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ORTHOPAEDIC SURGERY

The impact of resident involvement on post-operative morbidity and mortality following orthopaedic procedures: a study of 43,343 cases

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Abstract
Background Few studies have addressed the role of residents' participation in morbidity and mortality after orthopaedic surgery. The present study utilized the 2005–2010 National Surgical Quality Improvement Program (NSQIP) dataset to assess the risk of 30-day post-operative complications and mortality associated with resident participation in orthopaedic procedures.

Methods The NSQIP dataset was queried using codes for 12 common orthopaedic procedures. Patients identified as having received one of the procedures had their records abstracted to obtain demographic data, medical history, operative time, and resident involvement in their surgical care. Thirty-day post-operative outcomes, including complications and mortality, were assessed for all patients. A step-wise multivariate logistic regression model was constructed to evaluate the impact of resident participation on mortality- and complication-risk while controlling for other factors in the model. Primary analyses were performed comparing cases where the attending surgeon operated alone to all other case designations, while a subsequent sensitivity analysis limited inclusion to cases where resident participation was reported by post-graduate year.
Results In the NSQIP dataset, 43,343 patients had received one of the 12 orthopaedic procedures queried. Thirty-five percent of cases were performed with resident participation. The mortality rate, overall, was 2.5 and 10 % sustained one or more complications. Multivariate analysis demonstrated a significant association between resident participation and the risk of one or more complications [OR 1.3 (95 % CI 1.1, 1.4); $p < 0.001$] as well as major systemic complications [OR 1.6 (95 % CI 1.3, 2.0); $p < 0.001$] for primary joint arthroplasty procedures only. These findings persisted even after sensitivity testing.
Conclusions A mild to moderate risk for complications was noted following resident involvement in joint arthroplasty procedures. No significant risk of post-operative morbidity or mortality was appreciated for the other orthopaedic procedures studied.
Level of evidence II (Prognostic).

Keywords Orthopaedic surgery · Resident education · Complications · Mortality · Arthroplasty

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Introduction

> *"In surgery…skill and confidence are learned through experience—haltingly and humiliatingly. Like the tennis player…and the guy who fixes hard drives, we need practice to get good at what we do. There is one difference in medicine though: it is people we practice upon."*
>
> *Atul Gawande,* [1]

The modern surgical residency system was instituted in the late-nineteenth century by William S. Halstead, MD, Chief Surgeon at Johns Hopkins Hospital [2]. This arduous program, predicated on a gradual learning process with incremental increases in professional responsibility, was heavily influenced by Halstead's experience training in Europe. Within 50 years, this concept of post-graduate education spread to every medical discipline and was implemented in hospitals across the United States [2]. While the Halsteadian concept of training remains in place today, societal changes, advances in medicine, and alterations in the medico-legal system over the last 30 years have presented robust challenges [1, 3–5]. Present concerns include the impact of work restrictions on residency training, reduced exposure to surgical cases and continuity of surgical patient care throughout the peri-operative period, diminished procedural autonomy, as well as the impact of resident involvement on post-operative complications and patient mortality [1, 3–9].

Although several investigations have dispelled the purported July phenomenon (an alleged increased risk of in-hospital errors when new interns start in July of every year) [6, 7], a substantial societal concern remains that resident involvement in patient care may potentiate adverse events [1, 10, 11]. Attending physician- and hospital-level perceptions of this effect may also be problematic, as concerns over the impact of complications deemed "never-events" by third-party payers on reimbursement may reduce resident exposure and/or technical experience in surgical cases.

Examinations regarding the impact of resident participation in surgical cases have largely been confined to the field of general surgery and have yielded conflicting results in many instances [3, 5–9, 12–16]. For example, while Jan et al. [14] maintained that resident involvement in vascular surgery procedures improved patient survival, no impact of resident participation was encountered in another work limited to carotid endarterectomy [16]. Moreover, several studies have reported an increased risk of patient mortality [9, 13] and/or elevated complication rates [3, 5, 8, 9, 13] among patients whose care was delivered, in part, by surgical residents.

Comparatively few works have addressed the impact of resident involvement on post-operative morbidity and mortality following orthopaedic procedures, with most efforts limited by a narrow scope of practice (e.g. single procedure or sub-specialty), incomplete evaluation of outcomes (e.g. focus on a single complication or procedural costs) and/or small sample size. This study endeavoured to utilize the dataset of the National Surgical Quality Improvement Program (NSQIP) to evaluate the influence of resident participation in common orthopaedic surgical cases on the risk of peri-operative complications and mortality. The NSQIP has been utilized in the past to evaluate resident surgeon impact on the incidence of complications and mortality, albeit only in instances of general or vascular surgery [3, 5, 8, 14–16]. To the best of our knowledge, this is the first effort to employ the NSQIP in an examination specific to residents engaging in orthopaedic procedures.

Materials and methods

This study received approval from our institution's investigational review board and was separately approved through application to the American College of Surgeons for access to the NSQIP dataset. The investigation was limited to patients whose records were uploaded to the civilian NSQIP. No data from the Veterans Administration NSQIP was assessed. The methodology behind the construction of the civilian NSQIP dataset has been extensively described in previous publications [3, 5, 8, 14–18], including studies focused on the impact of residents on mortality- and complication-risk following general [3, 5, 8, 15] or vascular surgery [14, 16].

Orthopaedic procedures selected for inclusion in this analysis were informed by the requirements mandated by the Residency Review Commission (RRC) [19]. However, the NSQIP does not capture information on pediatric cases, or those involving acute trauma, and these procedures could not be included within this study. Similarly, orthopaedic oncology cases were excluded because of an inherently high risk of complications as well as 30-day mortality. Ultimately, 12 procedures (Table 1) were selected based on emphasis within the orthopaedic educational curriculum [19, 20], as well as the presence of an established complication profile in the orthopaedic literature [17, 18, 21–33]. The selected procedures were intended to be representative of general orthopaedic practice as well as the surgical subspecialties of joint arthroplasty, spine surgery, sports medicine, and hand surgery.

The NSQIP dataset was queried by common procedural terminology (CPT) code to identify patients who had undergone at least one of the orthopaedic procedures eligible for inclusion. Because the NSQIP is an anonymous dataset and also limits post-operative censoring to the first 30 days following surgery, all instances of surgery identified were considered case-specific.

Table 1 Frequencies of orthopaedic procedures, by CPT code, included in the analysis

CPT code	Description	Frequency (%)[a]
Arthroplasty		23,783 (55)
27447	Total knee arthroplasty	15,517 (36)
27130	Total hip arthroplasty	8,266 (19)
Spine surgery		6,024 (14)
63030	Lumbar discectomy	4,558 (11)
22554	Anterior cervical arthrodesis	1,466 (3)
Amputation		11,050 (26)
27880	Below knee amputation	5,956 (14)
27590	Above knee amputation	5,094 (12)
Sports medicine		2,145 (5)
29888	Anterior cruciate ligament reconstruction	2,084 (5)
27705	High tibial osteotomy	36 (0.1)
24340	Distal biceps tenodesis	25 (0.1)
Hand		341 (0.8)
64708	Neuroplasty, major peripheral nerve	185 (0.4)
26350	Flexor tendon repair	71 (0.2)
26410	Extensor tendon repair	85 (0.2)
	Total	43,343 (100)

[a] Percentages do not add to 100 due to rounding

Demographic data and medical history, including patient age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) classification, and the specific diagnoses of diabetes and cardiac disease were abstracted for all individuals eligible for inclusion. Surgical data included operative time, type of procedure performed, and resident involvement in the case. Resident involvement was determined by query of the "residency supervision" cell in the NSQIP. Resident participation by post-graduate year (PGY) was also recorded when available. Thirty-day post-operative outcomes included mortality and complications, with complications categorized as major systemic, major local, minor systemic, or minor local according to accepted designations (Table 2). Because of previous reports documenting an increased incidence of infections associated with resident participation in surgical cases [8, 15], post-operative infections were also recorded as a separate outcome measure.

Statistical analysis

Due to concerns regarding heterogeneity between sub-specialties, a determination was made to limit statistical analysis to the categories of joint arthroplasty, spine surgery, amputation, and sports medicine/hand surgery. The sports medicine and hand procedures were grouped together because of similar complication and mortality rates [21, 24, 26, 30, 31], as well as the sample size for these categories in the NSQIP dataset. Within each category, the risk factors of age, sex, BMI, ASA classification, history of diabetes, history of cardiac disease, operative time, and resident participation were initially evaluated in univariate analysis to determine impact on the dependent variables of mortality, risk of one or more complications, major or minor systemic complications, major or minor local complications, and infection.

Univariate analysis was performed with linear/logistic regression for continuous, as well as categorical, variables. Risk factors that maintained a p value <0.2 following univariate testing were enrolled in a multivariate logistic regression model that was utilized to identify statistically significant independent variables associated with the outcomes identified. Significant independent predictor variables were determined, a priori, to be those that maintained p values <0.05 with odds ratios (OR) and 95 % confidence intervals (CI) exclusive of 1.0 following multivariate analysis.

Initial determinations were made comparing cases where the attending surgeon operated alone to all other case designations (attending and resident, attending available, attending in OR suite). A subsequent sensitivity analysis was performed where cases delineated as having a resident present by PGY were compared to those without a resident designation. Final predictor variables were limited to those that maintained significance after multivariate testing in both the primary model and sensitivity analysis.

Results

The query of the 2005–2010 NSQIP dataset returned 43,343 patients who had undergone one of the 12 orthopaedic procedures selected for inclusion (Table 1). The average

Table 2 Rates of mortality, major complications, and minor complications for the study cohort

Characteristic	Frequency (%)
Mortality	1,074 (2.5)
Major systemic complications	
Cardiac arrest/MI	277 (0.6)
Pulmonary embolism	228 (0.5)
Cerebrovascular accident	115 (0.3)
Acute renal failure	158 (0.4)
Post-operative sepsis	736 (2)
Septic shock	436 (1)
Other	925 (2)
Major local complications	
Deep infection	485 (1)
Peripheral nerve injury	40 (0.1)
Minor systemic complications	
Pneumonia	559 (1)
Urinary tract infection	980 (2)
Renal insufficiency	141 (0.3)
Deep venous thrombosis	430 (1)
Minor local complications	
Wound dehiscence	250 (0.6)
Superficial wound infection	773 (2)

Table 3 Rates of mortality and complications by procedural subgroup

	Frequency (%)
Spine	
Mortality	10 (0.2)
Complications	214 (4)
Total joint arthroplasty	
Mortality	58 (0.2)
Complications	1,310 (5.5)
Amputation	
Mortality	1,006 (9)
Complications	2,861 (26)
Sports/hand	
Mortality	0 (0)
Complications	34 (1)

age of patients in each of the sub-specialty categories was 51.2 (±14.6) for spine surgery, 66.6 (±11.1) for joint arthroplasty, 67.9 (±13.7) for amputation, and 34.3 (±13.3) for sports medicine/hand surgery. Fifty-two percent of the cohort was female and 79 % were classified as white. Fifty-six percent of the cohort ($n = 24{,}105$) was graded as ASA class 3 or higher and 26 % ($n = 11{,}221$) were diabetic. The average procedural time for the group was 91.7 min (±46.7). Based on case designation in the NSQIP, 15,370 procedures (35 %) were performed with resident participation. If resident participation was limited to those instances where a PGY was reported, 13,096 (30 %) procedures were conducted with resident assistance. PGY-Is and IIIs each participated in 16 % of cases, while PGY-IIs were recorded in 15 %. PGY-IV residents were reported in 19 %, with the remaining cases (35 %) listed as having a PGY-V or higher participating.

The mortality rate, for the cohort as a whole, was determined to be 2.5 % ($n = 1{,}074$, Table 2). The vast majority of patients who died following surgery ($n = 1{,}006$) were derived from the amputation group (Table 3). A complication was documented in 4,419 (10 %) cases, overall. Urinary tract infection was the most commonly encountered specific complication ($n = 980$, 2 %), followed by superficial wound infection ($n = 773$, 2 %).

Resident participation occurred in 3 (30 %) spine cases that resulted in mortality (Table 4) and 44 (21 %) procedures where one or more complications occurred. For amputation procedures, mortality was reported in 585 (58 %) resident associated cases and complications transpired in 1,730 (60 %). Among arthroplasty procedures, 13 (22 %) cases where mortality occurred were associated with resident participation, while 322 (25 %) resident-associated cases were documented as having sustained a complication (Table 5).

Unadjusted univariate analysis determined that resident participation increased the risk of one or more complications [OR 1.3 (95 % CI 1.1, 1.5); $p < 0.001$], major systemic complications [OR 1.6 (95 % CI 1.3, 2.0); $p < 0.001$] and minor systemic complications [OR 1.2 (95 % CI 1.02,

Table 4 Frequency and percentage of mortality and specific complications among spine, amputation and sports/hand cases as compared between procedures with resident participation and those without residents

Spine	Frequency in resident cases (% out of 1,180)	Frequency in non-resident cases (% out of 4,844)
Mortality	3 (0.25)	7 (0.14)
Major systemic complications	13 (1.10)	51 (1.05)
Cardiac arrest/MI	0 (0)	3 (0.06)
Pulmonary embolism	2 (0.17)	10 (0.21)
Cerebrovascular accident	1 (0.08)	2 (0.04)
Acute renal failure	0 (0)	1 (0.02)
Post-operative sepsis	6 (0.51)	9 (0.19)
Septic shock	1 (0.08)	4 (0.08)
Other	4 (0.33)	28 (0.58)
Major local complications	11 (0.93)	34 (0.70)
Deep infection	7 (0.59)	31 (0.64)
Peripheral nerve injury	4 (0.34)	4 (0.08)
Minor systemic complications	21 (1.78)	68 (1.40)
Pneumonia	2 (0.17)	16 (0.33)
Urinary tract infection	13 (1.10)	41 (0.85)
Renal insufficiency	1 (0.08)	1 (0.02)
Deep venous thrombosis	5 (0.42)	16 (0.33)
Minor local complications	8 (0.68)	50 (0.83)
Wound dehiscence	1 (0.08)	11 (0.23)
Superficial wound infection	7 (0.59)	40 (0.83)
Amputations	**Frequency in resident cases (% out of 6,573)**	**Frequency in non-resident cases (% out of 4,477)**
Mortality	585 (8.90)	421 (9.40)
Major systemic complications	1,021 (15.53)	630 (14.07)
Cardiac arrest/MI	151 (2.30)	95 (2.12)
Pulmonary embolism	38 (0.58)	28 (0.63)
Cerebrovascular accident	43 (0.65)	36 (0.80)
Acute renal failure	82 (1.25)	56 (1.25)
Post-operative sepsis	404 (6.15)	199 (4.44)
Septic shock	246 (3.75)	152 (3.39)
Other	495 (7.53)	282 (6.30)
Major local complications	211 (3.21)	136 (3.04)
Deep infection	210 (3.19)	136 (3.04)
Peripheral nerve injury	1 (0.02)	0 (0)
Minor systemic complications	682 (10.38)	434 (9.69)
Pneumonia	261 (3.97)	183 (4.09)
Urinary tract infection	329 (5.01)	216 (4.82)
Renal insufficiency	72 (1.10)	31 (0.69)
Deep venous thrombosis	96 (1.47)	47 (1.05)
Minor local complications	415 (6.31)	283 (6.32)
Wound dehiscence	96 (1.46)	90 (2.01)
Superficial wound infection	328 (4.99)	199 (4.44)
Sports/hand	**Frequency in resident cases (% out of 527)**	**Frequency in non-resident cases (% out of 1,959)**
Mortality	0 (0)	0 (0)
Major systemic complications	0 (0)	0 (0)

Table 4 continued

Sports/hand	Frequency in resident cases (% out of 527)	Frequency in non-resident cases (% out of 1,959)
Cardiac arrest/MI	0 (0)	0 (0)
Pulmonary embolism	0 (0)	0 (0)
Cerebrovascular accident	0 (0)	0 (0)
Acute renal failure	0 (0)	0 (0)
Post-operative sepsis	0 (0)	0 (0)
Septic shock	0 (0)	0 (0)
Other	0 (0)	0 (0)
Major local complications	1 (0.19)	7 (0.36)
Deep infection	1 (0.19)	7 (0.36)
Peripheral nerve injury	0 (0)	0 (0)
Minor systemic complications	4 (0.76)	7 (0.36)
Pneumonia	1 (0.19)	0 (0)
Urinary tract infection	0 (0)	1 (0.05)
Renal insufficiency	0 (0)	0 (0)
Deep venous thrombosis	3 (0.57)	6 (0.31)
Minor local complications	4 (0.76)	12 (0.61)
Wound dehiscence	2 (0.38)	0 (0)
Superficial wound infection	2 (0.38)	12 (0.61)

Table 5 Frequency and percentage of mortality and specific complications among joint arthroplasty cases as compared between procedures with resident participation and those without residents

Total joint arthroplasty	Frequency in resident cases (% out of 4,816)	Frequency in non-resident cases (% out of 18,967)
Mortality	13 (0.27)	45 (0.24)
Major systemic complications	120 (2.49)	306 (1.61)
Cardiac arrest/MI	5 (0.10)	23 (0.12)
Pulmonary embolism	45 (0.93)	105 (0.55)
Cerebrovascular accident	6 (0.12)	27 (0.14)
Acute renal failure	4 (0.08)	15 (0.08)
Post-operative sepsis	37 (0.77)	81 (0.43)
Septic shock	4 (0.08)	29 (0.15)
Other	33 (0.69)	83 (0.44)
Major local complications	30 (0.62)	94 (0.50)
Deep infection	22 (0.46)	71 (0.37)
Peripheral nerve injury	8 (0.17)	23 (0.12)
Minor systemic complications	173 (3.59)	566 (2.98)
Pneumonia	17 (0.35)	79 (0.42)
Urinary tract infection	91 (1.89)	289 (1.53)
Renal insufficiency	7 (0.15)	29 (0.15)
Deep venous thrombosis	65 (1.35)	192 (1.02)
Minor local complications	48 (1.00)	182 (0.96)
Wound dehiscence	16 (0.33)	34 (0.18)
Superficial wound infection	37 (0.77)	148 (0.78)

1.4); $p = 0.03$] within the category of joint arthroplasty. Resident involvement was also found to be associated with an increased risk of major systemic complications [OR 1.1 (95 % CI 1.01, 1.3); $p = 0.03$] in amputation procedures. Resident involvement was not associated with a significant risk of mortality for any selected procedural category, nor was the threshold criteria for inclusion in the multivariate test for this outcome achieved in any instance. No

significant association between resident participation and any complication-based outcome was identified in univariate analysis for spine surgery or sports medicine/hand procedures, and threshold criteria were also not achieved.

Following multivariate analysis, controlling for other factors in the model, a statistically significant association was maintained for the joint arthroplasty category with regard to resident involvement and the risk of one or more complications [OR 1.3 (95 % CI 1.1, 1.4); $p < 0.001$] as well as major systemic complications [OR 1.6 (95 % CI 1.3, 2.0); $p < 0.001$]. No significant impact of resident participation on the risk of major systemic complications was encountered for the amputation category after multivariate testing [OR 1.1 (95 % CI 0.9, 1.2); $p = 0.36$]. The sensitivity test maintained the associations between resident participation and complication risks for joint arthroplasty procedures, with good fidelity between the primary ORs and those derived from sensitivity testing [one or more complications—OR 1.3 (95 % CI 1.1, 1.4; $p = 0.001$), major systemic complications—OR 1.5 (95 % CI 1.2, 1.9; $p < 0.001$)].

Discussion

The modern graduate medical education system continues the legacy instituted by Halstead at the end of the nineteenth century [1, 2]. While the residency training model has remained relatively unaltered in the century and a half since its inception [1, 2], the medical environment in which it takes place has changed dramatically [1, 3–5, 10, 11]. Substantial changes in the medico-legal environment and societal opinion have culminated to create an atmosphere that is more restrictive, scrutinized, and regulated than it was in the past [1, 3, 5, 10, 11]. Although such realities may be warranted, the fact of the matter remains that surgical training necessitates clinical practice and operative exposure [1, 4]. While holding great promise, computer-based models and other modalities of skill development have not proven capable of reproducing the surgical environment to a comparable extent [5, 20].

Thus, the potential remains for concerns on the part of patients, third-party payers, and administrative/physician staff regarding the impact of resident participation on post-operative morbidity and mortality, to further reduce already truncated training opportunities for residents [1, 4, 10, 11]. This issue has not previously been addressed satisfactorily for the field of orthopaedics [34–36], and investigations regarding general and vascular surgery procedures have yielded conflicting results [3, 5–9, 12–16]. This study sought to systematically investigate the impact of resident participation on the risk of post-operative morbidity and mortality following a selected group of common orthopaedic procedures representative of the fields of joint arthroplasty, spine surgery, amputations, sports medicine and hand surgery. The selected cases were informed by procedural requirements for residency training as delineated by the RRC [19].

Our results, derived from a substantial cohort of over 43,000 orthopaedic procedures, indicate that resident involvement in surgical care resulted in an increased risk of one or more complications [OR 1.3 (95 % CI 1.1, 1.4)] and major systemic complications [OR 1.6 (95 % CI 1.3, 2.0)] in joint arthroplasty procedures only. No increased risk of complications was appreciated for the other procedures under investigation. Moreover, no relationship was identified between resident participation and risk of mortality for any category. These associations were maintained, even after sensitivity analysis that restricted case consideration to those where resident involvement by PGY was reported.

The composition of the patient cohort, including demographic features and medical history, as well as the complication and mortality rates for the procedures of interest, approximate other orthopaedic reports in the literature [17, 18, 21–33], and lend additional credibility to our findings as does the size of the study sample. The methodology of the NSQIP also enabled us to access a robust patient cohort with prospectively collected, case-specific data that were not limited to the experience of a single center or region of the United States. This may have important implications regarding the translation of our findings to residency programs across the nation.

Only a few putative studies have been conducted regarding an association between the training environment and outcomes in the orthopaedic field [34–36] and none of these are comparable to our effort in terms of population size or scope. Auerbach and colleagues [34] maintained that resident involvement in scoliosis surgery led to increased operative times without an elevated risk in complications. Banco and co-workers [35] postulated that resident training was not associated with an increased risk of post-operative spinal infections although this was solely based on temporal associations. More substantial research, including efforts that have relied on NSQIP data, has been conducted within the fields of general and vascular surgery [3, 5–9, 12–16]. Some of these studies have shown that resident involvement increased the risk of wound related complications, as well as infection [5, 8].

Limitations present in this work include reliance on information from a dataset that precludes knowledge of case complexity, the extent of resident participation, and the potential for analytical errors that may be generated by mistakes in data entry or coding. Paucity of case numbers, particularly in the area of sports medicine and hand, could also have impacted our ability to detect differences in morbidity rates between cases associated with residents and

those that were not. Moreover, we recognize that our findings are not necessarily generalizable, even to the sub-specialty/procedural categories that we devised, because they are represented by no more than 2–3 surgical procedures that are by no means exhaustive. It should also be appreciated that, while the procedures selected are frequently performed by orthopaedic specialists, the operative surgeon stated in the NSQIP was not always orthopaedic, as cases from neurosurgical (spine) and plastic surgery (hand) specialties were included as well.

Despite its limitations, this study remains the largest work conducted to date investigating the influence of resident participation on post-operative morbidity and mortality following orthopaedic surgery. Due to the study's size and methodology, as well as paucity in existent literature, this work can be considered among the best available evidence on this topic. Our findings indicate that, while there may be a mild to moderate risk in complications following joint arthroplasty procedures, resident involvement does not appear to be significantly associated with post-operative morbidity or mortality following lower extremity amputation procedures, anterior cervical arthrodesis, lumbar discectomy, ACL reconstruction, and tendon repairs of the hand, among others.

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