

Analysis of Postoperative Complications in Spinal Surgery, Hospital Length of Stay, and Unplanned Readmission: Application of Dindo-Clavien Classification to Spine Surgery

Gaston Camino Willhuber, MD¹, Cristina Elizondo, MD¹ , and Pablo Slullitel, MD¹

Global Spine Journal
2019, Vol. 9(3) 279-286
© The Author(s) 2018
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/2192568218792053
journals.sagepub.com/home/gsj



Abstract

Study Design: Retrospective study. Level of evidence III.

Objective: Postoperative complications in spine surgery are associated with increased morbidity, hospital length of stay, and health care costs. Registry of complications in orthopedics and the spine surgery is heterogeneous.

Methods: Between July 2016 and June 2017, 274 spinal surgeries were performed, the presence of postoperative complications was analyzed at 90 days (according to the classification of Dindo-Clavien, grades I-V), hospital length of stay, surgical complexity (low, medium, and high), unplanned readmission, and risk factors were evaluated.

Results: A total of 79 patients suffered a complication (28.8%), of them 21 (26.7%) were grade I, 24 (30.3%) were grade II, 4 (5.7%) were grade IIIA, and 29 (37.3%) were grade IIIB. There were no IV and V grade cases. The most frequent complication was excessive pain followed by deep wound infection and anemia. Surgical complexity and surgical time were significantly associated with the risk of developing a complication. The average number of hospital length of stay in patients without and with complications were 2.7 and 10.6, respectively, and the unplanned readmission rate was 11%.

Conclusions: Registry of postoperative complications allows the correct standardization and risk factors required to establish measures to decrease them, the application of Dindo-Clavien classification was useful for the purpose of our study.

Keywords

postoperative complication, Dindo-Clavien classification, hospital length of stay, unplanned readmission

Introduction

Surgical complications are defined as any event that represents a deviation in the expected postoperative course.¹ Such eventualities following spine surgery constitute a major concern associated with increased morbidity, mortality, hospital length of stay (LOS), and health costs. The prevalence of complications in spinal surgery is estimated between 13% and 40%.² It is known that complications after orthopedic surgery are usually underreported, and spinal surgeries are not exempted. Besides, there is a lack of a uniform classification system to categorize complications, making it difficult to assess the real magnitude of this issue, which clearly needs measures to reduce them.^{3,4} Multiple classification systems

have been developed for postoperative complications, many of which are often difficult to interpret and reproduce.⁵ Dindo and Clavien, developed a system originally applied to general surgery that has shown high reproducibility; this classification is graded from 1 to 5 according to increasing severity and the type of intervention required to treat the complication⁶⁻⁸

¹ Hospital Italiano de Buenos Aires, Buenos Aires, Argentina

Corresponding Author:

Gaston Camino Willhuber, Orthopaedic and Traumatology Department, Institute of Orthopedics "Carlos E. Ottolenghi," Hospital Italiano de Buenos Aires, Potosí 4215 (C1199ACK), Buenos Aires, Argentina.
Email: gaston.camino@hospitalitaliano.org.ar



Table 1. Classification of Surgical Complications According to Dindo and Clavien.

Grade	Definition
I	Any deviation from the normal postoperative course without the need for pharmacologic treatment or surgical, endoscopic, and radiographic interventions
II	Requiring pharmacologic treatment with drugs Blood transfusions and total parenteral nutrition are also included
III	Requiring surgical, endoscopic, or radiographic intervention IIIA Intervention not/under general anesthesia IIIB Intervention under general anesthesia
IV	Life-threatening complication requiring IC/ICU management IVA Single-organ dysfunction IVB Multiorgan dysfunction
V	Death of a patient

(see Table 1). Later, this classification system was applied to other specialties such as urology, nephrology, gastroenterology,⁹⁻¹⁴ and even in orthopedic surgery¹⁵ and spinal surgery¹⁶ with different adaptations.

The aim of this study was to assess the 90-day postoperative complication rate following spinal surgeries by applying the Dindo-Clavien classification system as well as to analyze the unplanned readmission rate and total hospitalization LOS in patients with and without complications.

Material and Methods

The study protocol was approved by the institution's ethics review board (Approval Number IRB00010197) and in concordance with the Declaration of Helsinki.

Spine surgeries performed at our institution between July 2016 and June 2017 were retrospectively analyzed. The presence of postoperative complications was evaluated at 90 days of surgery. Complications were registered through the electronic medical record applying the Dindo-Clavien (DC) classification based on 5 grades according to the severity and type of intervention required to treat the complication (see Table 1). In patients with more than 1 complication, the complication of greater degree was considered, and in cases of 2 complications that belonged to the same degree, both were considered. In addition, complications graded I, II, and IIIA of DC were considered as minor, while IIIB, IV, and V were considered as major.

Postoperative pain was categorized as a complication when it reached a specific threshold. It was considered normal within the first 72 hours postoperatively; however, it was considered a grade I complication if intravenous management beyond 72 hours was required and patients in whom intravenous treatment was restarted after a period of postoperative oral treatment, Pain was graded as DC IIIA if periradicular block injection guided by fluoroscopy or tomography was required and grade IIIB if reoperation was needed. Symptomatic anemia requiring blood transfusion or iron was considered grade II, transfusion protocol during the postoperative hospital stay was

performed when Hemoglobin was 7 g/dL or less or hematocrit was of 20% or lower.¹⁷

Variables such as patient age, sex, body mass index (BMI), type of pathology (deformity, degenerative, infection, tumor, trauma) were analyzed. We classified surgical procedures by complexity as follows: type A, low-complexity surgeries (eg, microdiscectomy, vertebroplasty, discoplasty, 1 or 2 level simple decompression); type B, intermediate-complexity surgeries (eg, decompression and fusion, percutaneous stabilization, laminoplasty, laminectomy and fusion, anterior/oblique/extreme lateral lumbar interbody fusion and type C, high-complexity surgeries (eg, surgery by double/triple approach, en bloc resection). The duration of surgery, unplanned readmission at 90 days, hospital LOS in patients with and without complications and days between surgery and complication were also recorded. Revision surgeries referred to our institution from another center were also excluded. Revision surgery in the same anatomical region operated at our center were included.

Statistical Analysis

Categorical variables were described as their absolute and relative frequency with percentages. The quantitative variables were described as mean and standard deviation (SD) or median and interquartile range (IQR) according to the observed distribution. Comparisons among the categorical variables (unplanned readmission, sex, type of pathology, surgical complexity) were made between the different groups (with and without complication), based on degree of complication with a global chi-square or Fisher test according to the assumptions. The quantitative variables (age, hospital stay, BMI, surgical time, etc) were compared between the groups of complication yes/no or degrees of complication with a *t* test or Mann-Whitney test according to the distribution of the observed variable.

The risk of presenting complications and unplanned readmission within the first 90 days was estimated with a logistic regression model; odds ratios were reported with their 95% confidence intervals.

It was considered a significant association if $P < .05$. The statistical analysis was performed with the software STATA 13.1.

Results

General Characteristics of the Studied Population

Between July 2016 and June 2017, 299 surgeries were performed; 15 patients were surgically treated at another center in the same anatomical region and were excluded, 10 patients were missed at 90-day follow-up and were also excluded. A total of 274 patients were analyzed (161 [58%] female), with a median age 68 years (IQR 54-76 years). The median BMI was 27.5 kg/m² (IQR 24.4-31.2 kg/m²). A total of 79 patients (28.83%; 95% CI 23.4% to 34.2%) presented a postoperative

Table 2. Absolute and Relative Complications According to Frequency.

Complication	n	Percentage
Excessive radicular pain ^a	16	5.8
Deep wound infection	12	4.3
Anemia	7	2.5
Fracture	5	1.8
Acute urinary retention	3	1.1
Deep vein thrombosis	3	1.1
Disc hernia recurrence	3	1.1
Wound dehiscence	3	1.1
Urinary infection	2	0.7
Phlebitis	2	0.7

^a Five patients with excessive radicular pain were surgically treated (Dindo-Clavien IIIB), 3 required periradicular injection (Dindo-Clavien IIIA), and 8 were treated with intravenous analgesia (Dindo-Clavien II).

complication within 90 days. Twenty-nine patients (10.5%) required reoperation due to a postoperative complication during the period analyzed and 32 patients (11.72%; 95% CI 7.88% to 15.56%) suffered an unplanned readmission due to a complication.

Type of Pathology

Of the 274 surgeries, 200 (73%) were due to degenerative pathology, 41 (14.6%) due to scoliosis (deformity), 14 cases due to tumoral pathology (5%), 10 cases due to infection (3.6%), and 9 cases due to acute trauma (3.2%). Main procedures were as follows: 69 vertebroplasties/discoplasties, 44 cases of lumbar microdiscectomy, 39 cases of lumbar decompression without arthrodesis, 30 lumbar decompression and arthrodesis, 27 cases of anterior, oblique, and lateral interbody fusion, 16 anterior cervical decompression and fusion, 16 thoracolumbar double approaches, 10 cases of laminoplasty and 23 other procedures (percutaneous stabilization, instrumental removal).

Primary Surgery and Revision Surgery

A total of 53 patients (19.34%) had a previous surgery at the same level at our institution. Though not significant ($P = .209$), there was a higher incidence of complications in patients with revision surgery 19/53 (35.85%) compared with patients with primary surgery 60/221 (27.15%).

Spinal Surgeries According to Complexity

Of the 275 procedures, 158 (57.6%) were classified as low complexity, 100 (36.5%) of intermediate complexity, and 16 (5.8%) of high complexity.

Absolute and Relative Frequency of Complications

In patients who presented with at least 1 postoperative complication ($n = 78$), the observed complications are listed in Table 2.

Table 3. Complications According to Dindo-Clavien Classification.

Classification	Complication (N = 79)	
	n	Percentage
Grade I	21	26.7
Grade II	24	30.3
Grade IIIA	4	5.7
Grade IIIB	29	37.3
Grade IVA	—	—
Grade IVB	—	—
Grade V	—	—

Table 4. Baseline Characteristics and Length of Stay in Patients With and Without Complications.

Characteristic	With Complications (n = 79)	Without Complications (n = 195)	P
Age (years)			.602
Median (IQR)	65 (54-74)	70 (53-76)	
Mean (SD)	63.78 (15.99)	63 (16.71)	
Male sex, n (%)	29 (36.71)	84 (56.92)	.332
BMI (kg/m ²)			.813
Median (IQR)	27 (24.4-31.5)	27.7 (24.4-30.9)	
Mean (SD)	27.95 (5.25)	28.05 (4.92)	
Total length of stay (days)			<.001
Median (IQR)	7 (4-14)	1 (1-3)	
Mean (SD)	10.65 (9.82)	2.37 (3.50)	
Days between surgery and complication		—	—
Median (IQR)	9 (2-22)		
Mean (SD)	15.15 (18.04)		
Surgical length (minutes)			.029
Median (IQR)	150 (90-240)	120 (75-187.5)	
Mean (SD)	172.18 (90.02)	188.61 (197.30)	
Length of stay during the first admission (days)			<.001
Median (IQR)	5 (2-8)	1 (1-3)	
Mean (SD)	6.53 (6.71)	2.37 (3.5)	

Abbreviations: BMI, body mass index; IQR, interquartile range; SD, standard deviation.

Complications According to the DC Classification

Table 3 shows the complications according to DC. Of 79 complications, 49 (62%) were classified as minor (DC grades I, II, and IIIA) and 30 as major (DC grades IIIB, IV, and V).

Baseline characteristics of the groups with and without complications are shown in Table 4. No differences were observed in terms of age, sex, and BMI between complicated and non-complicated surgeries. Significant differences were observed in duration of surgery (higher in patients with complications, $P = .029$), there were also significant differences in hospital LOS in patients with complications compared with patients without complications ($P = .001$). When analyzing complications by severity, there were significant differences in the patients of the DC grade IIIB group in terms of LOS and duration of surgery (see Table 5).

Table 5. Factors Associated With Complications According to Severity (Dindo-Clavien [DC]).

Characteristic	DC Grade I (n = 21)	DC Grade II (n = 24)	DC Grade IIIA (n = 4)	DC Grade IIIB (n = 29)	P
Age (years)					.389
Median (IQR)	65 (53-80)	61.5 (51.5-79)	50.5 (38.5-70)	65 (60-71)	
Mean (SD)	64.76 (17.92)	63.29 (19.34)	54.25 (20.48)	64.58 (10.70)	
Male sex, n (%)	9 (42.86)	7 (29.17)	3 (75)	10 (34.48)	.408
BMI (kg/m ²)					.719
Median (IQR)	27.3 (24.4-30.0)	25.9 (24.45-31.5)	29.9 (27.45-31.9)	27.1 (23.9-32.6)	
Mean (SD)	27.01 (3.9)	27.7 (5.22)	29.67 (2.71)	28.73 (6.29)	
Total length of stay (days)					<.001
Median (IQR)	6 (2-8)	6.5 (5-10.5)	1.5 (1-10.5)	15 (9-23)	
Mean (SD)	6.38 (4.05)	7.66 (4.42)	5.75 (8.84)	17.24 (12.63)	
Days between surgery and complication					.002
Median (IQR)	3 (2-22)	3 (2-8.5)	20.5 (10.5-42.5)	15 (10-25)	
Mean (SD)	12.23 (14.47)	8.25 (12.16)	26.5 (23.78)	21.93 (21.31)	
Surgical length (minutes)					<.001
Median (IQR)	150 (105-230)	180 (120-265)	80 (65-150)	150 (90-240)	
Mean (SD)	164.76 (84.01)	197.29 (93.84)	107.46 (69.46)	168.55 (91.38)	

Abbreviations: BMI, body mass index; IQR, interquartile range; SD, standard deviation.

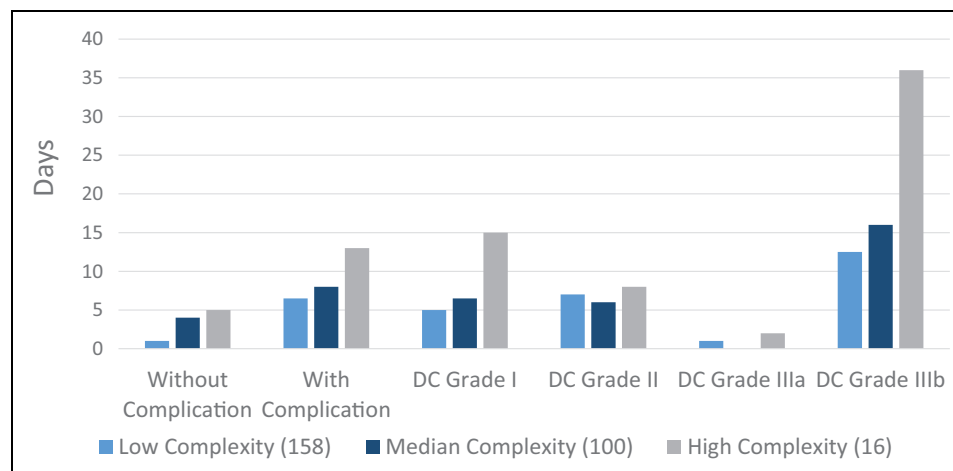


Figure 1. Median hospital length of stay according to complication grade and complexity, significant differences were observed in patients with complications.

Based on surgical complexity complications (n = 79), they were categorized as follows: 33 were low-complexity (41%), 36 intermediate-complexity (45.5%), and 9 high-complexity surgery (9.3%). Patients without complications (n = 145): 125 low-complexity (63.5%), 64 intermediate-complexity (32.8%), and 7 high-complexity surgeries (3.6%). A higher percentage of intermediate- and high-complexity surgeries was observed in patients with complications compared to patients without complications (P = .002).

Length of Stay According to Pathology in Patients Without and With Complications

The median LOS was 2 days (IQR 1-5 days). The median LOS in patients without complications was 1 (range 25%-75%, 1-3) while in patients with at least 1 complication it was 7 (IQR 4-

14) (P < .001). Complications occurred at a median of 9 post-operative days (IQR 2-22 days).

The median hospital LOS due to complications according to DC were as follows: DC grade I, 6 (IQR 2-8); DC grade II, 6 (IQR 5-10); and DC grade III (A and B), 27.1 (IQR 23.9-32.6). Figure 1 shows the median days of hospitalization in patients with and without complications based on the degree of surgical complexity. Among the complications, patients with severe excessive radicular pain (n = 16) mean days of hospitalization were 4.3 (SD 3.6 days), cases with deep wound infection (n = 12) had a mean hospital stay of 22.1 days (SD 12 days) and patients with anemia (n = 7) had a mean of 8.4 days (SD 4.4 days) (see Figure 2).

Ninety-Day Unplanned Readmission Rate

A total of 32 patients (11.72%; 95% CI 7.88% to 15.56%) were readmitted due to a complication. The median time between

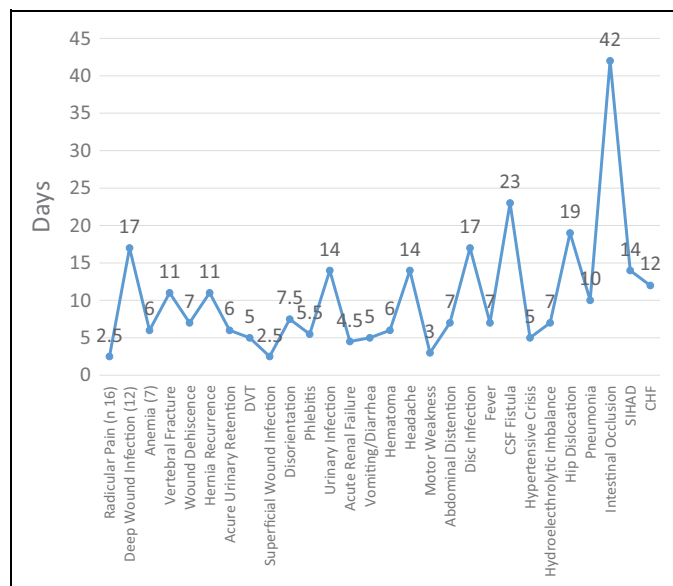


Figure 2. Median hospital length of stay in specific complications ordered by number of cases.

surgery and readmission was 16 days (IQR, 7-29 days). Figure 3 shows the median time between surgery and each type of complication.

Risk Factors Associated With the Development of Complications

Table 6 presents the odds ratios of the studied variables to develop a complication. Surgical complexity showed a significant trend toward undergoing a complication, increasing 2.11 times the risk of developing a complication in medium-complexity surgeries (type B) compared with low-complexity (type A) and 4.22 times the risk of having a high-complexity surgery (type C) when compared with low-complexity (type A) ones. This risk was significant in both the crude and the adjusted analyses.

Discussion

The aim of this study was to apply the DC classification to a series of consecutively treated patients in a third-level care center, as well as to know the prevalence of the main complications and how they influence the hospital LOS. In this study, a 90-day postoperative complication rate of 28.7% was observed based on DC classification, with excessive postoperative pain, postoperative infection, and anemia being the most frequent complications. Two-thirds of the complications were minor (grades I, II, and IIIA).

The report of complications in spinal surgery is heterogeneous and lacks a universally accepted classification system, added to the fact that complications are sometimes difficult to code, resulting in underreporting and in an incorrect analysis to assess the quality of medical assistance provided by a specific institution.⁴

In our study, the rate of postoperative complications was 28%, which is in line with what Bellut et al¹⁶ observed. The authors applied the classification of DC to spinal surgery reporting a complication rate of 31% (44/138 surgeries), the majority of them being grades I and II, similar to our findings.

After studying 448 patients with adult spinal deformity, Soroceanu et al¹⁸ observed a complication rate of 26%. Similarly, Glassman et al¹⁹ reported a complication rate of 24.9% in patients with adult scoliosis (108 of 434 patients). Schwab et al²⁰ found an 8.4% rate of major complications in 953 patients (80 cases). These authors report similar complication rates; however, they have specifically analyzed adult scoliosis. In our study, all types of spinal surgeries were included.

The average LOS in noncomplicated patients was 2.3, whereas for those who suffered any complication it was 10.6, DC grade IIIB and high-complexity surgery were associated with the most extended LOS in our study. Multiple factors are reported to increase LOS, such as age, anemia, or diabetes and the development of postoperative complications.²¹ However, to our knowledge, there are no studies that analyzed the impact of different complications in extended LOS.

Surgical complexity is a factor that may influence surgical results and complications due to surgical time and blood loss. We found it to be a critical factor that showed the greatest association with complication rates. In this scenario, complexity doubled the complications between a low-complexity and intermediate-complexity surgery and quadrupled the risk of complications between a low- and high-complexity procedure.

Surgical time has also been associated with a higher rate of complications such as postoperative infections and cardiorespiratory eventualities.²²⁻²⁴ Phan et al,²⁵ in a study of 5338 patients with spinal deformity in adults, found that the duration of surgery was directly associated with complications of the surgical wound, hospital stay, respiratory complications, the need for transfusion, and a higher rate of unplanned readmission. In our study, surgical time was associated with an increase in the rate of complications. However, this issue is probably related to surgical complexity.

We found an unplanned readmission rate of 11%, which is higher than what has been published in other series. Saleh et al²⁶ observed a complication rate of 16% and 6% of unplanned readmission rate. In addition, a systematic review showed hospital readmission rates at 30 days between 4% and 7% in spinal surgery.²⁷

Considering age as a risk factor, some authors reported an increase morbidity rate in elderly patients²⁸⁻³⁰; however, other studies^{31,32} report lower rates of complications, it is probably due to the advent of minimally invasive techniques with lower blood loss and days of hospitalization, combined with adequate patient selection. Kobayashi et al³³ studied morbidity in 262 patients older than 80 years who underwent spinal surgery and found a higher rate of perioperative complications, especially in patients older than 85 years. In our study, age was related to an increased risk of complications; however, the differences were not significant.

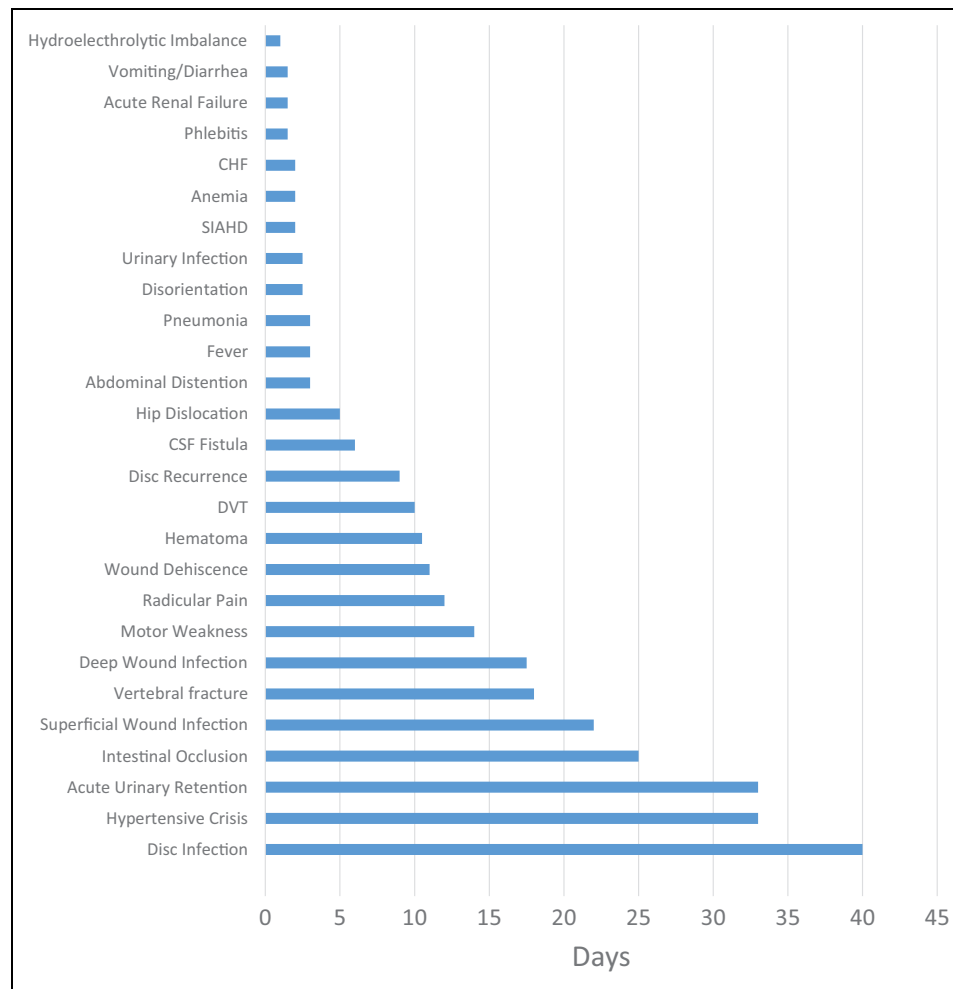


Figure 3. Median of days between surgery and specific complication.

Table 6. Risk Factors for Developing a Complication.

Risk Factors	Odds Ratio	95% CI	P
Surgical complexity (A, B, C)	2.11	1.37-3.23	.001
Male sex	0.76	0.44-1.31	.333
Age	1.00	0.98-1.01	.955
Type of surgery	1.10	0.86-1.41	.412
Body mass index	0.99	0.94-1.04	.867
Reoperation	1.49	0.79-2.82	.211
Surgical complexity (A, B, C) Adjusted for sex, body mass index, age	2.17	1.40-3.36	.001

The use of DC classification has been applied to orthopedic surgery; however, few studies have mentioned it in the literature. Sink et al¹⁵ adapted the system to hip surgery; however, the modifications were made exclusively to be applied in conservative hip surgery, making it difficult to apply to other orthopedic specialties.

Our study maintained the principles of classification in order to use it in the most frequent postoperative scenarios. Similar analysis was performed by Bellut et al¹⁶ in spinal surgeries, with similar results regarding complication prevalence,

we focused on hospital LOS to know how a complication affect the hospital LOS.

This study has its limitations: First, the registry of complications was retrospective, through the electronic medical record, so there could be patients with some complication that has not been registered in the hospital either due to lack of report from the treating professional or unplanned readmission or even treatment performed in another center. However, the vast majority of patients are followed and monitored in our institution. Finally, we included all surgical procedures making interprocedure comparison more difficult; however, it allowed us to estimate the overall complication rate in our service. It is important to mention that the DC classification was designed to be applied in general surgery, there are few reports regarding its use in orthopedic and spinal surgery, so more studies are required to assess its real usefulness in this specialty.

Conclusion

The 90-day complication rate was 28%, two-thirds of them were minor complications, the mean hospital LOS in patients

without complications was 2.3 days and in patients with any complication it was 10.7 days. The unplanned readmission rate was 11%. The most frequent complications were excessive postoperative pain, postoperative wound infection, and anemia and the most important risk factor associated with the development of a complication in our study was the surgical complexity and duration of surgery. The registry of postoperative complications is an important tool for the health quality assessment, allowing to identify the most prevalent complications that help to establish measures to reduce the them, the use of the DC classification was useful to assess the complications; however, it probably requires adaptations related to the wide variability of orthopedic and spinal surgery procedures.


Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Cristina Elizondo  <https://orcid.org/0000-0002-3262-2176>

References

- Dindo D, Clavien PA What is a surgical complication? *World J Surg* 2008;32:939-941.
- Cho KJ, Suk SI, Park SR, et al. Complications in posterior fusion and instrumentation for degenerative lumbar scoliosis. *Spine (Phila Pa 1976)*. 2007;32:2232-2237.
- Goldhahn S, Sawaguchi T, Audigé L, et al. Complication reporting in orthopaedic trials. A systematic review of randomized controlled trials. *J Bone Joint Surg Am*. 2009;91:1847-1853.
- Dekutoski MB, Norvell DC, Dettori JR, Fehlings MG, Chapman JR. Surgeon perceptions and reported complications in spine surgery. *Spine (Phila Pa 1976)*. 2010;20;35(9 suppl):S9-S21.
- de Waal Malefijt MC. An orthopedic complication-registration system. *Acta Orthop Scand*. 1995;66:84-89.
- Clavien PA, Barkun J, de Oliveira ML, et al. The Clavien-Dindo classification of surgical complications: five-year experience. *Ann Surg*. 2009;250:187-196.
- Clavien PA, Sanabria JR, Strasberg SM. Proposed classification of complications of surgery with examples of utility in cholecystectomy. *Surgery*. 1992;111:518-526.
- Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg*. 2004;240:205-213.
- Permapongkosol S, Link RE, Su LM, et al. Complications of 2,775 urological laparoscopic procedures: 1993 to 2005. *J Urol*. 2007;177:580-585.
- Patel S, Cassuto J, Orloff M, et al. Minimizing morbidity of organ donation: analysis of factors for perioperative complications after living-donor nephrectomy in the United States. *Transplantation*. 2008;85:561-565.
- Sundaram CP, Martin GL, Guise A, et al. Complications after a 5-year experience with laparoscopic donor nephrectomy: the Indiana University experience. *Surg Endosc*. 2007;21:724-728.
- McKay A, Sutherland FR, Bathe OF, Dixon E. Morbidity and mortality following multivisceral resections in complex hepatic and pancreatic surgery. *J Gastrointest Surg*. 2008;12:86-90.
- Chun YS, Vauthey JN, Ribero D, et al. Systemic chemotherapy and two-stage hepatectomy for extensive bilateral colorectal liver metastases: perioperative safety and survival. *J Gastrointest Surg*. 2007;11:1498-1504.
- Clavien PA, Sanabria JR, Mentha G, et al. Recent results of elective open cholecystectomy in a North American and a European center. Comparison of complications and risk factors. *Ann Surg*. 1992;216:618-626.
- Sink EL, Leunig M, Zaltz I, Gilbert JC, Clohisy J; Academic Network for Conservational Hip Outcomes Research Group. Reliability of a complication classification system for orthopaedic surgery. *Clin Orthop Relat Res*. 2012;470:2220-2226.
- Bellut D, Burkhardt JK, Schultze D, Ginsberg HJ, Regli L, Sarnthein J. Validating a therapy-oriented complication grading system in lumbar spine surgery: a prospective population-based study. *Sci Rep*. 2017;7:11752.
- Fígar A, Mc Loughlin S, Slullitel PA, Scordo W, Buttaró MA. Influence of single-dose intravenous tranexamic acid on total hip replacement: a study on transfusions, collateral complications, and readmissions. *Orthopade*. 2017;46:359-365.
- Soroceanu A, Burton DC, Oren JH, et al; International Spine Study Group. Medical complications after adult spinal deformity surgery: incidence, risk factors, and clinical impact. *Spine (Phila Pa 1976)*. 2016;41:1718-1723.
- Glassman SD, Hamill CL, Bridwell KH, Schwab FJ, Dimar JR, Lowe TG. The impact of perioperative complications on clinical outcome in adult deformity surgery. *Spine (Phila Pa 1976)*. 2007;32:2764-2770.
- Schwab FJ, Hawkinson N, Lafage V, et al. Risk factors for major perioperative complications in adult spinal deformity surgery: a multi-center review of 953 consecutive patients. *Eur Spine J*. 2012;21:2603-2610.
- Gruskay JA, Fu M, Basques BA, et al. Factors affecting length of stay and complications after elective anterior cervical discectomy and fusion: a study of 2164 patients from the American College of Surgeons National Surgical Quality Improvement Project Database (ACS NSQIP). *Clin Spine Surg*. 2016;29:E34-E42.
- Peersman G, Laskin R, Davis J, Peterson MG, Richart T. Prolonged operative time correlates with increased infection rate after total knee arthroplasty. *HSS J*. 2006;2:70-72.
- Kim BD, Hsu WK, De Oliveira GS Jr, Saha S, Kim JY. Operative duration as an independent risk factor for postoperative complications in single-level lumbar fusion: an analysis of 4588 surgical cases. *Spine (Phila Pa 1976)*. 2014;39:510-520.
- Johnson AS, Lombard HL. The estimation of operative risk in patients with cancer. *N Engl J Med*. 1941;224:759-762.
- Phan K, Kim JS, Capua JD, et al. Impact of operation time on 30-day complications after adult spinal deformity surgery. *Global Spine J*. 2017;7:664-671.

26. Saleh A, Thirukumaran C, Mesfin A, Molinari RW. Complications and readmission after lumbar spine surgery in elderly patients: an analysis of 2,320 patients. *Spine J.* 2017;17:1106-1112.
27. Bernatz JT, Anderson PA. Thirty-day readmission rates in spine surgery: systematic review and meta-analysis. *Neurosurg Focus.* 2015;39:E7.
28. Carreon LY, Puno RM, Dimar JR 2nd, Glassman SD, Johnson JR. Perioperative complications of posterior lumbar decompression and arthrodesis in older adults. *J Bone Joint Surg Am.* 2003; 85-A:2089-2092.
29. Imagama S, Kawakami N, Tsuji T, et al. Perioperative complications and adverse events after lumbar spinal surgery: evaluation of 1012 operations at a single center. *J Orthop Sci.* 2011;16:510-515.
30. Lee MJ, Konodi MA, Cizik AM, et al. Risk factors for medical complication after cervical spine surgery: a multivariate analysis of 582 patients. *Spine (Phila Pa 1976).* 2013;38:223-228.
31. Best NM, Sasso RC. Outpatient lumbar spine decompression in 233 patients 65 years of age or older. *Spine (Phila Pa 1976).* 2007; 32:1135-1139.
32. Rosen DS, O'Toole JE, Eichholz KM, et al. Minimally invasive lumbar spinal decompression in the elderly: outcomes of 50 patients aged 75 years and older. *Neurosurgery.* 2007;60:503-509.
33. Kobayashi K, Imagama S, Ando K, et al. Complications associated with spine surgery in patients aged 80 years or older: Japan Association of Spine Surgeons with Ambition (JASA) multicenter study. *Global Spine J.* 2017;7:636-641.