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Review

Does Surgeon Volume Affect Outcomes Following Primary Total Hip Arthroplasty? A Systematic Review

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ABSTRACT

Background: Surgeon volume has been identified as an important factor impacting postoperative outcome in patients undergoing orthopedic surgeries. With an absence of a detailed systematic review, we sought to collate evidence on the impact of surgeon volume on postoperative outcomes in patients undergoing primary total hip arthroplasty.

Methods: PubMed (MEDLINE) and Google Scholar databases were queried for articles using the following search criteria: ("Surgeon Volume" OR "Provider Volume" OR "Volume Outcome") AND ("THA" OR "Total hip replacement" OR "THR" OR "Total hip arthroplasty"). Studies investigating total hip arthroplasty being performed for malignancy or hip fractures were excluded from the review. Twenty-eight studies were included in the final review. All studies underwent a quality appraisal using the GRADE tool. The systematic review was performed in accordance with the PRISMA guidelines.

Results: Increasing surgeon volume was associated with a shorter length of stay, lower costs, and lower dislocation rates. Studies showed a significant association between an increasing surgeon volume and higher odds of early-term and midterm survivorship, but not long-term survivorships. Although complications were reported and recorded differently in studies, there was a general trend toward a lower postoperative morbidity with regard to complications following surgeries by a high-volume surgeon.

Conclusion: This systematic review shows evidence of a trend toward better postoperative outcomes with high-volume surgeons. Future prospective studies are needed to better determine long-term postoperative outcomes such as survivorship before healthcare policies such as regionalization and/or equal-access healthcare systems can be considered.

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Total hip arthroplasty (THA) is one of the most successful orthopedic procedures performed today. Studies have shown that THAs can be safely performed in a wide range of age-groups [1–4] and for various disorders [5], with more than 90% of patients undergoing THA reporting successful freedom from pain [6]. More than 300,000 THAs are performed in the United States annually, with the numbers project to increase by 174% between 2005 and 2030 [7]. There is an impending need to minimize the costs of these procedures while maintaining quality of care.

Over the past 2 decades, several studies have investigated patient-level factors affecting outcomes after THA such as age [8,9], gender [10,11], comorbidities [12,13], higher American Society of Anesthesiologists grades [14], elevated body mass index [15], neuropsychiatric disturbances [16,17], and technical factors such as implant type, surgical complexity of the cases, head size, and bearing couple [18–21]. Recently, there has been focus upon the identification of hospital-level and surgeon-level factors that may affect postoperative outcomes after THA.

A number of studies have examined the effect of surgeon volume on outcomes following primary and revision total joint arthroplasty procedures [22–25]. However, there has not been a systematic review to consolidate the impact of surgeon volume on primary THA itself. We conducted a systematic review of literature to investigate the association between surgeon volume and outcomes in primary THA.

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Materials and Methods

Eligibility Criteria

To be included in the review, the study population had to include patients undergoing a primary THA. Eligible studies had to carry out a comparison of primary outcomes between low-volume (LV) and high-volume (HV) surgeons. Primary outcomes include postoperative morbidity/complications, in-hospital and postprocedure mortality, hospital charges/cost of stay, hospital length of stay (LOS), reoperation/revision rates, readmissions, dislocation rates, and postoperative patient-reported functioning. Studies that involved the volume-outcome relation in patients undergoing THA for malignancies or hip fractures were excluded unless they contained separate raw analytical data with regard to other indications. Studies that contained data on other total joint arthroplasties (total knee and total shoulder arthroplasty) were excluded from the study unless they contained separate raw data analyses for THA as well. Similarly, articles based on hospital volume were excluded from the study unless they also included separate data on surgeon volume. Relevant articles were reviewed using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement as a guideline [26].

Information Sources and Study Selection

We searched the PubMed (MEDLINE) and Google Scholar databases in January 2017 using the following search criteria: ("Surgeon Volume" OR "Provider Volume" OR "Volume Outcome") AND ("THA" OR "Total hip replacement" OR "THR" OR "Total hip arthroplasty"). No restrictions were placed on study design. Articles published between 1997 and 2017 were included. Only articles in English were included. A total of 1510 publications were retrieved from the databases. One author (ATM) screened titles and abstracts of all articles. Full-length texts of articles that seemed clinically relevant to the study were then retrieved. Additionally, the bibliographies of these full-length articles were reviewed and full-length articles included for those references deemed potentially relevant. In case of disagreement, a senior author was used for reaching mutual agreement of including the article or not. A final total of 28 studies were included in the review. A flowchart of data extraction is shown in Figure 1.

Data Extraction

Data from the final included articles were extracted and tabulated. Variables that were documented included author, year of publication, study design, source of data, sample size, volume thresholds, and primary outcomes studied.

Quality Appraisal of Studies

The studies that were included in our review underwent an appraisal of the quality of methodology as outlined by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system [27].

Results

Study Design

All 28 studies were observational and retrospective in nature employing the use of large-volume databases.

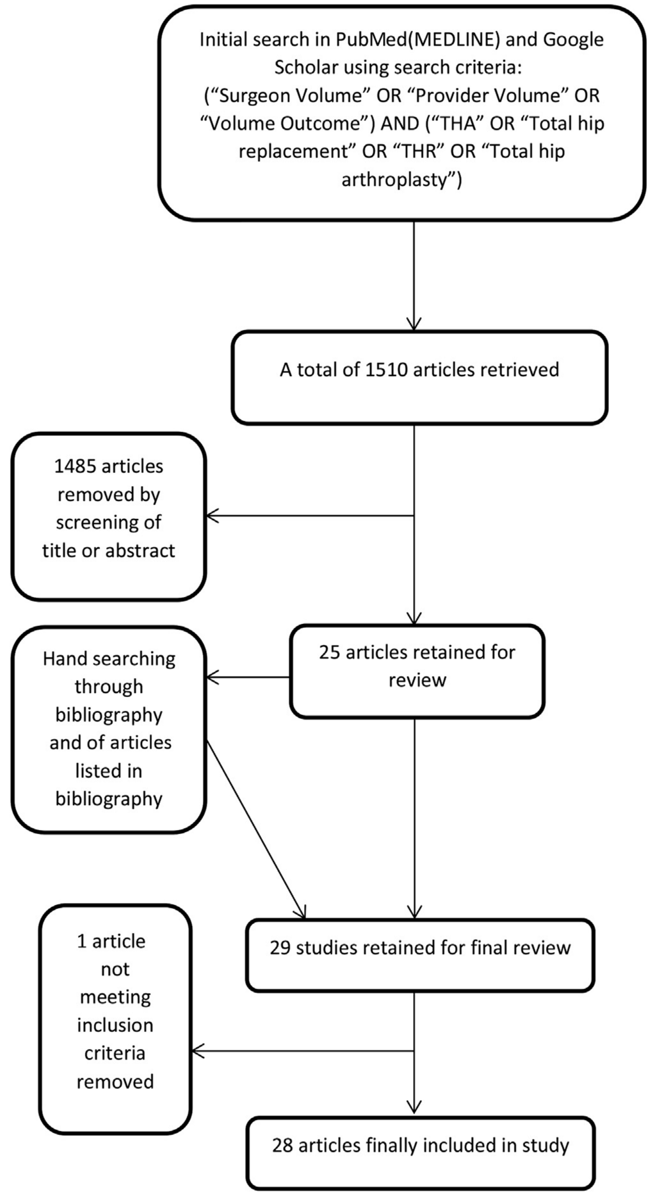

Fig. 1. Flowchart showing extraction of data.

Sample Size

Sample size (N) was recorded as the number of patients in the study. With the exception of 1 study [28], all others reported sample sizes. The total sample size was 1,121,175 patients with a reported range of 508 to 442,333.

Origin of Studies

The majority of studies were from North America (N = 21), with 17 studies based in the United States [28–44] and 4 studies based in Canada [24,45–47]. The remainder of the studies (N = 7) were from United Kingdom (N = 2) [48,49], Taiwan (N = 2) [50,51], France (N = 1) [52], New Zealand (N = 1) [53], and Belgium (N = 1) [54]. A wide variety of databases were employed by these studies. Table 1 shows the characteristics of studies included in the review.

Nine studies used the Medicare database, which contains longitudinal national inpatient and outpatient records for events for beneficiaries [28,29,31,33–36,38,44].

One study used the Health Care Cost and Utilization Project Nationwide Inpatient Sample database [41]. This database was developed to help track and analyze trends in healthcare utilization, cost, and quality and is collected on an annual basis. It is the largest all-payer national database of the states and is a 20% stratified sample of all nonfederal hospitals in which the stratification is based on hospital characteristics, region, location, teaching status, ownership, and size [55].

All 4 of the Canadian studies used the Canadian Institute for Health Information database [24,45–47]. This database contains information from all patient-hospital encounters and is also linked to the Ontario Health Insurance Plan (OHIP) database. The OHIP is a government-run health insurance plan. It contains claims data for all physician billing and hospital-specific and surgeon-specific data in the province of Ontario [56].

Three studies queried information from state-wide databases [32,39,40]. Kreder et al used the Washington Computerized Hospital Abstract Reporting System (CHARS) database, Thompson et al used the Minnesota Clinical Comparison Assessment Project, and Goldstein et al collated data from an all-payers claim database from the state of Maine. The CHARS database collects record-level information on inpatient and observation patient community hospitals in Washington [57]. The Minnesota Clinical Comparison Assessment Project was a voluntary collection of healthcare records from Minnesota hospitals for assessment of quality of care in the state [58].

The 2 studies from Taiwan collated information from the Taiwan Bureau of National Health Insurance database [50,51]. Being the only insurance provider in the country, it is considered as a very comprehensive and national representative sample. It collects information from contracted medical facilities, the registry of board-certified physicians, and monthly summaries of all inpatient claims.

Only 1 study from the United Kingdom used the National Joint Registry [49]. The National Joint Registry was set up in 2002 by the Department of Health and Welsh Government to collect information on all arthroplasty procedures performed in England, Wales, Northern Island, and the Isle of Man [59]. Its principal purpose was to monitor performance of implants and analyze the effectiveness of different types of surgeries.

Three studies collated data from the Kaiser Permanente Total Joint Replacement Registry [30,37,43], a private database in an integrated healthcare delivery system across 8 different regions of the United States. It consists of standardized electronic health record forms integrated into the preoperative, intraoperative, and postoperative workflow to produce a progress note [60].

The Belgian study used the National Hospital Clinical Data registry [54]. It is a mandatory requirement for every hospital in Belgium to fill out data relevant to each hospitalized patient, such as administrative information, LOS, and International Classification of Diseases, Ninth Revision, procedure and diagnosis codes.

The French study used the French National Health Insurance Database (SNIIRAM) [52]. The SNIIRAM database merges health information such as demographic data, healthcare encounters, medicines, medical conditions, hospitalizations, and procedures across several plans and links it to the national hospital discharge summaries database system (PMSI) and the national death registry [61].

The study from New Zealand used the New Zealand Joint Registry [53]. The New Zealand Joint Registry was established in 1999 and covers arthroplasty data from all 52 New Zealand hospitals that perform arthroplasty. It is validated against the New Zealand Health Information database for public hospitals by cross-checking with implant manufacturer's databases for private hospitals. An overall capture rate of more than 95% has been predicted according to reports [62].

Surgeon Volume Thresholds

With the exception of 3 studies that did not explicitly state surgeon volume thresholds [38,39,47], a majority of the studies defined surgeon volume into groups of 2-5. A large amount of variability was seen in the thresholds for each group. With the exception of one study which reported monthly surgeon volumes [52], the remainder of the studies gave annual surgeon volume values. Two studies used percentiles to define annual surgeon volumes [32,50]. For tabulation and analysis purposes, the majority of the studies used the group with the highest amount of surgeries per year as the reference group when comparing outcomes. Only 5 studies explicitly used the LV group as a reference group [24,33,34,43,50]. Because of the wide variation and significant overlap in the thresholds reported, conducting a meta-analysis is difficult.

Outcomes Studied

In all 28 studies, a wide variety of outcomes were reported—including but not limited to in-hospital and postoperative mortality, in-hospital and postoperative complications, revision and readmissions rates, LOS, and total cost/charges.

In-hospital mortality was reported in 2 studies [32,45]. Ten studies reported revisions and reoperations [24,29,30,32,34,36,45,46,52,53]. Two studies reported readmissions due to reasons apart from revision surgery [24,38]. Six studies reported risks of dislocation [29,35,43,46–48]. Cost of stay and LOS were reported in a total of 3 studies [32,50,51] and 6 studies [23,24,32,39,41,50], respectively. One study reported costs up to 90 days following the index procedure [39]. Fourteen studies reported complications for various time periods [24,29,32,35,37,42,43,45–50,54]. Two studies reported data on postoperative patient-reported outcomes [41,44]. Complications were defined differently in all studies (Table 2). A summary of the covariates adjusted for in each study is presented in Table 3.

Quality Appraisal of Studies

All studies are retrospective, observational, cohort studies and are considered low-grade (level III) quality studies as per GRADE system guidelines [27].

Results

Mortality Rate

In-Hospital Mortality

Conflicting findings were seen with regard to the impact of surgeon volume on mortality during index hospital admission. Both studies were by the same author using 2 different state databases of different countries [32,45]. The study published by Kreder et al (1997) [32] used the Washington CHARS database and concluded that surgery by an LV surgeon was associated with a significantly higher in-hospital mortality rate as compared to HV groups. In the other study published in 1998, Kreder et al [45] used the Canadian Institute for Health Information-OHIP database and found no significant association between an LV surgeon and a higher risk of mortality (0.3% [LV] vs 0.4% [HV]; $P > .05$).

90-Day Mortality

Out of the 4 studies investigating 90-day mortality, only one (Kreder et al, 1997) [32] found a significant association between a low surgeon volume and a higher risk of death within 90 days of operation (LV [2.1%] vs HV [0.5%]; $P < .05$). Interestingly, the same study found no significant association when carrying out a comparison of mortality in medium volume (MV) vs HV (0.9% vs 0.5%; *P*

Table 1
Characteristics of Studies Included in the Review.

Study	Patients	Procedure	Country	Database	Outcomes Studied
Camberlin et al (2011) [54]	11,586	Primary THA	Belgium	Belgian Hospital Clinical Data registry	90-d Complications
Kreder et al (1998) [45]	3645	Primary THA	Canada	Canadian Institute for Health Information (CIHI)	Index hospital stay—complications, mortality, UTI, LOS, 90-d mortality, 1-y and 3-y infection rate, revision surgery, 1-y mortality, and 3-y DVT rate
Paterson et al (2010) [24]	20,290	Primary THA	Canada	CIHI and Ontario Health Insurance Plan (OHIP)	In-hospital complications, 90-d mortality, readmission within 1 y, and LOS
Ravi et al (2014) [46]	37,881	Primary THA	Canada	CIHI and OHIP	90-d and 2-y complications and revisions
Ravi et al (2014) [47]	43,997	Primary THA	Canada	CIHI	90-d Venous thromboembolism
Cossec et al (2017) [52]	62,906	Primary THA	France	French National Health Insurance Database (SNIIRAM)	Revision surgery
Huang et al (2011) [50]	9335	Primary THA	Taiwan	National Health Insurance and THA Inpatient Database	In-hospital adverse events/ complications, total hospital discharge, LOS
Shi et al (2013) [51]	78,364	Primary THA	Taiwan	Taiwan Bureau of National Health insurance	Hospital charges
Annan et al (2017) [48]	4334	Primary THA	United Kingdom	Single-center arthroplasty database	Postoperative dislocation within 10 y
Baker et al (2011) [49]	248	Primary THA	United Kingdom	National Joint Registry	Need for postoperative transfusion
Katz et al (2001) [29]	71,477	Primary and revision THA	USA	Medicare	Mortality, dislocation, deep infection, pulmonary embolism within 90 d after index procedure
Katz et al (2012) [31]	51,347	Primary THA	USA	Medicare	Risk of revision within 12 y
Kreder et al (1997) [32]	8774	Primary THA	USA	Computerized Hospital Abstract Reporting System (CHARS)	In-hospital complications, mortality, readmissions, revision, infection, LOS, discharge disposition, cost of stay
Khatod et al (2014) [30]	35,960	Primary THA	USA	Kaiser Permanente Total Joint Replacement Registry	Aseptic revision of THA
Pablo et al (2004) [33]	758	Primary THA	USA	Medicare	Discharge to inpatient rehab
Losina et al (2004) [34]	57,488	Primary THA	USA	Medicare	Rates of failure/revision
Malkani et al (2010) [35]	39,266	Primary THA	USA	Medicare	Incidence of dislocation (within 2 y of the index procedure and after 2 y of the index procedure)
Manley et al (2008) [36]	26,036	Primary THA	USA	Medicare	Revision rates at 6 mo, 2 y, 5 y, and 8 y
Namba et al (2012) [37]	30,491	Primary THA	USA	Kaiser Permanente Total Joint Replacement Registry	Surgical site infection
Ong et al (2009) [28]	Not specified	Primary THA	USA	Medicare	Operative time/procedure duration
Kurtz et al (2016) [38]	442,333	Primary THA	USA	Medicare	30-d Readmissions, 90-d readmissions
Goldstein et al (2016) [39]	1398	Primary THA	USA	All-payers claim database from State of Maine	90-d Costs, LOS, discharge to nurse facility, home or home care, and PT within 1 y
Solomon et al (2002) [40]	5211	Primary THA	USA	Medicare, American Board of Medical Specialties, hospital survey, American Hospital Association 1995 survey	Hip dislocation, deep wound infection of the hip within 90 d of index admission
Styron et al (2011) [41]	42,231	Primary THA	USA	Nationwide Inpatient Sample (NIS)	LOS, hospital charges/cost of stay
Thompson et al (2002) [42]	1810	Primary THA	USA	Minnesota Clinical Comparison Assessment Project	In-hospital mortality and complications, posthospital outcomes using condition-specific measures
Khatod et al (2006) [43]	1970	Primary THA	USA	Kaiser Permanente Total Joint Replacement Registry	Dislocation within 1 y
Katz et al (2003) [44]	926	Primary THA	USA	Medicare	Harris hip scores, satisfaction scores
Hooper et al (2009) [53]	42,665	Primary THA	New Zealand	New Zealand Joint Registry	Revision surgery

THA, total hip arthroplasty; UTI, urinary tract infection; LOS, length of stay; DVT, deep venous thrombosis; PT, physical therapy.

> .05). The remaining studies by Kreder et al (1998) [45], Katz et al (2001) [29], and Paterson et al [24] found no significant association with regard to an increasing surgeon volume and a lower odds of 90-day mortality across various thresholds.

1-Year Mortality

Both studies investigating 1-year mortality following the index procedure found no relation between surgeon volume and a higher risk of death at 1 year. Kreder et al (1998) [45] found equal rates of mortality when comparing LV vs HV (0.3% vs 0.3%) and MV vs HV (0.4% vs 0.3%). Similarly, Kreder et al (1997) [32] also found that although LV (3.2%) and MV surgeons (2.0%) had a higher crude risk of mortality as compared to HV surgeons (1.3%), the significance was lost following adjustment. It is important to note that these studies used administrative databases and thus the 1-year mortality may be affected by other confounding factors that happened up to 1-year postsurgery.

Table 2
Definitions of Complications Described in Studies.

Study	Definitions of Complications	Time Period/Follow-Up
Camberlin et al (2011) [54]	Phlebitis/thrombophlebitis of lower extremities, pulmonary embolism (PE) and infarction, mechanical complications of internal orthopedic device, implant and graft, infection and inflammatory reaction due to internal joint prosthesis and dislocation of hip	90 d
Annan et al (2017) [48]	Dislocation	Up to 10 y postoperatively
Baker et al (2011) [49]	Postoperative transfusion	In-hospital
Huang et al (2011) [50]	Acute infection (cellulitis and wound infection), PE, deep venous thrombosis (DVT), acute myocardial infarction (MI), pneumonia, urinary tract infection (UTI), and upper gastrointestinal (GI) bleed	In-hospital
Katz et al (2001) [29]	Deep surgical site infection (requiring surgical debridement or removal of prosthesis), dislocation, and PE	90 d
Kreder et al (1997) [32]	Infection, complications during index admission, DVT, UTI	In-hospital, 90 d and 1 y
Kreder et al (1998) [45]	Major complications—surgical mishaps, infections, MI, stroke, etc.	In-hospital, 90 d, 1 y, and 3 y
Malkani et al (2010) [35]	Dislocation	2 y and 7 y postoperatively
Namba et al (2012) [37]	Deep surgical site infection	1 y
Paterson et al (2010) [24]	Surgical complications (infections and inflammatory reactions, hemorrhage, vascular complications, respiratory complications, mechanical complications of the prosthesis, and complications of anesthesia)	In-hospital
Ravi et al (2014) [46]	Venous thromboembolism/DVT/PE (90 d), infection, dislocation, periprosthetic fracture, and dislocation	90 d and 2 y
Ravi et al (2014) [47]	Venous thromboembolism (90 d), dislocation, and infection (2 y)	90 d and 2 y
Thompson et al (2002) [42]	Operative complications Serious—puncture of blood, vessel/nerve/organ, dislocation of component/component failure, fracture of acetabulum, fracture of femur, limb ischemia, major vessel damage, neuropathy/femoral nerve damage/palsy/foot drop/sciatic nerve damage, perforation of femur by stem, wound infection (positive culture), wound infection (purulent drainage), subluxation, unrecognized malposition of components, wound failure (partial/complete) Mild—hematoma/wound infection with erythema General complications Serious—acute MI, adult respiratory distress syndrome, bowel obstruction/ileus, cardiac arrest, cardiogenic shock, cerebrovascular accident, coma, congestive heart failure/pulmonary edema, DVT/venogram positive, GI hemorrhage, pneumonia, PE, renal failure, ventricular tachycardia Mild—pneumonia, acute tubular necrosis, bacteremia, gastric stress ulcer, intubation > 24 h, transfusion reaction, UTI	In-hospital
Khatod et al (2006) [43]	Dislocation	Up to 1 y postoperatively

Revision Surgery

Out of the 10 studies reporting revision rates at different time periods, 7 found a significant association between a higher surgeon volume and a higher survivorship at certain time periods [24,31,32,34,36,46,52]. Cossec et al [52] found a higher survivorship rate in the first 4 years following surgery by an HV group as compared to an LV (hazard ratio [HR], 1.7 [1.4-2.1]). Katz et al [31] also reported that surgeons who performed <6 THAs/year (LV) had a higher risk of revision at 12 years than those whose surgeons performed more than 12 per year (HV) (HR, 1.2 [1.1-1.3]). However, a similar significant association was not found when comparing MV (6-12 THAs/year) and HV (HR, 1.1 [1.0-1.2]). Kreder et al (1997) [32] found a significantly higher odds of having revision surgery at 90 days and 1 year in the LV group as compared to the HV group. However, no significant association was found when comparing revision rates in MV vs HV in both time periods. Losina et al [34] reported that LV groups were significantly associated with a higher 4-year revision rate in only HV (>50 THAs/year) hospitals. Associations were nonsignificant in hospitals performing less than 50 THAs/year. Manley et al [36] reported significant associations with regard to risk of revision at 6 months between LV vs very high volume (VHV) (HR, 1.7 [1.1-2.65]) and MV vs VHV (HR, 1.6 [1.1-2.45]). No significant volume-revision associations were found at 2 years, 5 years, and 8 years postoperatively. Paterson et al [24] similarly reported a significantly higher readmission rate for revision arthroplasty at 1 year between LV (12.8%) vs VHV (9.2%) surgeons. Ravi et al [46] also found a high revision rate at 2 years with LV (1.5%) vs HV (1.0%) using matched cohorts.

Kreder et al (1998) [45] found no significant volume-revision relationship at 1 year and 3 years postoperatively. Similarly, Khatod et al [30] also found no significant relation between surgeon volume and revision rates at 8 years postoperatively. Hooper et al [53] evaluated revision rates at 7 years following surgery and reported a higher rate of revision with very low volume (VLV) groups. However, no statistical analysis was conducted in this study.

Risk of Dislocation

Of the 6 studies reporting dislocation rates at various time periods, all except one [43] found a significant association between a lower surgeon volume and higher odds of having a dislocation. Annan et al [48] found significantly higher odds of having dislocation following surgery by an LV as compared to an HV surgeon (odds ratio [OR], 4.96 [2.94-8.4]). Katz et al [29] reported a higher incidence of 90-day dislocation with VLV (4.2%) as compared to LV (3.4%), MV (2.6%), HV (2.4%), and VHV (1.5%) groups. Malkani et al [35] reported a significantly lower survival from dislocation in a VLV vs HV group at 2 years (93.2% vs 97.2%) and 7 years (90.2% vs 95.8%). Similar associations were reported by Ravi et al [46,47].

Only 1 study by Khatod et al (2006) [43] also found no significant relation between surgeon volume and rate of dislocation at 1 year when comparing LV (1.3%) vs HV (1.9%) surgeons (OR, 1.6 [0.71-3.5]).

LOS and Cost of Stay/Hospital Charges

Of the 4 studies reporting cost of stay/hospital charges, 3 reported a significant association between LV surgeries and a higher cost of stay [39,50,51].

Table 3
Covariates Adjusted for in Studies.

Study	Covariates Adjusted for
Annan et al (2017) [48]	Adjusted for BMI (kg/m^2), Harris hip score, head size, approach (anterolateral and posterior), acetabulum (cemented and noncemented)
Baker et al (2011) [49]	Adjusted for age, preoperative hemoglobin < 12 g/dL, gender, anesthesia type, surgeon grade, ASA grade, indication for surgery, DVT prophylaxis, years as consultant, surgical approach, and hip implant
Camberlin et al (2011) [54]	Adjusted for age, gender, indication/diagnosis, Charlson comorbidity index (CCI) score
Cossec et al (2017) [52]	Adjusted for age, gender, social deprivation index, patient's medications, comorbidities, bearing surface (metal-on-polythene, ceramic-on-polythene, metal-on-metal), fixation type (noncemented, cemented with antibiotic, cemented without antibiotic), hospital volume, and length of stay (LOS)
Huang et al (2011) [50]	Adjusted for age, gender, diagnosis/indication, comorbidity (CCI score), hospital-specific covariates (public vs private, profit vs nonprofit) and hospital accreditation status (medical center, regional hospital, and district hospital), infections, and complications
Katz et al (2001) [29]	Adjusted for age, gender, race, Medicaid eligibility, diagnosis/indication, CCI, and hospital volume
Katz et al (2012) [31]	Adjusted for age, gender, race, Medicaid eligibility, CCI, and hospital volume
Khatod et al (2014) [30]	Adjusted for age, gender, race, ASA grade, comorbidities, BMI, diagnosis/indication, procedure (bilateral/unilateral), surgical approach (anterolateral/lateral/posterior), fixation (noncemented vs cemented vs hybrid), head size, bearing surface types, surgeon fellowship trained (yes/no), and hospital volume
Kreder et al (1997) [32]	Adjusted for age, comorbidities, gender, diagnosis/indication, and hospital volume
Kreder et al (1998) [45]	Adjusted for age, gender, comorbidities, diagnosis/indication, and hospital volume
Pablo et al (2004) [33]	Adjusted for age, gender, annual income, education level, hospital volume, obesity, comorbidities, preoperative functional status, and distance from home to hospital
Losina et al (2004) [34]	Adjusted for age, sex, poverty status, comorbidities, diagnosis/indication, and stratified by varying hospital volumes
Malkani et al (2010) [35]	Adjusted for age, gender, CCI, race, socioeconomic status (Medicare buy-in status), hospital teaching status, ownership (public, private, nonprofit), location (rural, urban), bed size, hospital volume, procedure duration, and year of procedure performed
Manley et al (2008) [36]	Adjusted for sex, age, race/ethnicity, diagnosis/indication, hospital volume, hospital teaching status, hospital ownership (private, public, or nonprofit), hospital location (rural/urban), hospital size, and socioeconomic status (Medicare buy-in status)
Namba et al (2012) [37]	Adjusted for age, gender, comorbidities, race, ASA grade, BMI, diagnosis/indication, hospital volume, surgeon fellowship (yes or no), operative time, bilateral/unilateral procedure, anesthesia type, infection prophylaxis (antibiotic-laden cement, clean air, intravenous antibiotics, laminar flow, body exhaust suit, other), surgical approach (anterolateral, direct anterior, other, posterior, trochanteric)
Ong et al (2009) [28]	Adjusted for age, gender, race, diagnosis/indication, socioeconomic status (Medicare buy-in status), comorbidities (CCI), hospital teaching status, hospital ownership, hospital location, and hospital size
Paterson et al (2010) [24]	Adjusted for age, gender, CCI, diagnosis/indication, hospital teaching status, and hospital volume
Ravi et al (2014) [46]	Adjusted for age, sex, rurality index, fifth of income distribution, marginalization index, CCI, frailty, presence of specific comorbidities, hospital volume, age of primary surgeon, teaching hospital status
Ravi et al (2014) [47]	Adjusted for age, gender, income quintile, rurality, CCI, and hospital volume
Kurtz et al (2016) [38]	Adjusted for age, gender, race, census region, socioeconomic status, CCI, presence of specific comorbidities, hospital location, bed size, hospital type (profit vs nonprofit, teaching vs nonteaching), discharge status, and LOS
Goldstein et al (2016) [39]	Adjusted for age, sex, hospital location, insurance status, approach, comorbidities
Solomon et al (2002) [40]	Adjusted for hospital location, accreditation, teaching status, presence of dedicated orthopedic unit, use of laminar exhaust flow in operating room, year of procedure, Medicaid eligibility, primary diagnosis of aseptic necrosis, and comorbidity score
Styron et al (2011) [41]	Adjusted for age, gender, race, CCI score, income, insurance type, region, hospital location, teaching status, bed size, hospital ownership, and hospital volume
Thompson et al (2002) [42]	Adjusted for age, gender, preadmission loss of motion, arthritis in either knee, arthritis in contralateral hip, preadmission pain score, comorbidity scale, preadmission walking score, preoperative anticoagulants, preadmission steroids, ASA grade, used homemaker services before admission, mean activities of daily living score before admission, activity level before admission, visual or hearing impairment, acetabulum radiographic abnormality, used physical therapy before admission, preoperative chest radiograph, and preoperative warfarin
Shi et al (2013) [51]	Adjusting for age, gender, CCI score, primary diagnosis, hospital type, hospital volume, and LOS
Khatod et al (2006) [43]	Adjusted for age, gender, ASA score, diagnosis, procedure type (primary vs revision), femoral head size, and surgical approach (posterior vs others)
Katz et al (2003) [44]	Adjusted for age, gender, income, education level, diagnosis/indication, preoperative functioning, comorbidities, BMI, prior orthopedic surgery, and hospital volume

BMI, body mass index; ASA, American Society of Anesthesiologists; DVT, deep venous thrombosis.

Of the 6 studies reporting LOS, all found a significant association between a longer LOS when surgeries were performed by an LV surgeon.

Complications

Because complications were defined differently in all studies, it is difficult to derive conclusions with regard to each specific complication. However, we did notice that there was a wide variation in regard to the impact of surgeon volume on postoperative complications (Table 3).

Baker et al [49] found that procedures performed by LV surgeons were associated with a higher risk of postoperative transfusion (17%) as compared to HV surgeons (5%). Camberlin et al [54] assessed 90-day complications following surgery by LV (5.0%), MV (4.5%), and HV (3.0%) surgeons and found no significant association (LV vs HV: OR, 1.4 [0.93-2.2]; MV vs HV: OR, 1.1 [0.99-1.9]). Huang et al [50] found a significantly higher incidence of acute postoperative infection following surgery by LV (1.33%) as compared to MV (0.48%) and HV (0.27%) surgeons. However, with regard to other perioperative complications, as defined before, no similar significant association was found. Katz et al (2001) [29] found no significant association between a higher surgeon volume and a lower incidence of deep infection and pulmonary embolism. Kreder et al (1997) [32] found a higher risk of in-hospital complications when comparing LV (12.9%) vs HV (8.8%) surgeons (OR, 1.6 [1.1-2.3]). The study also carried out comparisons for 90-day and 1-year rates of infection and found that a lower surgeon volume was significantly associated with a higher risk of infection at both time points.

In another study by Kreder et al (1998) [45], no significant associations were seen for in-hospital complications and 1-year and 3-year infection rates. Similarly, Namba et al [37] also found no significant association between a lower surgeon volume and a higher incidence of infection. Paterson et al [24] reported a higher risk of in-hospital complications when surgery was performed by an LV surgeon (69.9%) vs MV (50.1%), HV (55.8%), and VHV (65.8%) surgeons. Ravi et al [46,47] in both his studies found no significant association between surgeon volume and rates of 90-day venous thromboembolism episodes. However, he did show that a lower 2-year infection rate was seen when surgery was performed by an HV surgeon. Solomon et al [40] reported higher occurrence of adverse events by LV surgeons as compared to HV when stratified by varying hospital sizes. Thompson et al [42] only found a significant association with a higher rate of general complications in LV and MV surgeons as compared to VHV surgeons performing cemented THA. No significant association was seen with regard to operative complications and all complications following uncemented THA (Table 4).

Patient-Reported Outcomes

Neither of the 2 studies reporting patient-reported outcomes found any significant association between operating/provider volume and functional outcomes [42,44].

Discussion

This review reveals significant findings with regard to volume-outcome relationships in primary THA. Few systematic reviews investigating the impact of provider and hospital volume on healthcare have been published in the realm of orthopedic surgery, with a majority focusing on knee [22], spine [63], hip fracture [64], and shoulder conditions [65]. This systematic review is intended to collate literature and facilitate discussion with regard to care improvement and cost-effectiveness. Broadly summarizing the results, we found that an increasing surgeon volume was associated with better surgical outcomes following THA.

We documented a linear trend between increasing surgeon volume and a lower hospital cost and LOS. Probable reasons for LV surgeons having a longer LOS include a higher incidence of postoperative complications or lack of confidence with early discharge to home. However, out of the 2 studies investigating postoperative discharge to inpatient rehabilitation [33,39], skilled nursing, or home care, only 1 showed that increasing volume was associated with a decrease in discharge to a nursing facility vs home care [39]. This finding is particularly important as recently published literature has shown that continued inpatient care after total joint arthroplasty is associated with higher odds of 30-day complications and readmissions [66].

The association between higher provider volume and lower complication rates has been described extensively in other orthopedic literature pertaining to hip, spine, knee, and shoulder surgeries. We saw a wide variation in the reported complications, and with the inability to conduct a detailed meta-analysis, it is difficult to arrive at definitive conclusions. However, a general trend toward lower complication rates including dislocation was seen with an increasing surgeon volume.

It is probable that HV surgeons are more adept at identifying postoperative complications early in the course and are also more experienced in identifying patients who can be discharged early. Ong et al [28] reported that LV surgeons had a significantly higher total operative duration as compared to HV surgeons. This can be explained by the fact that HV surgeons are more efficient surgical technicians. This may also affect the risk of postoperative complications as studies have shown that long operative times are correlated with an increase in the number of complications [67].

Adherence to clinical care pathways and evidence-based processes of care may also impact LOS and costs after total joint arthroplasty. Bozic et al [68] found a negative corelation between surgeon volume and the number of missed evidence-based processes of care. In addition, clinical care pathways have been shown to reduce LOS [69], improve quality of care [70], and reduce costs [71]. However, the relationships between surgeon volume, adherence to clinical care pathway guidelines, and LOS require further study before definitive conclusions can be made.

With regard to survivorship following primary THA, there was a general trend toward lower revision rates with increasing surgeon volumes. However, the majority of these associations were only seen in early-term to midterm follow-up (up to 4 years) after surgery. With regard to long-term survivorship (>5 years), 2 studies showed no association between surgeon volume and revision rates at 8 years [32,43]. A study that evaluated 12-year revision risks showed that low surgeon volume was associated with a higher overall revision risk at 12 years, primarily due to failures in the early postoperative period of 18 months. After that, hazard ratios did not differ through 12 years [31]. It seems therefore that surgeon volume primarily affects early technical failures and long-term survivorship may depend upon other factors. However, further long-term prospective studies would be required before a more affirmative answer can be reached.

Only 2 studies evaluated patient-reported outcomes following surgery and found no significant association between surgeon volumes and reported functioning after surgery [42,44]. However, these 2 studies used different metrics in assessing postoperative outcomes. Future studies are required to better define any relationships between provider volumes and patient-reported outcomes.

An important aspect to mention is that there has been an increase in the magnitude of difference between volume threshold groups. The "oldest" study in our review (Kreder et al, 1997) defined an LV threshold as <2 cases/year and HV as >10 cases/year, whereas relatively newer studies published such as Khatod et al (2014) and Ravi et al (2014) have defined LV as <30-35 cases/year and HV as >30-35 cases/year. It is expected that the magnitudes of these differences will increase over time, concurrent with a rising number of THAs being performed globally.

Another interesting aspect to investigate is whether education/training and mentoring by HV surgeons vs LV surgeons have any impact on a junior surgeon's outcomes. While it may be assumed that arthroplasty fellows who undergo training at HV centers under HV surgeons may be more clinically and technically adept, current literature does not hold answers to this question. Future studies may yield more affirmative answers to this interesting concept.

The concept of "regionalization" is based upon the preferential management of high-risk cases to centers of excellence [72]. As yet, only low-grade studies have examined the merits of this concept; sufficient evidence is not yet present to advocate widespread implementation of regionalization of THA. Moreover, patient acceptance [73] and the financial burden of travel expenses require further study [74]. Furthermore, it has been suggested that regionalization may amplify racial disparities in healthcare [75]. Chaudhry et al [76] successfully proved that the introduction of a universal insurance and equal access healthcare system may be an effective way of avoiding such racial disparities. Future studies assessing impact of equal-access healthcare system may shine further light upon what may be a promising solution to a pressing problem.

There are limitations to this systematic review. Firstly, due to differences in volume thresholds across studies and variations in the definitions of reported outcomes, significant heterogeneity existed among the studies. This is one of the main reasons why a meta-analysis could not be conducted. Secondly, the majority of the studies included used large-scale administrative databases and registries that may be prone to coding errors. Thirdly, only few studies adjusted for implant types and femoral head sizes, which

Table 4
Surgeon Volume Thresholds and Outcomes in Studies.

Author (Year)	Reference Group	Surgeon Volume Thresholds						Outcomes	Sig.	Crude Outcomes	Adjusted Outcomes—LR/HR/OR/RR (95% CI)
		VLV	LV	MV	HV	VHV	Other				
Kreder et al (1997) [32] N = 8.774	Ref: HV	—	<40th centile (<2 cases/y)	40th to 80th centile (2-10 cases/y)	>80th centile (>10 cases/y)	—	—	Index hospital			
								Total hospital charge ($)			
								LV vs HV	NS	$13,538 vs $12,355	LR, 126 (−858 to 1110)
								MV vs HV	NS	$12,329 vs $12,355	LR, −303 (−992 to 386)
								LOS (d)			
								LV vs HV	Sig.	8.96 vs 7.73	LR, 0.8 (0.4-1.3)
								MV vs HV	NS	7.72 vs 7.73	LR, −0.1 (−0.3 to 0.2)
								Discharge to home			
								LV vs HV	Sig.	85% vs 91.1%	NR
								MV vs HV	—	87.4% vs 91.1%	NR
								Mortality			
								LV vs HV	Sig.	1.8% vs 0.3%	NR
								MV vs HV	—	0.4% vs 0.1%	NR
								Complications			
								LV vs HV	—	12.9% vs 8.8%	OR, 1.6 (1.1-2.3)
								MV vs HV	Sig.	7.9% vs 8.8%	OR, 1.0 (0.8-1.3)
								UTI			
								LV vs HV	NS	3.9% vs 3.7%	NR
								MV vs HV	NS	4.5% vs 3.7%	NR
								90-d Outcomes			
								Mortality			
								LV vs HV	NR	2.1% vs 0.5%	OR, 3.0 (1.4-7.3)
								MV vs HV	NR	0.9% vs 0.5%	OR, 1.0 (0.6-1.9)
								Infection			
								LV vs HV	Sig.	1.1% vs 0.3%	OR, 4.3 (1.5-12.2)
								MV vs HV	NS	0.7% vs 0.3%	OR, 1.8 (0.9-3.3)
								Revision surgery			
								LV vs HV	—	1.8% vs 0.5%	OR, 2.9 (1.2-6.8)
								MV vs HV	Sig.	0.7% vs 0.5%	OR, 1.0 (0.7-1.4)
								DVT			
								LV vs HV	NS	1.1% vs 1.1%	NR
								MV vs HV	NS	1.1% vs 1.1%	NR
								1-y Outcomes			
								Mortality			
								LV vs HV	NS	3.2% vs 1.3%	OR, 1.9 (0.9-3.8)
								MV vs HV	NS	2.0% vs 1.3%	OR, 1.4 (1.0-2.0)
								Infection			
								LV vs HV	Sig.	1.1% vs 0.6%	OR, 3.2 (1.3-7.7)
								MV vs HV	NS	1.2% vs 0.6%	OR, 1.6 (0.9-2.8)
								Revision surgery			
								LV vs HV	Sig.	3.2% vs 1.6%	OR, 2.1 (1.1-6.8)
								MV vs HV	NS	1.9% vs 1.6%	OR, 1.0 (0.7-1.4)
Kreder et al (1998) [45] N = 3645	Ref: HV		<9	9-27	>27			Index hospital			
								Mortality			
								LV vs HV	NS	0.3% vs 0.3%	NR
								MV vs HV	NS	0.4% vs 0.3%	NR
								Compli.			
								LV vs HV	NS	6.9% vs 9.0%	OR, 0.8 (0.5-1.3)
								MV vs HV	NS	8.7% vs 9.0%	OR, 1.0 (0.7-1.3)
								UTI			
								LV vs HV	NS	2.4% vs 2.7%	NR
								MV vs HV	NS	3.0% vs 2.7%	NR
								LOS (d)			
								LV vs HV	Sig.	13.6 vs 11.0	LR, 2.4 (1.3-3.1)
								MV vs HV	Sig.	12.3 vs 11.0	LR, 1.2 (0.7-1.7)
								90-d Mortality			
								LV vs HV	NS	1.0% vs 0.7%	1.9 (0.4-10.2)
								MV vs HV	NS	0.7% vs 0.7%	1.3 (0.4-3.8)
								1-y Outcomes			
								Mortality			
								LV vs HV	NS	2.4% vs 1.4%	1.6 (0.6-4.6)
								MV vs HV	NS	2.0% vs 1.4%	1.3 (0.6-2.6)
								Infection			
								LV vs HV	NS	1.4% vs 0.8%	1.7 (0.5-5.9)
								MV vs HV	NS	1.1% vs 0.8%	1.3 (0.6-2.9)
								Revision surgery			
								LV vs HV	NS	1.4% vs 1.2%	1.4 (0.4-4.8)

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Table 4 (*continued*)

Author (Year)	Reference Group	Surgeon Volume Thresholds						Outcomes	Sig.	Crude Outcomes	Adjusted Outcomes—LR/HR/OR/RR (95% CI)
		VLV	LV	MV	HV	VHV	Other				
								MV vs HV	NS	1.1% vs 1.2%	1.1 (0.5-2.3)
								3-y Outcomes			
								Infection			
								LV vs HV	NS	2.8% vs 1.6%	1.7 (0.7-4.2)
								MV vs HV	NS	2.2% vs 1.6%	1.4 (0.8-2.5)
								Revision surgery			
								LV vs HV	NS	3.5% vs 2.2%	2.1 (1.0-4.5)
								MV vs HV	NS	1.9% vs 2.2%	1.1 (0.6-2.0)
								DVT			
								LV vs HV	NS	3.5% vs 3.3%	NR
								MV vs HV	NS	3.3% vs 3.3%	NR
Katz et al (2001) [29] N = 58,521	Ref: VLV	1-5 cases/y	6-10 cases/y	11-25 cases/y	26-50 cases/y	>50 cases/y	—	90-d Outcomes			
								Mortality			
								VLV vs LV	NS	1.1% vs 1.0%	OR, 0.98 (0.78-1.23)
								VLV vs MV	NS	1.1% vs 0.9%	OR, 0.97 (0.77-1.22)
								VLV vs HV	NS	1.1% vs 0.8%	OR, 1.10 (0.95-1.54)
								VLV vs VHV	NS	1.1% vs 0.7%	OR, 0.95 (0.56-1.62)
								Dislocation			
								VLV vs LV	Sig.	4.2% vs 3.4%	OR, 0.85 (0.76-0.96)
								VLV vs MV	Sig.	4.2% vs 2.6%	OR, 0.68 (0.59-0.78)
								VLV vs HV	Sig.	4.2% vs 2.4%	OR, 0.68 (0.54-0.86)
								VLV vs VHV	Sig.	4.2% vs 1.5%	OR, 0.49 (0.34-0.69)
								Deep infection			
								VLV vs LV	NS	0.3% vs 0.3%	OR, 0.90 (0.59-1.37)
								VLV vs MV	NS	0.3% vs 0.2%	OR, 0.80 (0.51-1.26)
								VLV vs HV	NS	0.3% vs 0.1%	OR, 0.64 (0.30-1.36)
								VHV vs VHV	NS	0.3% vs 0.1%	OR, 0.28 (0.07-1.11)
								Pulmonary embolism			
								VLV vs LV	NS	1.0% vs 1.0%	OR, 0.98 (0.78-1.23)
								VLV vs MV	NS	1.0% vs 0.9%	OR, 0.91 (0.72-1.14)
								VLV vs HV	NS	1.0% vs 0.7%	OR, 0.75 (0.51-1.08)
								VHV vs VHV	NS	1.0% vs 0.7%	OR, 0.73 (0.44-1.21)
Solomon et al (2002) [40] N = 5211	Stratified by hospital volume	—	<10 cases/y	—	≥10 cases/y	—	—	Adverse events			Hazard ratios were used but values were not specified
								Hospital volume (1-25 cases/y)			
								LV vs HV	Sig.	NR	
								Hospital volume (26-100 cases/y)			
								LV vs HV	Sig.	NR	
								Hospital volume (>100 cases/y)			
								LV vs HV	Sig.	NR	
Thompson et al (2002) [42] N = 1810	Ref: VHV Results stratified by cemented types	—	≤10 cases/y	11-18 cases/y	19-31 cases/y	>32 cases/y	—	Cemented op. compli.			
								LV vs VHV	NS	—	1.41 (.582-3.41)
								MV vs VHV	NS	—	0.79 (.272-2.28)
								HV vs VHV	NS	—	0.69 (.237-2.01)
								General compli.			
								LV vs VHV	Sig.	—	0.513 (.281-.936)
								MV vs VHV	Sig.	—	0.495 (.257-.952)
								HV vs VHV	NS	—	0.628 (.367-1.27)
								Walking compli. score			
								LV vs VHV	NS	—	0.036 (2.089-.209)
								MV vs VHV	NS	—	0.043 (2.080-.232)
								HV vs VHV	NS	—	0.014 (2.135-.185)
								Pain on follow-up			
								LV vs VHV	NS	—	
								MV vs VHV	NS	—	
								HV vs VHV	NS	—	
								Noncemented op. compli.			
								LV vs VHV	NS	—	1.06 (.428-2.62)
								MV vs VHV	NS	—	0.74 (.272-2.02)
								HV vs VHV	NS	—	0.63 (.248-1.59)
								General compli.			
								LV vs VHV	NS	—	0.745 (.326-1.70)
								MV vs VHV	NS	—	0.629 (.258-1.53)
								HV vs VHV	NS	—	0.899 (.406-1.99)
								Walking compli. score			

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Table 4 (*continued*)

Author (Year)	Reference Group	Surgeon Volume Thresholds						Outcomes	Sig.	Crude Outcomes	Adjusted Outcomes—LR/HR/OR/RR (95% CI)
		VLV	LV	MV	HV	VHV	Other				
								LV vs VHV	NS	—	.034 (2.095-.206)
								MV vs VHV	NS	—	.011 (2.137-.176)
								HV vs VHV	NS	—	.048 (2.070-.229)
								Pain on follow-up			
								LV vs VHV	NS	—	.870 (.537-1.41)
								MV vs VHV	NS	—	.966 (.585-1.60)
								HV vs VHV	NS	—	1.10 (.655-1.83)
Katz et al (2003) [44]	Ref: HV	—	≤12 cases/y	—	>12 cases/y	—	—	Harris hip score in lowest 10%			
								LV vs HV	NS	—	—
								Satisfaction score < 50			
								LV vs HV	NS	—	—
Pablo et al (2004) [33] N = 758	Ref: LV	—	≤14 cases/y	—	>14 cases/y	—	—	Discharge to inpatient rehab			
								LV vs HV	NS	NR	
Losina et al (2004) [34] N = 57,488	Results stratified by hospital volume Ref: LV in LV hospital	—	<12 cases/y	—	≥12 cases/y	—	—	4-y Revision surgery			
								Hospital volume (1-25 cases/y)			
								LV vs HV	NS	4.9% vs 4.0%	NR
								Hospital volume (26-50 cases/y)			
								LV vs HV	NS	4.0% vs 3.9%	NR
								Hospital volume (51-100 cases/y)			
								LV vs HV	Sig.	4.4% vs 3.3%	NR
								Hospital volume (>100 cases/y)			
								LV vs HV	Sig.	4.9% vs 3.3%	NR
								Early failure (1-18 mo)			
								Hospital volume (1-25 cases/y)			
								LV vs HV	Sig.	—	NR
								Hospital volume (26-50 cases/y)			
								LV vs HV	Sig.	—	NR
								Hospital volume (51-100 cases/y)			
								LV vs HV	Sig.	—	NR
								Hospital volume (>100 cases/y)			
								LV vs HV	Sig.	—	NR
								Late failure (19-48 mo)			
								Hospital volume (1-25 cases/y) LV vs HV	NS	—	NR
								Hospital volume (26-50 cases/y) LV vs HV	NS	—	NR
								Hospital volume (51-100 cases/y) LV vs HV	NS	—	NR
								Hospital volume (>100 cases/y) LV vs HV	NS	—	NR
Khatod et al (2006) [43] N = 1970	Ref: LV	—	≤30 cases/y	—	>30 cases/y	—	—	Dislocation at 1 y			
								LV vs HV	NS	1.3% vs 1.9%	OR, 1.6 (0.71-3.5)
Manley et al (2008) [36] N = 26,036	Ref: VHV	1-5 cases/y	6-10 cases/y	11-25 cases/y	26-50 cases/y	>50 cases/y	—	Revision surgery			
								At 6 mo			
								VLV vs VHV	NS	—	HR, 1.23 (0.73-2.10)
								LV vs VHV	Sig.	—	HR, 1.67 (1.05-2.65)
								MV vs VHV	Sig.	—	HR, 1.63 (1.08-2.45)
								HV vs VHV	NS	—	HR, 1.17 (0.75-1.82)
								At 2 y			
								VLV vs VHV	NS	—	HR, 1.06 (0.75-1.50)
								LV vs VHV	NS	—	HR, 1.21 (0.89-1.65)
								MV vs VHV	NS	—	HR, 1.27 (0.97-1.65)
								HV vs VHV	NS	—	HR, 1.08 (0.82-1.43)

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Table 4 (*continued*)

Author (Year)	Reference Group	Surgeon Volume Thresholds						Outcomes	Sig.	Crude Outcomes	Adjusted Outcomes—LR/HR/OR/RR (95% CI)
		VLV	LV	MV	HV	VHV	Other				
								At 5 y			
								VLV vs VHV	NS	—	HR, 0.99 (0.74-1.34)
								LV vs VHV	NS	—	HR, 1.11 (0.85-1.44)
								MV vs VHV	NS	—	HR, 1.23 (0.99-1.54)
								HV vs VHV	NS	—	HR, 1.11 (0.87-1.40)
								At 8 y			
								VLV vs VHV	NS	—	HR, 1.0 (0.76-1.33)
								LV vs VHV	NS	—	HR, 1.07 (0.83-1.37)
								MV vs VHV	NS	—	HR, 1.22 (0.98-1.50)
								HV vs VHV	NS	—	HR, 1.15 (0.92-1.43)
Ong et al (2009) [28] N = not specified	Ref: VHV	1-5 cases/y	6-10 cases/y	11-25 cases/y	26-50 cases/y	>50 cases/y	—	Median procedure duration (min)			
								VLV vs VHV	Sig.	174.0 min vs 138.0 min	Not reported
Hooper et al (2009) [53]	None	<10	11-24	25-49	50-74	75-99	>100	7-y Revision rate	NR		No analysis conducted
								VLV		0.85%	
								LV		0.56%	
								MV		0.68%	
								HV		0.59%	
								VHV		0.53%	
								Other		0.55%	
Camberlin et al (2011) [54] N = 11,856	Ref: HV	—	≤6 cases/y	7-20 cases/y	>20 cases/y	—	—	90-d Compli.			
								LV vs HV	NS	5.0% vs 3.0%	OR, 1.43 (0.93-2.21)
								MV vs HV	NS	4.5% vs 3.0%	OR, 1.09 (0.99-1.89)
								VLV vs Other	NS	5.0% vs 2.2%	OR, 1.68 (0.96-2.96)
								LV vs Other	Sig.	4.6% vs 2.2%	OR, 1.98 (1.15-3.43)
								MV vs Other	NS	3.7% vs 2.2%	OR, 1.25 (0.77-2.04)
								HV vs Other	NS	4.0% vs 2.2%	OR, 1.41 (0.92-2.17)
								VHV vs Other	NS	2.8% vs 2.2%	OR, 1.05 (0.69-1.60)
Malkani et al (2010) [35] N = 39,266	Ref: not specified	1-5 cases/y	6-10 cases/y	11-25 cases/y	26-50 cases/y	>50 cases/y	—	Dislocation risk			
								At 2 y			
								VLV vs VHV	Sig.	93.2% vs 97.2%	NR
								At 7 y			
								VLV vs VHV	Sig.	90.2% vs 95.8%	NR
Paterson et al (2010) [24] N = 20,290	Ref: LV	—	2-25 cases/y	26-40 cases/y	41-60 cases/y	>61 cases/y	—	In-hospital compli.			
								LV vs MV	Sig.	69.9% vs 50.1%	OR, 0.73 (0.6-0.87)
								LV vs HV	Sig.	69.9% vs 55.8%	OR, 0.75 (0.63-0.90)
								LV vs VHV	Sig.	69.9% vs 65.8%	OR, 0.67 (0.55-0.82)
								LOS (d)			
								LV vs MV	Sig.	—	RR, 0.93 (0.89-0.98)
								LV vs HV	Sig.	—	RR, 0.93 (0.89-0.98)
								LV vs VHV	Sig.	—	RR, 0.89 (0.81-0.98)
								90-d Mortality			
								LV vs MV	NS	7.4% vs 6.2%	OR, 0.72 (0.47-1.09)
								LV vs HV	NS	7.4% vs 5.7%	OR, 0.79 (0.48-1.29)
								LV vs VHV	NS	7.4% vs 5.8%	OR, 1.00 (0.52-1.93)
								1-y Readmission for amputation, fusion, or excision			
								LV vs MV	NS	2.0% vs 2.6%	OR, 1.33 (0.61-2.90)
								LV vs HV	NS	2.0% vs 1.9%	OR, 0.56 (0.21-1.49)
								LV vs VHV	NS	2.0% vs 3.4%	OR, 0.62 (0.37-1.06)
								1-y Readmission for revision arthroplasty			
								LV vs MV	Sig.	12.8% vs 10.1%	OR, 0.72 (0.54-0.96)
								LV vs HV	NS	12.8% vs 12.1%	OR, 0.8 (0.58-1.10)
								LV vs VHV	Sig.	12.8% vs 9.2%	OR, 0.58 (0.42-0.79)
Baker et al (2011) [49] N = 508	Ref: HV	—	<52 cases/y	—	>52 cases/y	—	—	Postoperative transfusion			
								LV vs HV	Sig.	17% vs 5%	RR, 3.3 (1.5-9.1)
Huang et al (2011) [50] N = 9335	Ref: LV	—	< 40th centile (mean [range]) = 1.03 [0.5-1.5]	40th-80th centile (median [range]) = 4.8 [2-7.5]	>80th centile (median [range]) = 40.29 [8-119]	—	—	LOS (d [SD])			
								LV vs MV	Sig.	9.18 (4.5) vs 8.72 (3.58)	LR, −0.66 (−1.2 to −0.13)
								LV vs HV	Sig.	9.18 (4.5) vs 7.32 (3.18)	LR, −1.13 (−1.65 to −0.61)
								Hospital charge ($[SD])			
								LV vs MV	Sig.	116,708 (28.294) vs 112,470 (14,724)	LR, −4827 (−1605 to −8049)
								LV vs HV	Sig.		

(continued on next page)

Table 4 (*continued*)

Author (Year)	Reference Group	Surgeon Volume Thresholds						Outcomes	Sig.	Crude Outcomes	Adjusted Outcomes—LR/HR/OR/RR (95% CI)
		VLV	LV	MV	HV	VHV	Other				
										116,708 (28.294) vs 109,157 (177,552)	LR, −7056 (−2735 to −0.61)
								Acute infection			
								LV vs MV	Sig.	1.33% vs 0.48%	OR, 1.12 (0.5-2.52)
								LV vs HV	Sig.	1.33% vs 0.27%	OR, 0.92 (0.39-2.19)
								Perioperative compli.			
								LV vs MV	NS	1.77% vs 1.90%	—
								LV vs HV	NS	1.77% vs 1.34%	—
Styron et al (2011) [41] N = 42,231			1-10 cases/y	11-21 cases/y	22-52 cases/y	≥53 cases/y	—	Transformed mean LOS (d) LV vs VHV	Sig.	NR (18.8% increase in LOS)	LR, 3.95 (2.48-5.42)
Katz et al (2012) [31] N = 51,347	Ref: HV	—	1-6 cases/y	7-12 cases/y	>12 cases/y	—	—	12-y Revision surgery			
								HV vs LV	Sig.	Not reported	HR, 1.21 (1.12-1.32)
								HV vs MV	NS	Not reported	HR, 1.08 (1.0-1.17)
								0-18 mo postoperative			
								HV vs LV	Sig.	Not reported	HR, 1.65 (1.39-1.97)
Namba et al (2012) [37] N = 30,491	Ref: HV	—	<20 cases/y	20-49 cases/y	≥50 cases/y	—	—	Occurrence of deep SSI			Not included in final multivariate model
								LV vs HV	NS	0.4% vs 0.6%	
								MV vs HV	NS	0.4% vs 0.6%	
Shi et al (2013) [51] N = 78,364	—	—	<25 cases/y	—	≥25 cases/y	—	—	Hospital charges			Not applicable as both cohorts were matched using propensity scoring algorithms
								LV vs HV	Sig.	$4404.7 vs $3438.5	
Khatad et al (2014) [30] N = 36,834	Ref: HV	—	<30 cases/y	—	≥30 cases/y	—	—	8-y Revision surgery			
								LV vs HV	NS	2.0% vs 1.6%	HR, 1.18 (0.91-1.53)
Ravi et al (2014) [46] N = 37,881	Ref: NA (matched group)	—	≤35 cases/y	—	>35 cases/y	—	—	90-d Venous thromboembolism			Not applicable as cohorts were matched before running analysis
								LV vs HV	NS	1.7% vs 1.4%	
								90-d Mortality			
								LV vs HV	NS	0.7% vs 0.5%	
								2-y Revision			
								LV vs HV	Sig.	1.5% vs 1.0%	
								2-y Dislocation			
								LV vs HV	Sig.	1.9% vs 1.3%	
								2-y Infection			
								LV vs HV	NS	1.0% vs 1.1%	
								2-y Periprosthetic fracture			
								LV vs HV	NS	0.3% vs 0.3%	
Ravi et al (2014) [47] N = 43,997	Ref: not specified	—	—	—	—	—	—	90-d Venous thromboembolism	NS	—	
								2-y Outcomes	Sig.	—	HR, 0.5 (0.38-0.67)
								Dislocation	Sig.	—	HR, 0.66 (0.48-0.93)
								Infection			
Kurtz et al (2016) [38] N = 442,333	Ref: not specified	—	—	—	—	—	—	30-d Readmission	Sig.	Each additional surgeon volume of 100 procedures had a 7% reduction in risk	NR
								90-d Readmission	Sig.		
Goldstein et al (2016) [39]	Surgeon volume							90-d Costs	Sig.	Increase in volume was associated with a decrease in costs, nurse facility and home care discharge, and length of stay	NR
								LOS	Sig.		
								DC to nurse facility	Sig.		
								DC to home	NS		
								DC to home care	Sig.		
								PT within 1 y	NS		
Annan et al (2017) [48] N = 4334	Ref: HV	—	<43 cases/y	—	≥43 cases/y	—	—	Dislocation			
								LV vs HV	Sig.	—	OR, 4.96 (2.94-8.37)
Cossec et al (2017) [52] N = 62,906	Ref: HV	—	<1.5 cases/mo	1.5-4 cases/mo	>4 cases/mo	—	—	4-y Revision surgery			
								LV vs HV	Sig.	Not reported	HR, 1.70 (1.40-2.05)
								MV vs HV	Sig.	Not reported	HR, 1.19 (1.07-1.34)

VLV, very low volume; LV, low volume; MV, medium volume; HV, high volume; VHV, very high volume; other, threshold defined as being greater than VHV; LR, logistic regression; HR, hazard ratio; OR, odds ratio; RR, relative risk; CI, confidence interval; Sig., significant; NS, nonsignificant; compli, complications; DVT, deep venous thrombosis; UTI, urinary tract infection; SSI, surgical site infection; SD, standard deviation; DC, discharge; LOS, length of stay; NR, not reported; op, operation; PT, physical therapy.

may impact implant survival and dislocation rates. Clinical data are relatively absent from administrative databases, meaning that certain important patient factors such as American Society of Anesthesiologists grades, case complexity, and obesity classes (based on body mass index) are not recorded. Given that these factors may impact surgical outcomes, future researchers should promote the use of well-audited, prospective surgical registries which hold such granular clinical data to allow more accurate comparisons. Certain well-audited surgical databases, such as the American College of Surgeons National Surgical Quality Improvement Program, may be of immense benefit if, in addition to other 30-day outcome variables, surgeon and hospital volume variables are also recorded. Fourthly, the review was a collation of different country-specific registries and databases, including hospital system–specific and statewide databases which may not be representative of a large-scale national population. Finally, all of the studies included were derived from large-scale, retrospective databases and therefore are low quality according to the GRADE guidelines.

Conclusions

The concept of HV vs LV surgeons will likely come into discussion for many musculoskeletal-related procedures as cost-efficiencies continue to drive care pathways and policies of institutions. There is a general trend toward improved outcomes following a primary THA by an HV surgeon as compared to an LV surgeon. However, given the retrospective nature of the studies and the limitations present, future large-scale prospective studies, with more uniform thresholds and recording of additional confounding factors to allow substantial analytical comparison, are required before widespread adoption of sweeping changes in healthcare policy can be set in motion.

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