals, with 12 EDs. We identified 6270 patients. Patient demographics, comorbidities with calculation of the Charlson Comorbidity Index [11], and surgical variables were collected. Overall, the mean age of the study cohort was $63 \pm 12$ years. The majority of the individuals were Caucasian (89.4%). Diabetes without end-organ damage was the most common comorbidity (11.7%), followed by chronic pulmonary disease (8.9%) and tumor (8.2%). The mean Charlson Comorbidity Index was $3.6 \pm 2.0$. The majority of individuals within this cohort resided in-state (90%) and had a primary care physician (99.7%). With regards to operative parameters, most of the index THA procedures were performed in community hospitals (62.6%) by fellowship-trained adult reconstruction surgeons (63.4%), who had a mean experience of $19 \pm 11$ years. The mean operative time was $101 \pm 33$ minutes. Patients stayed in the hospital for a mean of $3.0 \pm 1.4$ days and the majority were discharged home (71%).

Patients who received unplanned hospital services for complications within 30 days following surgery were identified. Hospital services include in-network facility ED visits with discharge destinations to either home or to hospital inpatient and direct hospital readmissions. Medical records of all patients with a prolonged inpatient length of stay over 5 days, which is 2 standard deviations above the average, and any in-network facility ED visit, hospital readmission, or surgical encounter for the 30 days following the date of surgery were reviewed by 2 of the authors (MF and DB).

**Table 1**
Medical Complications Described by Pulido et al.

| Complication | Definition |
|---|---|
| Neurologic | |
| Major | Stroke, anoxic brain injury, seizure |
| Minor | Delirium, confusion, transient ischemic attack |
| Cardiovascular | |
| Major | Myocardial infarction, cardiopulmonary arrest, hemodynamic instability requiring ICU, arrhythmia requiring intervention/treatment |
| Minor | Chest pain, sinus tachycardia, hypotension |
| Pulmonary | |
| Major | Requiring ventilator after surgery, aspiration pneumonia, pneumothorax |
| Minor | Atelectasis, shortness of breath, pneumonia requiring antibiotics |
| Gastrointestinal | |
| Major | GI bleed, bowel obstruction, acute abdomen |
| Minor | Ileus, gastroenteritis, constipation |
| Urinary | Urinary retention, urinary infection |
| "Other/nonspecific" medical symptoms | All complications requiring hospital care that did not fit into a defined category |

ICU, intensive care unit; GI, gastrointestinal.

**Table 2**
Surgical Complications Based on the Hip Society Criteria.

| Complication | Definition |
|---|---|
| Bleeding | Postoperative bleeding requiring surgical treatment |
| Wound complications | Failure of wound healing requiring reoperation or a change in THA protocol |
| Thromboembolic disease | Symptomatic thromboembolic event requiring more intensive, nonprophylactic anticoagulant or antithrombotic treatment |
| Neurovascular injury | Intraoperative vascular injury requiring surgical repair. Postoperative neural deficit (sensory or motor) related to the index THA |
| Dislocation | Dislocation of the femoral head out of the acetabulum or recurrent symptomatic subluxation of the hip |
| Periprosthetic fracture | Periprosthetic fracture of the proximal femur or the acetabulum |
| Abductor mechanism disruption | Symptomatic abductor dysfunction, which was not present before the operation, associated with positive Trendelenburg sign and use of an ambulatory assist (cane, crutch, walker) for treatment of limp or weakness |
| Periprosthetic joint infection | Meet Musculoskeletal Infection Society criteria |
| Heterotopic ossification | Symptomatic heterotopic ossification at 1 y after operation associated with stiffness, reduced ROM, and radiographic grade of Brooker III or IV |
| Implant loosening/failure | • Implant loosening confirmed intraoperatively or identified radiographically as a change in implant position or a progressive radiolucent line at the bone-cement or bone-implant interface<br>• Wear of the bearing surface that is symptomatic or requires operation<br>• Dissociation of the cup liner from the acetabular shell<br>• Implant fracture |
| "Other" surgery-related complications | All complications requiring hospital care that did not fit into a defined category (ie, leg swelling and postoperative hip pain) |

THA, total hip arthroplasty; ROM, range of motion.

Each identified patient record was manually reviewed to confirm the occurrence, classify the complication, and exclude any elective care unrelated to the index THA. We tabulated the number of complications requiring separate instances of hospital services occurring in the first 30 postoperative days. Complications were divided into medical and surgical. Medical complications were subclassified according to the definitions used by Pulido et al [12] (see Table 1). Surgical complications were subclassified according to the definitions of the Hip Society [13,14] (see Table 2). All complications requiring hospital care that did not fit into a defined category were recorded as "other." Chart review data were compiled in a REDCap database [15].

*Study Endpoints and Analysis*

Patient characteristics were compared between patients who returned to the ED and those who did not return within 30 days after THA. Next, we compared medical and surgical complications between patients who returned to the ED but were not readmitted and those who returned to the ED and were readmitted. We used chi-squared tests for binary and categorical variables and Student's t-tests for continuous variables. A $P$-value <.05 was considered statistically significant.

A multiple logistic regression analysis was utilized to identify risk factors predisposing patients to return to the ED without being readmitted within 30 days after THA. The pooled population included patients with no complications within 30 days following THA and patients who presented to the ED and were discharged home. Patients who presented to the ED and were admitted to inpatient service and patients who were directly admitted to inpatient services were excluded from the pooled population for the analysis. For all analyses, we used STATGRAPHICS Centurion XVIII software (Statpoint Technologies, Inc, Warrenton, VA).

## Results

*Frequency of ED Visits and Subsequent Disposition*

Of 6270 patients who underwent primary THA between January 2013 and December 2015, 440 patients (7%) had an unplanned return to the hospital within 30 days. Of those, 343 (5.5%) patients presented through the ED. One hundred sixteen patients (1.9%) were readmitted from the ED to an inpatient floor, and 227 (3.6%) patients were discharged from the ED (see Fig. 1).

*Patient Characteristics*

When comparing patients who did not have an unplanned return to the hospital with patients who returned to the ED, several differences were found (see Table 3). There was a higher percentage of African American patients in the group who returned to the ED versus those who did not (20.2% vs 9.8%, $P < .01$). Cerebrovascular disease, chronic pulmonary disease, chronic liver disease, and renal disease were more common in patients who returned to the ED ($P \leq .01$). These patients had slightly longer hospital stays (3.3 vs 3.0, $P < .01$). Among the group of patients who returned to the ED, more patients underwent THA at an academic hospital compared to patients who did not return to the ED (43.3% vs 37%, $P = .01$). Government insurance was more common among patients who returned to the ED (63.7% vs 56.5%, $P = .04$).

*Reasons for ED Visits*

Of the 343 patients who returned the ED, 184 (53.6%) had a medical reason and 206 (60%) had a surgery-related complication (see Table 4). The most common medical reason for returning to the ED was nonspecific medical symptoms which was not put into our a priori categorization (85 patients, 24.8%), including nausea and vomiting, nonsurgical site musculoskeletal pain, and nonspecific fever. The second most common medical reason for returning to the ED was minor gastrointestinal problems (36 patients, 10.5%) and most of these patients were not readmitted (24 patients, 66.7%). Patients who returned to the ED and were readmitted to an inpatient floor had a statistically higher percentage of major central nervous system complications, major cardiac complications, major gastrointestinal complications, and overall high medical complications when compared to patients who were not readmitted (see Table 4 and Fig. 2).

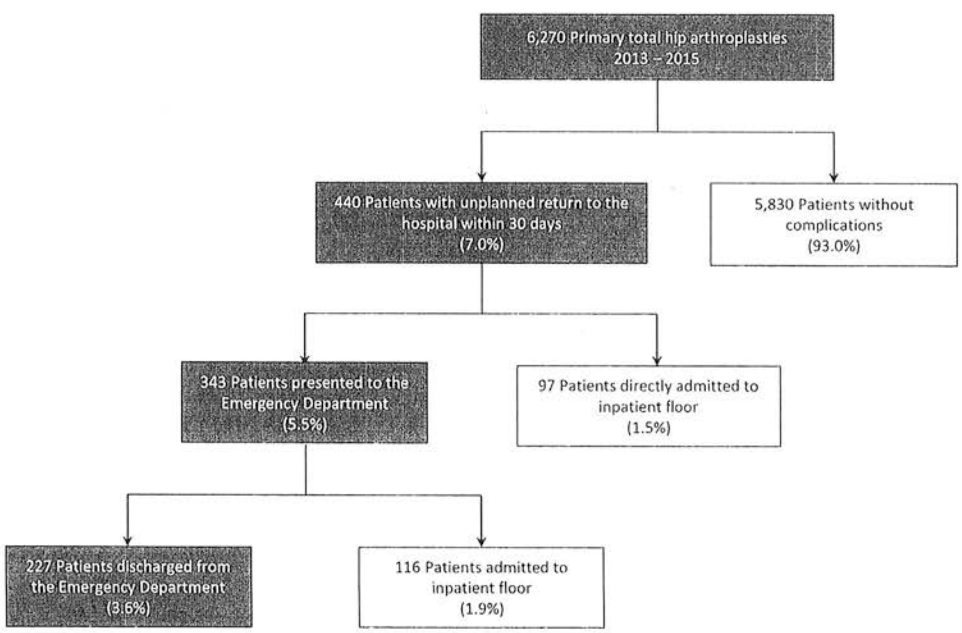


**Fig. 1.** A flowchart illustrating study cohort and frequency of unplanned return to the hospital.

**Table 3**
Characteristics of Patients Who Returned to ED and Those Who Did Not Return Within 30 d After Total Hip Arthroplasty.

| Characteristic | Total (N = 6270) | Returned to ED (N = 343) | Did Not Return to ED (N = 5927) | P Value |
| --- | --- | --- | --- | --- |
| Age (y)[a] | 63 ± 12 | 64 ± 13 | 63 ± 12 | .23 |
| Gender (%) | | | | .67 |
| Male | 3104 (49.5) | 166 (48.4) | 2938 (49.6) | |
| Female | 3166 (50.5) | 177 (51.6) | 2989 (50.4) | |
| Body mass index[a] (kg/m$^2$) | 30.3 ± 6.3 | 30.4 ± 6.7 | 30.3 ± 6.3 | .78 |
| Race (%) | | | | .0001 |
| Caucasian | 5491 (89.4) | 268 (79.8) | 5223 (90.0) | |
| African American | 638 (10.4) | 68 (20.2) | 570 (9.8) | |
| Other | 14 (0.2) | 0 (0.0) | 14 (0.2) | |
| Comorbidities (%) | | | | |
| MI | 92 (1.5) | 8 (2.3) | 84 (1.4) | .17 |
| CHF | 253 (4.0) | 16 (4.7) | 237 (4.0) | .52 |
| Cerebrovascular disease | 322 (5.1) | 35 (10.2) | 287 (4.8) | .0001 |
| Peripheral vascular disease | 294 (4.7) | 21 (6.1) | 273 (4.6) | .19 |
| Dementia | 14 (0.2) | 2 (0.6) | 12 (0.2) | .14 |
| Chronic pulmonary disease | 555 (8.9) | 52 (15.2) | 503 (8.5) | .0001 |
| Connective tissue disease | 221 (3.5) | 14 (4.0) | 207 (3.5) | .56 |
| Peptic ulcer | 105 (1.7) | 8 (2.3) | 97 (1.6) | .32 |
| Chronic liver disease | 159 (2.5) | 16 (4.7) | 143 (2.4) | .01 |
| DM: without end-organ damage | 732 (11.7) | 44 (12.8) | 688 (11.6) | .49 |
| DM: with end-organ damage | 139 (2.2) | 9 (2.6) | 130 (2.2) | .59 |
| Hemiplegia | 26 (0.4) | 2 (0.6) | 24 (0.4) | .61 |
| Renal disease | 229 (3.7) | 21 (6.1) | 2.8 (3.5) | .01 |
| Tumor | 511 (8.2) | 26 (7.6) | 485 (8.2) | .69 |
| Severe liver disease | 6 (0.1) | 1 (0.3) | 5 (0.1) | .22 |
| Metastatic tumor | 76 (1.2) | 4 (1.2) | 72 (1.2) | .93 |
| Acquired immunodeficiency disease syndrome | 0 (0) | 0 (0) | 0 (0) | N/A |
| Charlson Comorbidity Index[a] | 3.6 ± 2.0 | 3.9 ± 2.3 | 3.6 ± 2.0 | .002 |
| Operative time[a] (min) | 101 ± 33 | 103 ± 39 | 101 ± 32 | .41 |
| Surgeon's training (%) | | | | .26 |
| Adult reconstruction fellowship | 3974 (63.4) | 227 (66.2) | 3747 (63.2) | |
| General | 2296 (36.6) | 116 (33.8) | 2180 (36.8) | |
| Surgeon's years of experience[a] (y) | 19 ± 11 | 19 ± 11 | 19 ± 11 | .17 |
| Length of stay[a] (d) | 3.0 ± 1.4 | 3.3 ± 1.8 | 3.0 ± 1.4 | <.0001 |
| Hospital (%) | | | | .01 |
| Academic | 2343 (37.4) | 149 (43.3) | 2194 (37.0) | |
| Community | 3927 (62.6) | 194 (56.6) | 3733 (63.0) | |
| Discharge disposition (%) | | | | .01 |
| Home | 4423 (71.3) | 245 (72.2%) | 4178 (71.2%) | |
| Skilled nursing facility | 1692 (27.3) | 88 (26.0) | 1604 (27.4) | |
| Acute care hospital | 87 (1.4) | 6 (1.8) | 81 (1.4) | |
| In-state residence (%) | 5686 (90.7) | 324 (94.5) | 5362 (90.5) | .01 |
| Primary care physician (%) | 6235 (99.5) | 342 (99.7) | 5893 (99.5) | .53 |
| Insurance (%) | | | | .042 |
| Government | 3274 (56.9) | 209 (63.7) | 3065 (56.5) | |
| Private | 2373 (41.2) | 116 (35.4) | 2257 (41.6) | |
| Workers' compensation | 31 (0.5) | 0 (0.0) | 31 (0.6) | |
| Self-pay | 80 (1.4) | 3 (0.9) | 77 (1.4) | |

CHF, congestive heart failure; DM, diabetes mellitus; ED, emergency department; MI, myocardial infarction; N/A, not applicable.
[a] The values are given as the mean and the standard deviation.

The most common surgery-related reason for returning to the ED was a diagnosis of pain and/or swelling (120 patients, 35%), the majority of which did not warrant a readmission (96 patients, 80%). The second most common surgery-related reason was wound complications (41 patients, 12%), followed by hip dislocations (25 patients, 7.3%) (see Table 4). Diagnoses of wound complications, venous thromboembolism, periprosthetic fracture, and hip dislocations were more common in patients who were readmitted compared to those who were not readmitted. When looking at the disposition of patients who presented with wound complications, 20 of 41 patients (48.7%) were discharged from the ED (see Table 3 and Fig. 3). Similarly, for the 25 patients who had a hip dislocation, 10 patients (40%) were discharged from the ED and did not warrant a readmission.

### *Risk Factors for ED Visits Without Inpatient Readmission*

Multiple logistic regression analysis revealed 2 independent risk factors for a return to the ED without inpatient readmission (see Table 5). African American race was the main risk factor (odds ratio [OR] 2.28, 95% confidence interval [CI] 1.55-3.36). Interestingly, patients who are discharged home after their index THA are at a higher risk of return to the ED without being readmitted (OR 1.90, 95% CI 1.28-2.82).

## Discussion

Unplanned ED visits following THA may represent a lapse in quality of care and a large cost to the patient and healthcare system. Although most efforts by hospitals and policy makers focus on reducing readmissions, postoperative ED visits have received less attention as a quality metric, until bundled payment models shifted the burden of cost to the healthcare system [3–7]. Therefore, improving quality of care and minimizing costs associated with THA necessitate an analysis of ED visits that do not result in readmission. Hence, this study investigated the following: (1) the frequency and subsequent disposition; (2) unique patient

**Table 4**
Reason for Return to the ED in Patients Discharged From ED Compared to Patients Readmitted to Inpatient Status Within 30 d After THA.

| Reason for ED Visit | Total N (n = 343) | Returned to ED but Not Admitted (n = 227) | Returned to ED and Readmitted (n = 116) | *P* Value |
|---|---|---|---|---|
| Medical | | | | |
| Neurologic | | | | |
| Major | 5 (1.5) | 0 (0.0) | 5 (4.3) | .001 |
| Minor | 15 (4.4) | 9 (4.0) | 6 (5.2) | .60 |
| Cardiac | | | | |
| Major | 14 (4.1) | 3 (1.3) | 11 (9.5) | .0003 |
| Minor | 19 (5.5) | 12 (5.3) | 7 (6.0) | .77 |
| Pulmonary | | | | |
| Major | 0 (0) | 0 (0) | 0 (0) | N/A |
| Minor | 14 (4.1) | 7 (3.1) | 7 (6.0) | .19 |
| Gastrointestinal | | | | |
| Major | 12 (3.5) | 3 (1.3) | 9 (7.8) | .002 |
| Minor | 36 (10.5) | 24 (10.6) | 12 (10.3) | .94 |
| Genitourinary | 20 (5.8) | 11 (4.9) | 9 (7.7) | .28 |
| Nonspecific symptoms | 85 (24.8) | 50 (22.0) | 35 (30.2) | .09 |
| Any medical related | 184 (53.6) | 108 (47.6) | 76 (65.5) | .0016 |
| Surgical | | | | |
| Wound complications | 41 (12.0) | 20 (8.8) | 21 (18.1) | .01 |
| Venous thromboembolism | 19 (5.5) | 5 (2.2) | 14 (12.1) | .0001 |
| Neurovascular deficit | 0 (0) | 0 (0) | 0 (0) | N/A |
| Periprosthetic fracture | 5 (1.5) | 0 (0) | 5 (4.3) | .001 |
| Aseptic loosening | 0 (0) | 0 (0) | 0 (0) | N/A |
| PJI | 16 (4.7) | 0 (0) | 16 (13.8) | .0001 |
| Abductor mechanism disruption | 0 (0) | 0 (0) | 0 (0) | N/A |
| Heterotopic ossification | 0 (0) | 0 (0) | 0 (0) | N/A |
| Hip dislocation | 25 (7.3) | 10 (4.4) | 15 (12.9) | .004 |
| Pain and/or swelling | 120 (35.0) | 96 (42.3) | 24 (20.7) | .0001 |
| Any surgical related | 206 (60.0) | 131 (57.7) | 75 (65.0) | .21 |
| Inpatient complications | 8 (2.3) | 2 (0.9) | 6 (5.2) | .01 |

All values are given as the number of patients and percentage of all patients in that column. The percentage of complications in each column may not add up to 100% as some patients have multiple complications.
ED, emergency department; THA, total hip arthroplasty; N/A, not applicable; PJI, periprosthetic joint infection.

characteristics; and (3) reasons for visits. In addition, this study evaluated (4) potential risk factors for ED visits that did not result in an inpatient readmission within 30 days of discharge. Between 2013 and 2015, there were more ED visits that did not result in readmission within 30 days of an index primary THA than inpatient readmission (3.6% vs 1.9%). Several characteristics were identified in patients who had postoperative ED visits including African American race and having certain medical comorbidities. Moreover,

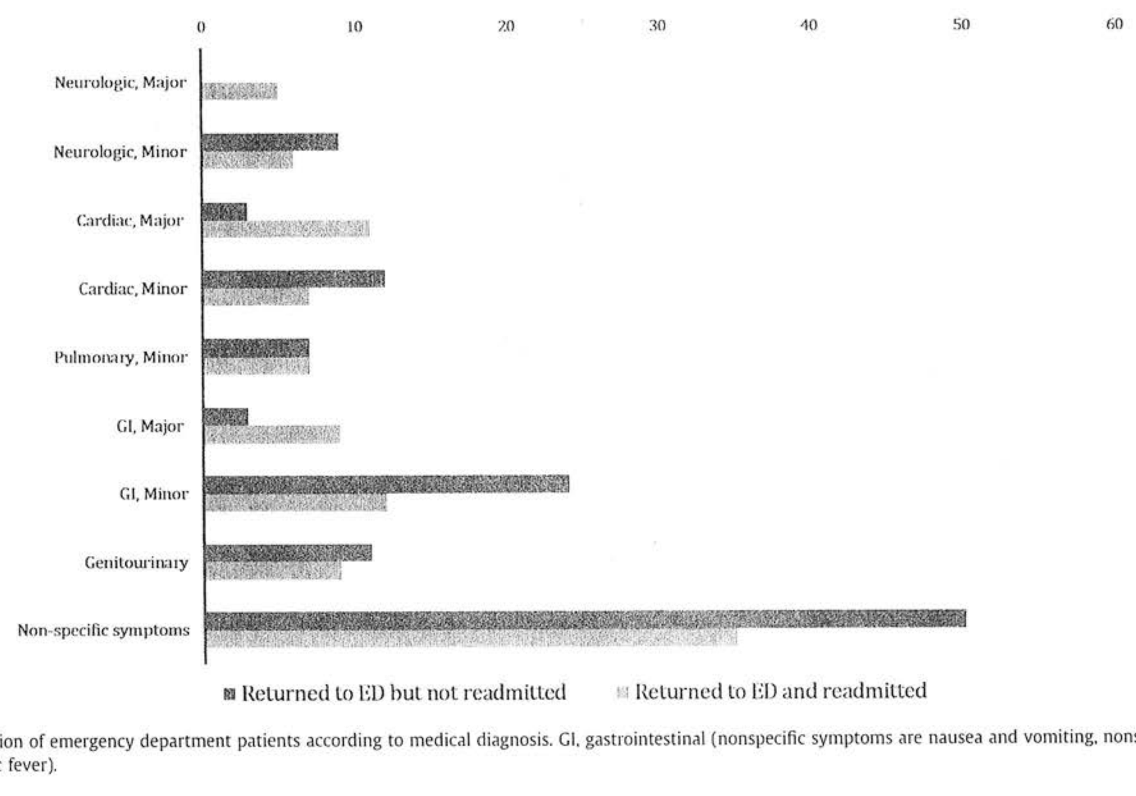


**Fig. 2.** Disposition of emergency department patients according to medical diagnosis. GI, gastrointestinal (nonspecific symptoms are nausea and vomiting, nonsurgical site pain, and nonspecific fever).

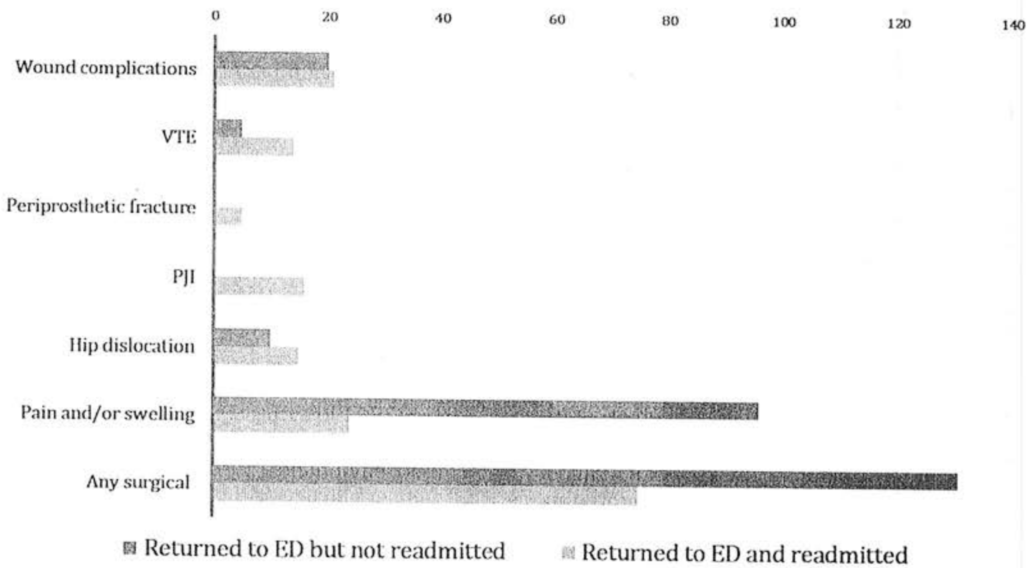


**Fig. 3.** Disposition of emergency department patients according to surgery-related diagnosis. VTE, venous thromboembolism; PJI, periprosthetic joint infection.

the majority of these visits, whether medical related or surgery related, could not be categorized into commonly reported complications. Approximately half of the wound complications and hip dislocations were managed in the ED and discharged without a 30-day readmission. Despite the seriousness of these presenting complications, quality metrics may not take this into account as it did not result in a hospital readmission. Furthermore, home disposition, in addition to race, were 2 independent risk factors of postoperative ED visits without inpatient admission.

This study is not without limitations. Our analysis of the population was retrospective in nature. However, this limitation is compensated for by our large sample size and the comprehensive review that encompassed patients who visited 12 EDs in 3 academic and 8 community hospitals. In addition, it is possible that this registry analysis may underestimate ED visit rates, as it only captures patients who returned to the same health system. Nevertheless, 90% of our patient population resided within 18-county large metropolitan region, where our health system has the largest geographical, state-wide ED coverage. Moreover, major complications are typically referred back to our hospital system, since it is a tertiary care center, and patients are more apt to return to their treating physician. Additionally, our data lack patient-reported outcomes and costs to determine the effect of ED visits on quality scores and assess the financial burden. However, the main aim of this study is to distinctively characterize patients who visit the ED after THA without inpatient readmission and to identify potential risk factors implicated. This work will also provide an impetus for future studies that incorporate quality of life metrics and episode costs into the assessment.

**Table 5**
Risk Factors Predisposing Patients to Return to the ED Without Being Readmitted Within 30 D After THA.

| Characteristic | Patients Returned to the ED and Discharged | |
|---|---|---|
| | OR (95% CI) | *P* Value |
| Age (y) | 1.00 (0.98-1.02) | .82 |
| Gender (male) | 0.90 (0.67-1.22) | .51 |
| Body mass index (kg/m$^2$) | 1.00 (0.98-1.03) | .80 |
| Race | | .0003 |
| Caucasian | Reference | |
| African American | 2.28 (1.55-3.36) | |
| Other | 0.12 (0.09-1.87) | |
| Charlson Comorbidity Index | 0.98 (0.89-1.09) | .77 |
| Inpatient complications | | .42 |
| Surgeon's fellowship trained | 1.09 (0.77-1.54) | .60 |
| Surgeon's years of experience (y) | 1.00 (0.99-1.01) | .52 |
| Length of stay (d) | 1.06 (0.95-1.19) | .30 |
| Hospital type | | .33 |
| Teaching | 1.17 (0.85-1.59) | |
| Community | Reference | |
| Discharge home | 1.90 (1.28-2.82) | .001 |
| Insurance | | .056 |
| Government | Reference | |
| Private | 0.70 (0.50-1.00) | |
| Workers' compensation | 0.09 (0.01-8.80) | |
| Self-pay | 0.25 (0.03-1.85) | |

CI, confidence interval; ED, emergency department; THA, total hip arthroplasty; OR, odds ratio.

In this study, the overall 30-day return to the ED rate was 5.5%, which is similar to the 5.8% rate published for California, Florida, and New York state databases [16]. When evaluating overall unplanned visits to the ED within 30 days after THA, several observations support prior reports on hospital readmission and ED visits. Patients with comorbidities such as cerebrovascular disease, chronic pulmonary disease, chronic liver disease, and renal disease were more common in patients who returned to the ED, as have been shown in multiple prior studies [17,18]. Most of these patients underwent their THA at an academic hospital. This is not necessarily caused by the teaching environment, as prior studies have shown no difference in early complications comparing teaching and private hospitals [19], but rather may reflect confounding of the higher complexity and comorbidities encountered in patients undergoing THA at the multidisciplinary academic hospital.

Most patients who returned to the ED within 30 days did not have a medical or surgical reason that is categorized into one of the commonly reported complications (24.8% medical and 35.0% surgical). These patients had complaints of nonspecific medical symptoms (nausea and vomiting, nonsurgical site pain, and nonspecific fever) or surgical pain and/or swelling, while their work-up did not yield a specific diagnosis. Finnegan et al [16] reported similar reasons for return to the ED in their state database study, where they found pain to be the most common reason (34%), followed by edema (19%) and miscellaneous diagnosis codes (33%). Sibia et al [20] retrospectively reviewed 655 total joint arthroplasties at a single institution and reported a 5.3% total ED visit rate, 36% of which presented for pain and/or swelling. Rossman et al [21] reported similar findings. These "other" surgery-related reasons were more common in patients who were not readmitted, indicating that these patients likely did not have a clinically important problem. A possible explanation is that these patients may not have been educated about proper expectations and normal postoperative course, and therefore had a lower threshold to present to the ED. This highlights the unnecessary burden imposed on patients who are referred to the ED with pain or swelling after THA.

When evaluating common surgery-related complications after THA, it was demonstrated that 48% of wound complications and 40% of hip dislocations were discharged from the ED and did not warrant a readmission. These are important metrics of quality that would miss the 30-day readmission window, and possibly present as delayed periprosthetic joint infections or recurrent dislocations. In this era of bundled reimbursement models, identifying and mitigating these preventable causes are critical.

Risk factors for unplanned postoperative visits to the ED within 30 days that do not result in a readmission were race and home discharge. African Americans were more common for patients who returned to the ED and were found to be an independent risk factor for return to the ED without inpatient readmission (OR 2.28, 95% CI 1.55-3.36). Finnegan et al [16] showed in their large administrative database study that these patients were more likely to return to the ED after total joint arthroplasty, mainly with pain diagnoses. The cause of this finding is likely complex, and perhaps is related to racial disparity in subjective experience of pain, or socioeconomic and level of education. An interesting finding in our study was home discharge which appeared to be a risk factor for return visit to the ED without a readmission. Most prior studies evaluating overall unplanned return to the hospital showed an association between home discharge and decreased readmission [20–23]. This is likely due to the fact that patients with multiple comorbidities who are at higher risk of readmission are typically discharged to skilled nursing facilities. Our regression analysis, however, focused on the subset of patients who returned to the ED, but were not readmitted. Possible explanations include poor patient understanding of postoperative course, inadequate discharge instructions and education, or lack of timely assessment of patients with pain or swelling by physicians or ancillary providers leading to increased referrals to the ED particularly after working hours.

In our multiple logistic regression analysis, other factors that were included in the analysis did not reach the threshold for statistical significance as a risk factor for unplanned ED visit without readmission. Notably, hospital teaching status (academic vs community) and surgeon's fellowship training and years of experience did not demonstrate statistical difference. In addition, insurance type also did not seem to be an independent risk factor. Previous studies have only attempted to investigate these factors in regard to its impact on readmission. We recommend and call for future studies to investigate this relationship in patients who had unplanned ED visits without readmission to confirm or correct our findings.

In conclusion, this study highlights the frequency and subsequent disposition of ED visits after primary THA. Unplanned return to the ED, even if not associated by an inpatient readmission, is extremely relevant to policy makers and for quality metrics. Hip dislocations and wound complications are examples of complications that are possibly preventable, but about 50% of these cases can be managed in the ED without needing an inpatient readmission. With comprehensive and bundled payment initiatives becoming more prevalent, studies evaluating hospital quality and performance need to capture ED visits as well as direct inpatient readmission.

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