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ORIGINAL ARTICLE

Comparison of perioperative outcomes in obese and non-obese patients subjected to open lumbar spine surgery

Comparación de los resultados quirúrgicos en pacientes obesos y no obesos sometidos a cirugía de columna lumbar abierta

Parménides Guadarrama-Ortiz[1], César O. Ruíz-Rivero[1], Deyanira Capi-Casillas[1], Alondra Román-Villagómez[1], Ulises Palacios-Zúñiga[2], Ángel D. Prieto-Rivera[1], and José A.Choreño-Parra[3]*

[1]Department of Neurosurgery, Centro Especializado en Neurocirugía y Neurociencias México; [2]Department of Neurosurgery, Spine Surgery Service, Hospital Regional 1° de Octubre, ISSSTE; [3]Department of Clinical Research, Centro Especializado en Neurocirugía y Neurociencias México. Mexico City, Mexico

Abstract

Objective: *Obesity is a global epidemic affecting developing countries. The relationship between obesity and perioperative outcomes during elective lumbar spine surgery remains controversial, especially in those without morbid disease.* **Materials and methods:** *We retrospectively revised the medical records of patients with lumbar spine degeneration subjected to elective surgery. The data retrieved included demographic and clinical characteristics, body mass index (BMI), obesity status (BMI ≥ 30), surgical interventions, estimated blood loss (EBL), operative time, length of stay (LOS), and postoperative complications. Perioperative outcomes were compared between Grade I-II obese and non-obese individuals.* **Results:** *We enrolled 53 patients, 18 with Grade I-II obesity. Their median age was 51, with no differences in gender, comorbidities, laboratory parameters, and surgical procedures received between groups. No clinically relevant differences were found between grade I-II obese and non-obese participants in EBL (300 mL vs. 250 mL, p = 0.069), operative time (3.2 h vs. 3.0 h, p = 0.037), and LOS (6 days vs. 5 days, p = 0.3). Furthermore, BMI was not associated with the incidence of significant bleeding and long stay but showed a modest correlation with operative time.* **Conclusion:** *Grade I-II obesity does not increase surgical complexity nor perioperative complications during open lumbar spine surgery.*

Keywords: *Obesity. Body mass index. Spine surgery. Lumbar decompression and fusion. Transforaminal lumbar interbody fusion.*

Resumen

Objetivo: *La obesidad es una epidemia mundial que afecta a países subdesarrollados. Su relación con los resultados de la cirugía de columna lumbar electiva sigue siendo controvertida, especialmente en obesos sin enfermedad mórbida.* **Métodos:** *Se revisaron los expedientes de pacientes con degeneración de la columna lumbar sometidos a cirugía. Los datos recuperados incluyeron características demográficas y clínicas, índice de masa corporal (IMC), estado de obesidad (IMC > 30), intervenciones quirúrgicas, sangrado estimado, tiempo operatorio, tiempo de estancia y complicaciones. Los resultados se compararon entre individuos obesos grado I-II y controles.* **Resultados:** *Se incluyeron 53 pacientes, 18 con obesidad de grado I-II. La edad media fue de 51 años, sin diferencias en el sexo, las comorbilidades, los parámetros de laboratorio y los procedimientos quirúrgicos recibidos entre grupos. No se encontraron diferencias relevantes entre los participantes obesos y los no obesos en sangrado (300 vs. 250 mL, p = 0.069), tiempo operatorio (3.2 vs. 3.0 horas, p = 0.037) y estancia (6 vs. 5 días, p = 0.3).*

***Correspondence:**
Parménides Guadarrama-Ortiz
E-mail: dr.guadarrama.ortiz@cennm.com

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El IMC no se asoció con hemorragia y larga estancia, pero mostró una correlación modesta con el tiempo operatorio. **Conclusiones:** *La obesidad grado I-II no predispone a complicaciones durante la cirugía de columna lumbar.*

Palabras clave: *Obesidad. Índice de masa corporal. Cirugía de columna. Descompresión y fusión lumbar. Transforaminal lumbar interbody fusion.*

Introduction

Obesity is a global public health problem in many regions of the globe carrying a wide range of complications[1,2]. Among morbidities related to a higher body mass index (BMI), lower back pain, and lumbar spine degeneration are gaining attention due to their increasing prevalence among overweight persons[3]. Indeed, several risk factors for obesity also contribute to the origin of musculoskeletal abnormalities of the lumbar spine, including poor diet habits, scarce physical activity, and postural problems related to sedentarism. Notably, up to a third of individuals subjected to operative procedures for lumbar decompression are obese[4]. Hence, some of the interests of spine surgeons are focused on elucidating the effects of obesity on surgical outcomes after lumbar spine operations.

At present, the findings of several investigations are contradictory, with opposite results regarding the possible impact of obesity on perioperative outcomes during open and minimally-invasive lumbar spine surgery, including the surgical estimated blood loss (EBL), operative time, length of hospital stay length of stay (LOS), rates of complications, and functional status after a variable period of follow-up[4]. This is especially true among individuals without morbid disease since it is not completely known whether their surgical risk is similar to individuals with more severe obesity. In contrast, the literature clearly shows an increased propensity of patients with morbid obesity (BMI > 40 kg/m^2 or > 35 kg/m^2 with cardiovascular/metabolic comorbidities) to perioperative adverse outcomes, postoperative complications, and long-term morbidity after lumbar decompression and fusion[4,5]. Thus, minimally invasive procedures have been recently advocated for this population with commendable results.

Importantly, minimally invasive approaches for lumbar decompression and fusion are not widely available. Hence, identifying potential risk factors for adverse surgical results after open lumbar spine surgery is very important to anticipate complications and establish preventive actions during this approach. Therefore, additional studies addressing the relationship between obesity and surgical outcomes of open lumbar decompression and fusion are needed. Notably, the most significant increases in the incidence of obesity occur in low-income regions, where a rise in the number of persons with overweight and Grade I-II, followed by Grade III obesity has been registered[6]. However, little literature exists on lumbar spine surgery from developing countries, where open approaches to the degenerative lumbar spinal stenosis are still the standard operative management. Here, we compared the perioperative results of patients with Grade I-II obesity and non-obese individuals subjected to elective surgery for lumbar spine degeneration from Mexico, where more than two-thirds of the population are overweight[7]. Our results demonstrate that, in our population, obesity does not increase the surgical complexity of open lumbar spine surgery, since perioperative outcomes did not differ between obese and non-obese patients. However, our study does not provide concluding evidence about the impact of obesity on the effectiveness of lumbar decompression and fusion in the long-term.

Materials and methods

Study population

We conducted a cohort study in consecutive non-Caucasian Mexican patients with degenerative lumbar spinal stenosis subjected to elective surgery at the Neurosurgery Department of the Centro Especializado en Neurocirugía y Neurociencias México in Mexico City during the period between 2016 and 2021. Individuals older than 18 years with moderate-to-severe manifestations of lumbar spinal degeneration who failed conservative therapy with non-steroidal anti-inflammatory drugs (NSAID) and physical rehabilitation for at least 3 months were eligible for the study. Patients with toracolumbar tandem spinal stenosis, fractures, tumors, movement disorders, or any other non-degenerative etiology of lumbar spinal stenosis were ineligible. Furthermore, individuals with incomplete medical records or those unavailable to be followed were excluded from the following analyses. All patients provided written informed consent to participate in the investigation according to the Declaration of Helsinki for Human Research. The study was conducted under the Mexican Constitution law NOM-012-SSA3-2012, which establishes the criteria for executing clinical investigations in humans.

Procedures

All patients were clinically assessed by a neurosurgeon and an orthopedist specialized in spine surgery, who determined the surgical plan based on clinical findings, physical examination, and magnetic resonance imaging of the spine. Furthermore, on enrollment, participants were screened by an anesthesiologist who ordered laboratory tests, estimated the pre-operative risk in terms of the American Society of Anesthesiologists (ASA) physical status classification system, and retrieved the clinical data. The decision for lumbar spine surgery was based on the persistence of a constellation of manifestations, including intractable lumbar radiculopathy, neurogenic claudication, intractable low back pain, cauda equina syndrome, severe lumbar spondylolisthesis with instability, and abnormal findings in the electromyography and evoked potentials of the lower limbs.

The same surgical team carried out surgical procedures under general anesthesia. The standard surgery for the lumbar spine was the open transforaminal lumbar interbody fusion (TLIF) with interbody fusion cages (ROI-T®, LDR Medical, ATX, USA) and bilateral pedicle screw fixation. In addition, posterior instrumentation, placement of interspinous spacers (InSWing™ Interspinous Spacer, Orthofix US LLC, USA), laminectomy, and/or hemilaminectomy were used alone or as complementary procedures according to pre-operative or perioperative findings. All patients received the same standard post-operative management based on analgesia with NSAIDs, steroids, antineuritics, selective serotonin reuptake inhibitors, benzodiazepines, and/or opioids, antibiotic prophylaxis, early mobilization after 24 h of surgery, and rehabilitation during hospitalization and for at least 3 months after discharge.

Data collection

Microsoft Excel (MS Excel 365) was used for data collection. On admission, the clinical and demographic characteristics of study participants were retrieved by direct interview, physical examination, and revision of their medical records. These data included age, gender, anthropometrics, comorbidities, presence of concomitant degenerative cervical spine stenosis, history of previous non-spinal surgeries, symptoms, pre-operative radiological findings, spinal segments radiologically involved, ASA category, and initial laboratory test results. Initial laboratory tests were defined as the first test results available (typically within 24 h of admission) and included white blood cell counts, glucose, kidney function, and lipid panel. During operations, a spine surgery fellow registered the specific surgical procedures performed on the patients, the operative time, and EBL. Furthermore, patients were closely monitored during convalescence, and data on in-hospital medications administered, time of hospitalization, and post-operative systemic and neurological complications were retrieved. After discharge, patients were radiologically followed for at least 6 months to evaluate the postoperative fusion, alignment, stability, and the incidence of pseudoarthrosis, hardware failure, interbody material migration, screw misplacement, or breech.

Statistical analyses

Descriptive statistics were used to characterize the study population clinically. Frequencies and proportions were calculated for categorical data. Medians and interquartile ranges were used for continuous variables since they did not show normal distribution in the Shapiro-Wilks test. Patients were grouped according to their obesity status, defined as a BMI $\geq$ 30 kg/m^2. Differences in categorical variables between groups were assessed by the Fisher's exact or Chi-square test. For comparisons of continuous variables, we used the Wilcoxon sum-rank test. Linear regression analyses using Spearman rank correlation coefficients were used to determine correlations between BMI, EBL, surgery time, and LOS after the operation. The study's primary outcomes were significant bleeding, prolonged surgery, and extended hospital stay after lumbar decompression and fusion. For this purpose, patients with EBL, surgery time, and LOS above the third quartile were considered as having the primary outcomes. The association of BMI and obesity with surgical results was evaluated by logistic regression models. All analyses were conducted using GraphPad Prism 8 (La Jolla, CA, USA) and R Statistical Software (Foundation for Statistical Computing, Vienna, Austria). Specific analysis tests are also mentioned in the tables. Two-tailed $p \leq 0.05$ were considered significant.

Table 1. Participant characteristics

Characteristics	Overall n = 53 (%)	Obese n = 18 (%)	Non-obese n = 35 (%)	p-value
Age, years	51.0 (42.0, 64.0)	52.5 (49.0, 64.0)	51.0 (39.0, 60.5)	0.3
Male gender	22 (42)	6 (33)	16 (46)	0.4
BMI, kg/m^2	27.3 (24.7,30.4)	33.2 (30.7, 34.2)	25.4 (23.9, 27.1)	< 0.001
Depression	18 (34)	5 (28)	13 (37)	0.5
Alcoholism	18 (34)	4 (22)	14 (40)	0.2
Anxiety	17 (32)	4 (22)	13 (37)	0.3
Hypertension	13 (25)	5 (28)	8 (23)	0.7
Smoking	11 (21)	3 (17)	8 (23)	0.7
Diabetes	7 (13)	3 (17)	4 (11)	0.7
Previous surgery*	36 (68)	13 (72)	23 (66)	0.6

*History of non-spinal surgical interventions under spinal or general anesthesia. The data are displayed as median (IQR); n (%). The differences between groups were calculated using the Wilcoxon rank-sum test, Pearson's Chi-squared test, or Fisher's exact test, as appropriate.
BMI: body mass index.

Results

Participant characteristics

Our cohort included 53 patients subjected to lumbar spine surgery, 22 males and 31 females, with a median age of 51. Of these, 18 were obese (BMI ≥ 30 kg/m^2), and 35 were non-obese. Although the study was open for all individuals who met the inclusion criteria independently of their obesity status, the final cohort included only two patients with BMI > 35 kg/m^2 but without a comorbid cardiovascular/metabolic condition. Hence, the following analysis results are intended to be most representative of or applicable to individuals with Grade I-II obesity. The demographic characteristics of both groups were comparable, as shown in table 1. The median BMI in obese and non-obese patients was 33 kg/m^2 and 25 kg/m^2, respectively. The most frequent comorbidities in the overall study population included depression (18/53), alcohol intake (18/53), anxiety (17/53), and hypertension (13/53). Up to two-thirds of enrolled individuals reported at least one previous non-spinal surgical intervention under spinal or general anesthesia.

As illustrated in table 2, both study groups showed similar clinical manifestations. The most frequent symptom of lumbar spine degeneration was radicular pain, followed by paresthesia and reduced muscle strength of the lower limbs. In general, patients had degenerative alterations in a median of two lumbar segments, with about 90% and 75% showing L5-S1 and L4-L5 abnormalities in radiological studies, respectively. The most frequent degenerative changes observed in the study participants included stenosis in the lateral recess and neural foramen leading to radiculopathy (92%), central canal stenosis secondary to disc herniations (89%), and a significant reduction in the lumbar canal anteroposterior diameter (49%). Initial laboratory test results showed no differences between obese and non-obese patients, except for a significant increase in platelet counts among obese individuals. However, most patients' parameters were within normal ranges (Table 3).

Surgical results

All patients showed similar pre-operative ASA categories and received similar surgical interventions, although interspinous spacers were more common among non-obese individuals (Table 4). Similarly, study participants received similar medical interventions during hospitalization (Table S1). The median EBL was 300 mL in the overall cohort, 300 mL in obese patients, and 250 mL in non-obese individuals. Despite this, the difference between groups did not reach statistical significance (Fig. 1, left panel). Furthermore, no significant correlation was found between BMI and estimated bleeding during surgery (Fig. 2, left panel). The median duration of surgical procedures was 3 h, 3.2 h in obese patients, and 3 h in non-obese individuals ($p < 0.05$; Fig. 1, middle panel) but there was no direct correlation between

Table 2. Clinical manifestations and radiological findings

Findings	Overall n = 53 (%)	Obese n = 18 (%)	Non-obese n = 35 (%)	p-value
Symptom onset	2.0 (0.0, 11.0)	1.0 (0.0, 8.0)	2.5 (0.0, 11.5)	> 0.9
Radicular pain	50 (94)	18 (100)	32 (91)	0.5
Paresthesia	35 (66)	10 (56)	25 (71)	0.2
Reduced muscle strength	24 (45)	8 (44)	16 (46)	> 0.9
Sensory impairment	8 (15)	1 (5.6)	7 (20)	0.2
Hypoesthesia	6 (11)	2 (11)	4 (11)	> 0.9
Plegia	2 (3.8)	0 (0)	2 (5.7)	0.5
Tremor	1 (1.9)	0 (0)	1 (2.9)	> 0.9
Lumbar segments, n	2.0 (1.0, 2.0)	2.0 (2.0, 2.0)	2.0 (1.0, 2.0)	0.8
L5-S1	47 (89)	16 (89)	31 (89)	> 0.9
L4-L5	40 (75)	14 (78)	26 (74)	> 0.9
L3-L4	6 (11)	1 (5.6)	5 (14)	0.7
L1-L2	1 (1.9)	1 (5.6)	0 (0)	0.3
L2-L3	0 (0)	0 (0)	0 (0)	--
Radiculopathy	49 (92)	16 (89)	33 (94)	0.6
Herniation	47 (89)	15 (83)	32 (91)	0.4
Lumbar stenosis	26 (49)	8 (44)	18 (51)	0.6
CLTSS	14 (26)	7 (39)	7 (20)	0.2
Lystesis	14 (26)	2 (11)	12 (34)	0.10
LFH	9 (17)	3 (17)	6 (17)	> 0.9

The data are displayed as median (IQR); n (%). The differences between groups were calculated using the Wilcoxon rank-sum test, Pearson's Chi-squared test, or Fisher's exact test, as appropriate.
CLTSS: cervico-lumbar tandem spinal stenosis; LFH: ligamentum flavum hypertrophy.

BMI and operative time (Fig. 2, middle panel). Regarding LOS after open lumbar spine surgery, enrolled patients stayed a median of 5 days in the hospital, without significant differences between obese and non-obese participants (6 days vs. 5 days, p = 0.3; Fig. 1, right panel). Similarly, there was no significant correlation between BMI and hospital stay (Fig. 2, right panel).

After dichotomizing the values of EBL, surgery time, and post-operative LOS above or below the third quartile, no differences were observed between obese and non-obese groups in the incidence of significant bleeding (> 400 mL), prolonged surgery (> 4 h), and extended stay after surgery (> 7 days; Table 4). Using logistic regression models adjusted for covariates (age, gender), obesity was not significantly associated with the incidence of significant perioperative bleeding, prolonged surgery, and extended stay. Interestingly, the individual variable BMI was not associated with significant bleeding and extended stay but showed a significant odds ratio value for prolonged surgery (Table 5). Finally, obese and non-obese patients showed similar rates of post-operative complications, as shown in table S2.

Discussion

Overweighted patients impose several challenges on spine surgeons. Accordingly, obesity may affect several aspects of the diagnosis and surgical management of lumbar degeneration, including the interference with pre-operative radiological images of the spine, the difficulty of intubation for general anesthesia, the complex positioning for incision, and the increased operative risk associated with comorbidities of obese individuals like diabetes and hypertension[8]. Despite this, there is

Table 3. Laboratory parameters

Test results	Overall (n = 53)	Obese (n = 18)	Non-obese (n = 35)	p-value
WBC, 10^9/L	7.2 (6.15, 8.5)	7.2 (5.4, 8.5)	7.4 (6.47, 8.35)	0.4
Neutrophils, 10^9/L	59.0 (54.0, 69.5)	54.5 (53.0, 61.1)	62.6 (54.8, 70.8)	0.10
Lymphocytes, 10^9/L	31.0 (24.5, 36.0)	32.2 (30.0, 36.5)	29.0 (21.6, 33.0)	0.15
Hb, g/dL	14.3 (12.8, 15.9)	13.6 (12.7, 15.1)	14.9 (13.6, 15.9)	0.2
Htc, %	43.1 (39.5, 47.2)	42.9 (38.4, 44.2)	43.9 (39.8, 47.8)	0.6
Platelets, 10^9/L	241.5 (214.0, 295.2)	283.0 (226.0, 322.0)	234.0 (195.5, 270.5)	0.035
Glucose, mg/dL	97.5 (89.8, 108.4)	97.5 (85.5, 102.5)	98.0 (91.0, 110.0)	0.4
Urea, mg/dL	28.8 (24.5, 37.6)	26.5 (18.0, 39.2)	30.4 (27.0, 35.9)	0.2
Cr, mg/dL	0.8 (0.7, 0.9)	0.7 (0.6, 1.0)	0.8 (0.7, 0.9)	0.5
Uric acid, mg/dL	4.8 (4.3, 6.2)	5.3 (4.6, 6.2)	4.7 (4.3, 6.3)	0.8
Cholesterol, mg/dL	184.2 (148.2, 220.8)	182.0 (146.0, 204.8)	189.3 (166.2, 238.2)	0.2
Triglycerids, mg/dL	184.0 (115.0, 237.0)	134.0 (104.0, 185.0)	202.5 (135.8, 250.8)	0.051

The data are displayed as median (IQR). The differences between groups were calculated using the Wilcoxon rank sum test.
ASD: adjacent segment degeneration; Cr: creatinine; Hb: hemoglobin; Htc: hematocrit; ICU: intensive care unit; LOS: length of stay; WBC: white blood cells.

Table 4. Surgical procedures and outcomes

Interventions	Overall n = 53 (%)	Obese n = 18 (%)	Non-obese n = 35 (%)	p-value
ASA	2.0 (2.0, 3.0)	2.0 (2.0, 3.0)	2.0 (1.5, 3.0)	0.7
TLIF	53 (100)	18 (100)	35 (100)	> 0.9
Interspinous spacer	36 (68)	9 (50)	27 (77)	0.045
Discectomy	35 (66)	9 (50)	26 (74)	0.077
Posterior instrumentation	32 (60)	14 (78)	18 (51)	0.063
Interbody fusion cage	30 (57)	8 (44)	22 (63)	0.2
Hemilaminectomy	11 (21)	4 (22)	7 (20)	> 0.9
Laminectomy	9 (17)	2 (11)	7 (20)	0.7
Laminotomy	1 (1.9)	1 (5.6)	0 (0)	0.3
Estimated bleeding, mL	300.0 (200.0, 400.0)	300.0 (212.5, 600.0)	250.0 (100.0, 400.0)	0.069
Surgery time, h	3.0 (2.0, 4.0)	3.2 (3.0, 4.0)	3.0 (2.0, 3.0)	0.037
LOS	5.0 (3.0, 7.0)	6.0 (3.0, 10.0)	5.0 (3.0, 7.0)	0.3
Significant bleeding	17 (32)	7 (39)	10 (29)	0.4
Long surgery	14 (26)	7 (39)	7 (20)	0.2
Long stay	17 (32)	7 (39)	10 (29)	0.4

The data are displayed as median (IQR); n (%). The differences between groups were calculated using the Wilcoxon rank sum test, Pearson's Chi-squared test, or Fisher's exact test, as appropriate.
ASA: the American Society of Anesthesiologists Health Status classification system; LOS: length of stay after surgery; TLIF: transforaminal lumbar interbody fusion.

controversy about the actual impact of obesity on the surgical complexity of lumbar spine surgery, as it is believed that the recommendation for weight-loss before the procedure is not directed to reduce the peri-operative morbidity but pre-operative challenges and the long-term outcomes. However, the relationship

Table 5. Logistic regression analysis

Variable	Significant bleeding			Prolonged surgery			Long hospital stay		
	OR	95% CI	p-value	OR	95% CI	p-value	OR	95% CI	p-value
Obesity	1.6	0.5, 5.30	0.45	2.55	0.72, 9.20	0.15	1.59	0.47, 5.30	0.45
BMI	1.09	0.96, 1.25	0.19	1.17	1.02, 1.37	0.028	1.04	0.91, 1.18	0.59

BMI: body mass index; CI: confidence interval; OR: odds ratio.

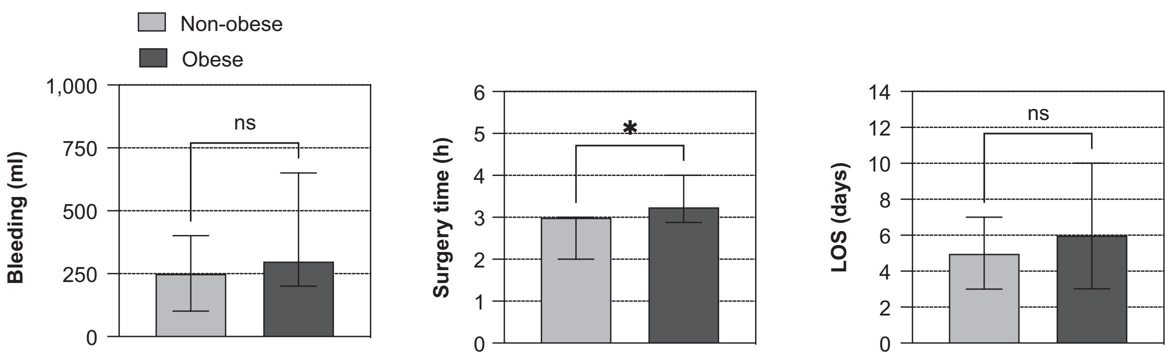

Figure 1. *Comparison of perioperative outcomes between obese and non-obese participants. The bars display medians with interquartile ranges. Differences between groups were analyzed using the Wilcoxon rank sum test. LOS: length of stay; *p < 0.05; ns: non-significant.*

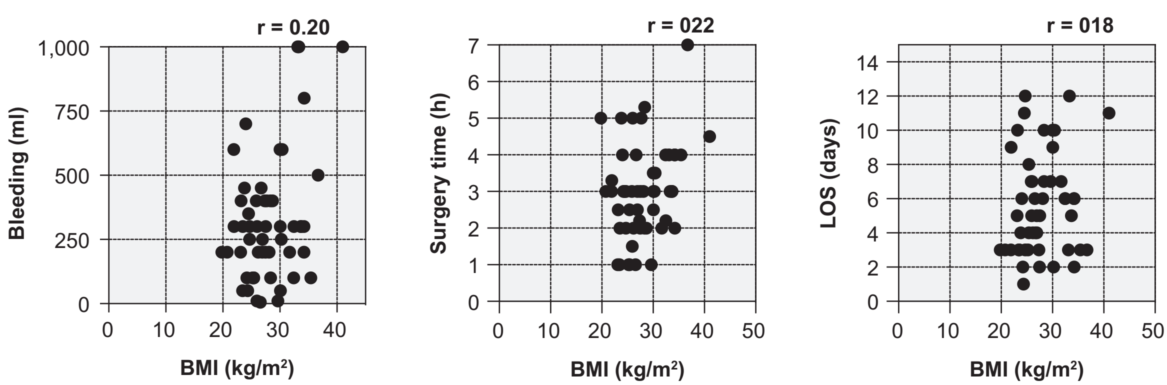

Figure 2. *Correlation between body mass index (BMI) and perioperative outcomes of lumbar decompression. The graphs show correlations between individual patient BMI and estimated blood loss calculated using the Spearman correlation coefficient (r).*

between obesity and perioperative outcomes during elective lumbar spine surgery is still a matter of debate that warrants further research.

Although several investigations have been conducted to clarify whether obesity impacts surgical results like the EBL, operative time, LOS, and functionality after lumbar spine surgery, the observations are frequently contradictory[9-11]. A possible explanation for this lack of agreement is the great methodological heterogeneity between existing studies, including the mixture of minimally invasive and open surgical approaches to the lumbar spine used for obese individuals[9-14]. Another source of heterogeneity is the distinct BMI thresholds used by different groups to define obesity, as illustrated in a recent meta-analysis of more than 23,000 patients subjected to lumbar decompression[4]. In this report, researchers identified several definitions for obesity used for comparisons of operative outcomes: BMI ≥ 25 kg/m^2, BMI ≥ 30 kg/m^2, BMI ≥ 35 kg/m^2, or BMI ≥ 95th percentile as per height and age. Interestingly, the meta-analysis also showed that up to 31% of individuals with lumbar degeneration requiring surgical intervention were obese, as defined by a BMI ≥ 30 kg/m^2, which reflects that spine surgeons are increasingly in the situation of providing care to obese patients with lumbar spine degeneration[4].

An additional factor to be considered when analyzing evidence about the role of obesity in lumbar spine surgery is that most investigations on this matter have been carried out in developed countries with Caucasian populations where obesity is not a major public health threat. Conversely, little is known about the surgical and functional outcomes of obese patients subjected to lumbar spine surgery from developing countries where minimally invasive approaches are not always available. For this reason, the relevance of our study is that we compared the perioperative outcomes of obese and non-obese Mexican patients subjected to elective open lumbar spine surgery from a region with one of the highest burdens of obesity globally, where the prevalence of degenerative alterations of the lumbar spine is expected to further increase in the following decades due to the current trends of obesity even among children[15].

Our results indicate no differences in the EBL, duration of surgery, and LOS after surgery for degenerative lumbar spinal degeneration between patients with Grade I-II obesity and non-obese individuals, indicating that the complexity of lumbar spine surgery is not impacted by the excessive body mass of obese individuals. These observations contrast with the findings of Goyal et al.[4], who showed that obese patients have a significantly higher EBL and duration of surgery than non-obese individuals based on the results of 12 studies with 6751 participants. However, the mean differences between groups estimated by these researchers were minimal. For instance, the mean difference in blood loss between obese and non-obese patients was about 46 mL, which agrees with what we observed in our study: 300 mL vs. 250 mL of EBL. Furthermore, the mean difference in operative time observed in the meta-analysis was 17 min, whereas, in our cohort, we found a difference of 12 min between obese and non-obese participants. In contrast, Shamji et al. found that in 244 170 patients who underwent lumbar spine fusion, the transfusion requirements, wound complications, and postoperative infections were higher among those morbidly obese[16].

Overall, the differences in our study and others are barely significant in terms of statistics and may not be clinically meaningful in all subgroups of obese patients, affecting principally those with morbid obesity. Together, these data suggest that non-morbidly obese patients might not more prone to perioperative complications during lumbar spine surgery as compared to individuals with morbid obesity, reinforcing the idea of the "obesity paradox" in the general surgical population[17]. This fact does not mean that obese patients would not benefit from weight loss because they could improve several other aspects of their health, like controlling comorbidities and preventing metabolic and cardiovascular long-term complications, especially in those with BMI > 40 kg/m^2. For instance, it has been proven in different studies that weight loss before surgery may reduce preoperative manifestations such as pain and disk herniation[18]. Furthermore, in a recent investigation by Jain D and colleagues, they found that bariatric surgery in morbidly obese patients performed before elective lumbar spine surgery reduces the incidence of post-operative complications, including urinary tract infection, acute renal failure, infections, and LOS[19].

Furthermore, it is clear that an obese patient would have a worse surgical outcome in the long-term than someone without overweight, at least in the case of the morbidly obese population. However, this assumption might not be true to non-morbidly obese patients and then, the recommendation of weight loss as a condition required before spine surgery for those patients without morbid obesity must be well supported by rigorous evidence since this intervention may carry significant efforts and economic burden[20,21], especially when bariatric surgery is used before lumbar spinal decompression[19]. Hence, based on our results, surgical treatment of lumbar spine degeneration should not be denied based on patients' weight in the group of people with Grade I-II obesity, which is a widespread practice among spine surgeons. Instead, obese patients who are candidates for surgery should receive surgery for lumbar spinal degeneration with equal priority to non-obese individuals and be counseled to lose weight during their preparation for surgery, convalescence, and follow-up to prevent other long-term post-operative complications and improve the effectiveness of the intervention. These statements apply only for those without morbid obesity, since current literature indicates that in people with more severe disease there is a clear increment in the surgical risk and a benefit from weight-loss before surgery[5], as well as from the use of minimally-invasive approaches[22].

An interesting finding of our study is that, when using BMI as an independent variable, we found a significant association with the operative time, suggesting that the threshold of BMI that is clinically relevant to determine surgical results after lumbar spine surgery is different from the cut-off used to define overweight or obesity. Similarly, Shamji et al. found that the BMI by itself correlated with higher requirements of blood transfusions after elective lumbar spine surgery[16]. Hence, as body mass increases, a critical point should be reached at which a more extensive dissection is required to gain access through the adipose tissue, thus determining a longer approach duration, which also carries the risk of a prolonged time of bleeding. Furthermore, the increased body mass might make the surgical corridor deeper, hindering the visibility of the surgical field. Although the exact significant BMI threshold leading to operative complications of lumbar spine surgery is not well defined, some studies have shown that in patients with BMI $\geq$ 35 kg/m^2, there is an incidence of prolonged surgery and wound infection[23].

The assumption that most complications of obese patients subjected to lumbar spine surgery are related to the extension of the approach and wound has led several groups to propose that minimally invasive surgery (MIS) is better to equalize surgical results of obese and non-obese groups, especially for those with morbid disease. Concurrently, several studies have shown that minimally invasive procedures like MIS-TLIF offer better outcomes than open TLIF for obese patients due to the smaller wound size and limited invasiveness to access the lumbar spine[12,14]. These findings were also corroborated in the meta-analysis by Goyal et al.[4] In this context, our study provides additional evidence showing that the outcomes after open TLIF for lumbar spine surgery are not impacted by grade I-II obesity. Hence, our results suggest that open TLIF is still a good option for non-morbidly obese patients with lumbar spine degeneration. In the case of individuals with morbid obesity, we acknowledge that our experience and the results of our study are not enough to make a conclusion about their postoperative risk. Hence, our results do not favor the use of open versus minimally invasive surgery for lumbar spine decompression and fusion.

This study has several limitations to be considered when interpreting the results, including its retrospective nature and single-center design. Furthermore, the relatively limited sample size of the study did not allow us to investigate the effect of obesity on post-operative surgical complications and long-term functional outcomes. There are several studies addressing this aspect available in the literature[24-27], which also need to be interpreted with caution due to the heterogeneity of the populations analyzed regarding the degree of overweight considered as obesity and the proportion of enrolled participants with morbid obesity. Furthermore, the study did not include enough individuals with extreme BMI to analyze the impact of morbid obesity on the perioperative lumbar spine surgery results. Future prospective studies using larger numbers of patients are required to confirm our findings.

Conclusion

The perioperative outcomes of patients with mild-to-moderate obesity are comparable to the results of non-obese individuals after lumbar spine surgery, with no clinically significant differences in post-operative EBL, operative time, and LOS between groups. Hence, lumbar spine surgery should not be denied to individuals with degenerative lumbar spinal disorders and Grade I-II obesity. The weight loss recommendation should not conditionate the spine surgery but instead promote integrative management to reduce long-term adverse post-operative outcomes, as well as metabolic and cardiovascular consequences of obesity. This assumption does not apply to the morbid obese patients, which constitutes a separate risk group with proved propensity to perioperative and post-operative adverse outcomes who require special diagnostic and therapeutic strategies to reduce perioperative and post-operative morbidity.

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Conflicts of interest

The authors declare that they do not have conflicts of interest.

Ethical disclosures

Protection of human and animal subjects. The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and with those of the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Confidentiality of data. The authors declare that they have followed the protocols of their work center on the publication of patient data.

Right to privacy and informed consent. The authors have obtained the written informed consent of the patients or subjects mentioned in the article. The corresponding author is in possession of this document.

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Supplementary data

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