

# Multivariate analysis of the effectiveness of the surgical treatment of the non-flail chest type of multiple rib fractures

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**Abstract.** The present prospective study aimed to analyze the effectiveness of surgery in treating the non-flail chest type of multiple rib fractures at the multivariate level. For this, patients with non-flail chest type multiple rib fractures were divided into two groups, namely the conservative therapy and surgery groups. Age, sex, the number of fractured and displaced ribs, injury severity, chest abbreviated scores, forced expiratory volume in one second (FEV1), narcotic drug dose, long-term FEV and forced vital capacity levels, drug additive (including pharmacological and individual agents for enhance of physicochemical properties, such as solvent systems), American Society of Anesthesiologists scores, duration of hospitalization, duration until feeling comfortable, follow-up duration, duration until return to workplace, discharge pain score, incidence of pneumothorax and pleural empyema, and pain levels were recorded and analyzed. The results showed that the baseline characteristics were not significantly different between the conservative treatment and surgery groups ( $P>0.05$ ). In addition, the pain level was notably associated with the FEV1 ( $r=0.499$ ;  $P<0.05$ ), drug administration ( $r=-0.445$ ;  $P<0.05$ ) and duration of hospitalization ( $r=0.559$ ;  $P<0.05$ ) in the conservative treatment group. The discharge pain level was also markedly associated with narcotic drug usage ( $r=0.478$ ;  $P<0.05$ ) and drug additive ( $r=0.618$ ;  $P<0.01$ ) in the surgery group. Furthermore, the duration of hospitalization significantly affected discharge pain in the conservative group ( $B=0.237$ ;  $P<0.01$ ), while drug additive notably affected

discharge pain in the surgery group ( $B=-2.547$ ;  $P<0.01$ ). Although surgery seemed to be more effective compared with the conservative method in terms of pain management, according to the multivariate analysis results, this effect was associated with the drug additive. Overall, the results of the present study indicated there was no significant difference between surgery and conservative therapy in the treatment of non-flail multiple rib fractures.

## Introduction

Patients with blunt chest trauma commonly experience rib fractures. In turn, these fractures are associated with sequelae and organ damage, thus increasing the morbidity and mortality risks. It has been reported that >250,000 individuals attend the emergency services in the United States, annually, due to rib fractures (1). Most patients with rib fractures are treated with conservative care. On the other hand, >30% of the above patients suffer from long-term disability that prevents them from holding down a full-time job, while up to 50% of patients, particularly those with combination injuries, such as flail chest, can experience chronic pain or chest wall deformities (2). In addition, 10-20% of patients who suffer physical trauma have rib fractures, which is the most common type of bone fracture. In extreme situations, these fractures can cause concurrent damage to the abdominal organs (3). In addition to trauma, rib fractures can result from medical procedures or from coughing, particularly in individuals with low bone density (4). In addition, ~40% of patients with acute chest trauma present with rib fractures, which are commonly seen in cases of chest trauma (5).

Flail chest is known as the condition where one side of the chest has more than three successive rib fractures with at least two fracture lines per rib (6). Multiple rib fractures and flail chest are considered distinct injuries and are synthesized independently for every extracted result (7). Patients with rib fractures present with a wide range of clinical symptoms. Certain patients who meet the diagnostic criteria for a flail chest may not exhibit aberrant breathing and they are therefore well managed with respect to their discomfort (8). Multiple rib fractures with flail or non-flail chest should be clearly distinguished, as the latter is associated with a higher mortality rate and considerable morbidity (9). The use of plating systems

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*Abbreviations:* ASA, American Society of Anesthesiologists; FEV1, forced expiratory volume in 1 sec; FVC, forced vital capacity; OR, odds ratio

*Key words:* rib fractures, surgical treatment, injury severity

for rib stabilization has shown promising results in reducing both the short- and long-term consequences of rib fractures, such as the occurrence of pneumonia, the requirement for a tracheostomy, prolonged hospital stay, increased dependence on painkillers and flail chest-related death (10).

In general, rib fractures are treated and managed with supportive measures, such as administration of local and systemic analgesics, airway clearance techniques, tube thoracostomy when pneumothorax or hemothorax is present and artificial breathing or surgery to reduce discomfort (11). A previous study demonstrated that the flail section was necessary for paradoxical chest wall motion; however, it was not sufficient for treating flail chest type rib fractures (12). The results of the most recent randomized controlled trial indicated that, although several previous small, non-randomized cohort studies supported the use of surgical fixation for improving pain and quality of life of patients with non-flail rib fractures, surgical stabilization of rib fractures allowed only a small proportion of patients to return to their work (13-15). Rib fixation for flail chest could improve the short-term outcomes, with the use of clinical results and implications of fixation. However, which patient subgroup is most likely to benefit from this technique has remained elusive (16).

Therefore, the present study aimed to analyze the effectiveness of the surgical treatment strategy in patients with non-flail chest type of multiple rib fractures at a multivariate level.

## Patients and methods

*Patients and diagnosis.* In the current randomized study, a total of 40 patients with multiple rib fractures and treated either conservatively (n=20) or with open surgical fixation (n=20) were prospectively enrolled from the were prospectively enrolled from the Adıyaman Training and Research Hospital Thoracic Surgery Clinic (Adıyaman, Türkiye) between April 2013 and December 2019. In the emergency clinic, all patients were subjected to three-dimensional computed tomography of the thorax, abdomen and skull. Patients with poor oxygen saturation and high injury score were monitored in the intensive care unit for the first 2-4 days. The remaining patients received treatment at the Thoracic Surgery clinic. Each patient underwent clinical and laboratory evaluation. A chest tube was inserted in every patient who experienced pneumothorax or hemothorax. In addition, internal or external stabilization of the limb fractures was performed. On the first or second day after the first hospitalization, the pain scale scores (17) and respiratory function test (18) results were recorded. Feeling comfortable was a dichotomous parameter with 'yes' or 'no' as the answers selected. Injury Severity Score was used for injury severity of patients (17). The total of 40 patients were randomly allocated into two groups, namely the surgery and conservative therapy groups. The inclusion criteria were as follows: i) Patients with a mean Injury Severity Score of 9-18; ii) those with 3-6 fractured ribs, with at least two being displaced; iii) those with no other complications or drug administration, which could have affected the results of the study; and iv) those without serious pulmonary contusion, and any head and abdominal trauma. Accordingly, if a patient received conservative therapy, they were then subjected to surgery fixation. Patients who refused surgery were only

treated with conservative therapy and were included in the conservative therapy group.

A power analysis was performed as previously described by Li *et al* (6) using GPower 3.1.9.2 software (Franz Faul). An effect size of 0.55 was obtained. Based on the above effect size, 95% confidence interval and Alpha level of 0.05, the minimum patient number for the study and control groups was 38 (critical t=1.69).

*Ethical approval.* The present study was approved by the İnönü University Medical School Ethics Committee (Battalgazi, Türkiye). All patients in the surgery group were informed about the surgical procedure and provided written informed consent to undergo surgery. Since there was no ethics committee at Adıyaman Training and Research Hospital (Adıyaman, Türkiye), where the data were collected, the corresponding author applied for and received ethics committee approval from the nearest academic institution, İnönü University (Battalgazi, Türkiye). Later, the corresponding author changed institutions.

*Conservative therapy.* For analgesic management, narcotic (tramadol, pethidine) and non-narcotic (paracetamol, diclofenac sodium) analgesics were used. All patients in the two groups were daily administered 300 mg intravenous tramadol combined with 3 g intravenous paracetamol as part of an analgesic management regimen (19,20). Further intravenous doses of pethidine (150 mg/day) and diclofenac sodium (225 mg/day) were administered to particular patients with inadequate pain control (21,22). For analgesic management, drug additives (including pharmacological and individual agents for enhance of physicochemical properties, such as solvent systems) were used, including intravenous injection of 300 mg tramadol daily in combination with intravenous infusion of 3 g paracetamol each day. Treatment for secretion retention included expectorant therapy, bronchodilator therapy, respiratory physiotherapy and tracheal aspiration.

*Surgery treatment.* A single lumen intubation was used for the surgery. To identify any broken ribs and fix displaced ones with titanium rib clips, incisions were made based on the location of the fracture. Following surgery, the patients were transferred to an intensive care or service unit.

*Data set.* Age, sex, etiology, accompanied pathologies, additional interventions, injury severity score, number of fractured and displaced ribs, pain scale, respiratory function values, analgesic doses and hospitalization duration were recorded and analyzed. Pain scale scoring and respiratory function tests were repeated prior to discharge. The aforementioned factors were analyzed and compared using the registration system. After discharge, pulmonary function tests were carried out in an outpatient clinic and the results were analyzed to evaluate long-term treatment efficacy. Hospitalization duration, feeling comfortable, return to workplace, pain and occurrence of complications were the primary outcome measures of the present research.

*Statistical analysis.* Nominal and ordinal parameters were expressed as frequencies, while continuous variables were expressed as the mean  $\pm$  standard deviation. The

Table I. Baseline characteristics of patient groups and differences between conservative and surgery method groups.

Item	Conservative (n=20)	Surgery (n=20)	P-value
Age, years	55.60±18.68 (41.50-71.00)	55.90±13.97 (48.50-65.50)	0.954 <sup>a</sup>
Sex			0.282 <sup>b</sup>
Males	19 (95.0)	17 (85.0)	
Females	1 (5.0)	3 (15.0)	
Number fractured ribs	4.60±0.99 4.00 (3.00-6.00)	5.15±0.93 5.00 (3.00-6.00)	0.076 <sup>c</sup>
Number of displaced ribs	2.85±0.67 3.00 (2.00-4.00)	3.05±0.83 3.00 (2.00-5.00)	0.529 <sup>c</sup>
Injury severity score	10.80±3.69 9.00 (9.00-18.00)	10.90±3.52 9.00 (9.00-18.00)	0.883 <sup>c</sup>
Chest abbreviated score	5.60±1.35 6.00 (3.00-9.00)	5.60±1.10 6.00 (3.00-7.00)	0.841 <sup>c</sup>
FEV1	0.55±0.43 (0.22-0.74)	0.47±0.31 (0.24-0.65)	0.526 <sup>a</sup>
FEV1 percentage	11.95±9.53 11.00 (1.00-35.00)	13.70±9.71 9.50 (3.00-38.00)	0.529 <sup>c</sup>
FEV1 improvement, change	0.50±0.37 0.37 (0.02-1.42)	0.42±0.22 0.39 (0.10-0.84)	0.841 <sup>c</sup>
FEV1 improvement %	14.10±11.25 10.00 (1.00-40.00)	15.40±8.93 11.50 (3.00-34.00)	0.414 <sup>c</sup>
Narcotic drug dose, mg	22.10±24.58 17.00 (0.00-80.00)	46.40±51.97 24.00 (0.00-180.00)	0.149 <sup>c</sup>
Long-term FEV	1.88±0.73 1.71 (0.54-3.08)	1.68±0.55 1.70 (0.55-2.73)	0.461 <sup>c</sup>
Long-term FVC	2.35±0.62 2.04 (1.22-3.18)	2.08±0.77 1.93 (0.81-3.62)	0.183 <sup>c</sup>
Drug additive ASA score	11 (55.0)	15 (75.0)	0.185 <sup>b</sup>
1-2	18 (90.0)	17 (85.0)	0.632 <sup>b</sup>
>2	2 (10.0)	3 (15.0)	

<sup>a</sup>Independent-samples t-test, <sup>b</sup>Fisher's exact test, <sup>c</sup>Mann-Whitney U-test. Values are expressed as the mean ± standard deviation and median (1st and 3rd quartile) or n (%). FEV1, forced expiratory volume in 1 sec; FVC, forced vital capacity; ASA, American Society of Anesthesiologists; Min, minimum; Max, maximum.

Kolmogorov-Smirnov test was applied to test for normality of the scale parameters (23). An independent-samples t-test was carried out to assess the normally distributed scale parameter differences, while the Mann-Whitney U-test was performed to assess the non-normally distributed scale parameter differences. The differences between nominal and ordinal parameters in the two groups were compared with the Chi-squared test. Spearman's rho correlation analysis was performed to evaluate the correlation between different parameters. Due to linearization deviations, a Generalized Linear Model (Logit) was used for effect analysis (23,24). All statistical analyses were performed using SPSS 25.0 (IBM Corp.). P<0.05 was considered to indicate a statistically significant difference.

## Results

*Differences in baseline characteristics between the surgery and conservative treatment groups.* The mean age of the conservative group was 55.60±18.68 and was 55.90±13.97 in the surgery group. A total of 19 males (95%) and 1 female (5%) were included in the conservative group and 17 males (85%) and 3 females (15%) were included in the surgery group. Age, sex, the number of fractured and displaced ribs, injury severity score, chest abbreviated score, forced expiratory volume in one second (FEV1), narcotic drug dose, long term FEV and forced vital capacity (FVC) levels, drug additives and American Society of Anesthesiologists (ASA) scores were not significantly different between the conservative treatment

Table II. Treatment outputs and differences between conservative and surgery method groups.

Item	Conservative (n=20)	Surgery (n=20)	P-value
Hospitalization duration, days	8.20±3.89 8.00 (3.00-18.00)	8.95±3.59 9.50 (3.00-15.00)	0.530 <sup>a</sup>
Feeling comfortable	6 (30.0)	5 (25.0)	0.723 <sup>b</sup>
Follow-up duration, days	11.85±7.69 9.00 (2.00-24.00)	9.25±9.12 5.00 (1.00-28.00)	0.108 <sup>c</sup>
Return to workplace	61.35±32.79 60.00 (5.00-120.00)	42.75±19.63 30.00 (15.00-90.00)	0.052 <sup>c</sup>
Pain	3.90±1.94 3.50 (1.00-7.00)	4.85±1.95 5.00 (1.00-9.00)	0.149 <sup>c</sup>
Pneumotorax	2 (10.0)	1 (5.0)	0.545 <sup>b</sup>
Pleural empyema	2 (10.0)	1 (5.0)	0.545 <sup>b</sup>
Infection of osteosynthesis material	1 (5.0)	-	N/A

<sup>a</sup>Independent-samples t-test, <sup>b</sup>Fisher's exact test, <sup>c</sup>Mann-Whitney U-test. Values are expressed as the mean ± standard deviation and median (1st and 3rd quartile) or n (%). N/A, not available.

and surgery groups (17-20) ( $P>0.05$ ; Table I). In addition, there were no significant differences between the conservative treatment and surgery groups in terms of hospitalization duration, feeling comfortable, follow-up duration, time to return to work and discharge pain score, or pneumothorax and pleural empyema incidence ( $P>0.05$ ; Table II).

**Correlation analysis results.** The Spearman's rho correlation analysis results showed that the pain score was significantly associated with the FEV1 ( $r=0.499$ ;  $P<0.05$ ), drug additives ( $r=-0.445$ ;  $P<0.05$ ) and hospitalization duration ( $r=0.559$ ;  $P<0.05$ ) in the conservative treatment group. By contrast, the discharge pain level was notably associated with narcotic drug using ( $r=0.478$ ;  $P<0.05$ ) and drug additives ( $r=0.618$ ;  $P<0.01$ ) in the surgery group (Table III; Figs. S1-4).

**Nonlinear regression analysis.** Generalized linear model (Logit) analysis revealed a statistically significant association between hospitalization duration and discharge pain levels in the conservative group ( $B=0.237$ ;  $P<0.01$ ). Additionally, in the surgery group, the effect of drug additives on discharge pain levels was also statistically significant ( $B=-2.547$ ;  $P<0.01$ ). However, multivariate analysis indicated that the number of fractured and displaced ribs did not significantly affect the pain level in both groups (Table IV).

**Pain level in the conservative treatment and surgery groups.** Pain levels in the conservative treatment group were significantly higher compared with the surgery group when no drug additives were used. By contrast, when drug additives were used, pain levels were significantly higher ( $P<0.05$ ) in the surgery group compared with the conservative treatment group (Fig. 1).

## Discussion

In the present study, the differences between conservative and surgical treatment approaches, which are commonly used

Table III. Spearman's rho correlation analysis between discharge pain level and baseline characteristics of patient groups.

Item	Conservative, rho value (n=20)	Surgery, rho value (n=20)
Sex	0.244	0.123
Number fractured ribs	0.062	0.371
Number displaced ribs	0.174	0.077
Injury Severity Score	-0.011	0.057
Chest Abbreviated Score	0.112	0.184
FEV1	0.499 <sup>a</sup>	0.016
FEV1 percentage	0.291	0.037
FEV1 improvement	0.327	0.229
FEV1 improvement percentage	0.178	0.233
Narcotic drug dose	-0.340	0.478 <sup>a</sup>
Drug additive	-0.445 <sup>a</sup>	0.618 <sup>b</sup>
Non-narcotic diclofenac	0.234	0.358
Non-narcotic paracetamol	0.214	-0.294
Hospitalization duration	0.559 <sup>a</sup>	0.346
Follow-up duration	-0.241	0.046
Long-term FEV	0.149	-0.095
Long-term FVC	0.021	-0.062
Return to workplace	-0.129	0.110
Feeling comfortable	-0.039	0.051
Age	-0.203	-0.160
ASA score	0.000	0.209
Pneumothorax	-0.103	-0.121
Pleural empyema	-0.221	-0.342
Infection of osteosynthesis material	-0.244	N/A

<sup>a</sup> $P<0.05$ , <sup>b</sup> $P<0.01$ . N/A, not applicable due to no infection of osteosynthesis material in the surgery group. FEV1, forced expiratory volume in 1 sec; FVC, forced vital capacity; ASA, American Society of Anesthesiologists.

Table IV. Generalized linear model (Logit) analysis for effects of significantly correlated factors on discharge pain levels according to treatment methods.

A, Conservative group (n=20)							
Parameter	Beta	Std. error	95% Wald confidence interval		Hypothesis test		
			Lower	Upper	Wald Chi-square	df	P-value
Intercept <sup>a</sup>	1.100	0.791	-0.451	2.651	1.931	1	0.165
Drug additive	0.940	0.680	-0.393	2.273	1.910	1	0.167
FEV1	0.784	0.803	-0.790	2.358	0.954	1	0.329
Hospitalization duration	0.237	0.088	0.066	0.409	7.350	1	0.007
Scale <sup>b</sup>	1.991	0.629	1.071	3.699	-	-	-

B, Surgery group (n=20)							
Parameter	Beta	Std. error	95% Wald confidence interval		Hypothesis test		
			Lower	Upper	Wald Chi-square	df	P-value
Intercept <sup>a</sup>	5.347	0.613	4.145	6.549	76.028	1	<0.001
Drug additive	-2.547	0.904	-4.320	-0.775	7.932	1	0.005
Narcotic drug dose	0.003	0.008	-0.012	0.018	0.151	1	0.698
Scale <sup>b</sup>	2.210	0.699	1.189	4.107	-	-	-

C, Entire sample (n=40)							
Parameter	Beta	Std. error	95% Wald confidence interval		Hypothesis test		
			Lower	Upper	Wald Chi-square	df	P-value
Intercept <sup>a</sup>	2.046	1.7467	-1.377	5.470	1.372	1	0.241
Approach	-0.672	0.6054	-1.859	0.514	1.233	1	0.267
Number fractured ribs	0.443	0.3409	-0.226	1.111	1.686	1	0.194
Number displaced ribs	0.172	0.4372	-0.685	1.029	0.154	1	0.694
Scale <sup>b</sup>	3.375	0.7548	2.178	5.232	-	-	-

<sup>a</sup>Generalized Linear Model intercept term; <sup>b</sup>scale value for the model. FEV1, forced expiratory volume in 1 sec; df, degrees of freedom.

to treat patients with non-flail multiple rib fractures, were evaluated in terms of pain and treatment outcomes using multivariate analysis. In this context, the study analyzed the baseline characteristics, clinical findings and discharge pain levels of patients who received one of the two treatment methods.

Previous studies on rib fractures indicated that the baseline characteristics of patients who underwent surgical treatment were similar with those receiving conservative therapy in terms of demographics (25-27). Therefore, studies on this subject did not reveal any significant differences in terms of age, sex or clinical history between the aforementioned therapy groups. In consistency with this, in the present study, patients in the

surgery group and those in the conservative therapy group displayed similarities in terms of age, sex, number of fractured and displaced ribs, injury severity score, chest abbreviated score, FEV1, narcotic drug dose, long-term FEV and FVC levels, drug additives and ASA classification. The differences in the above scores were statistically insignificant between the conservative treatment and surgery groups. This finding suggested that none of the treatment strategies was associated with the baseline characteristics of patients with non-flail rib fractures.

Previous studies also demonstrated that there were no statistically significant differences in patient outcomes between the conservative treatment and surgery groups (28,29). However,

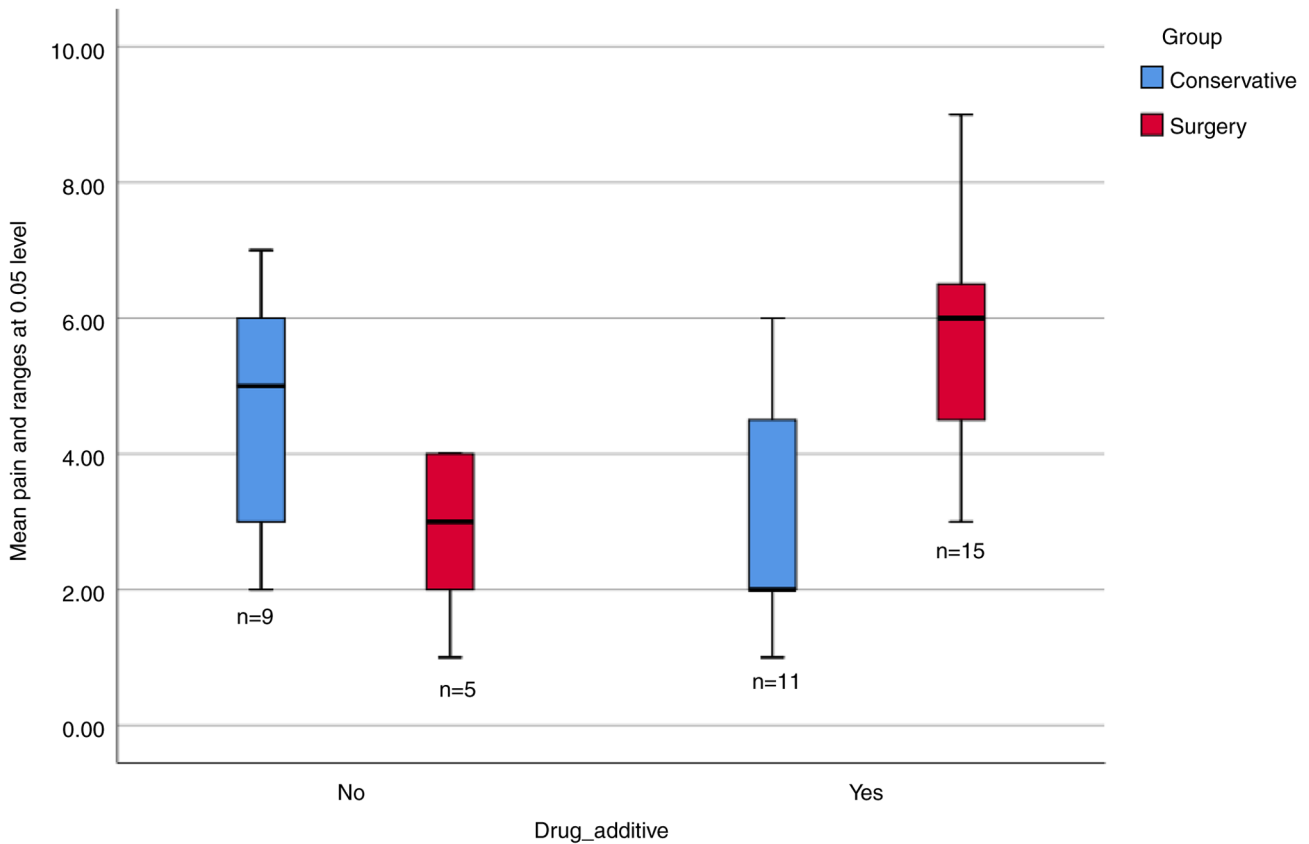


Figure 1. Pain levels and ranges of patient groups according to drug additive usage (mean and minimum-maximum values at 0.05 significance level; there were no significant differences).

a study by Zhang *et al* (8) reported that the surgical treatment option was more effective in terms of pain and quality of life. They recorded lower pain levels and higher quality of life in patients with non-flail multiple rib fractures who underwent surgery. In the present study, there were no significant differences between the conservative and surgical treatment groups regarding hospitalization duration, comfort level, follow-up duration, return to workplace, discharge pain score, and pneumothorax and pleural empyema incidence. This finding aligned with the existing literature when examined univariately. However, a multidimensional analysis within the framework of relational screening should be performed to provide a more comprehensive understanding.

Correlation analysis revealed that in the conservative treatment group, the pain level was significantly associated with the FEV1, drug additives and hospitalization duration. On the other hand, in the surgery group, the discharge pain level was notably associated with narcotic drug usage and drug additives. Regression analysis further indicated that the hospitalization duration had a statistically significant effect on discharge pain in the conservative treatment group, while in the surgery group, drug additives markedly affected discharge pain. The above results suggested that although surgery was able to offer greater pain management benefits, these outcomes could be largely affected by pain management medications. Considering the importance of pain, the results indicated that there were no statistically and clinically significant differences between the conservative and surgical treatment groups in patients with non-flail rib fractures. However, further research

is needed to generalize these findings and better understand the effects of different treatment strategies. In addition, the preference for conservative treatment due to its lower invasiveness warrants further investigation. Overall, these results may have significant implications for both clinical practice and the existing literature.

The primary limitation of the present study was the scarcity of similar studies in the field, making it difficult to draw comprehensive comparisons. Although there are several studies on multiple rib fractures, research particularly focusing on non-flail rib fractures remains limited. In this respect, the majority of clinical studies in this area have relied on comparative rather than multivariate analyses (4,8,12,13). Therefore, more research on this subject is needed to strengthen the existing literature.

A key contribution of the present study was that it challenged the hypothesis, suggested in previous univariate analyses that surgery could provide superior pain management compared with the conservative treatment approach. The multivariate analysis results indicated that the observed advantage of surgery in pain management was primarily associated with drug additives.

From a clinical perspective, this study could aid physicians in determining the most appropriate treatment method based on the physical condition and clinical findings of patients. Given the lack of a significant difference between the two treatment methods, the choice should be guided by individual patient needs rather than a presumed superiority of surgical intervention. Although surgery is more attractive and it is

most commonly chosen for pain management, the result of the present study indicated that this benefit could be effectively achieved through drug additives.

Although surgery could be more effective for pain management, the multivariate analysis revealed that this effect may be due to the use of drug additives. This observation indicated that findings from previous studies suggesting that the surgical method could improve the quality of life and reduce pain may have overlooked the role of drug additives due to their reliance on univariate analysis.

Therefore, it may be argued that there was no significant difference between surgical and conservative approaches in treating non-flail multiple rib fractures. However, further studies and clinical data are needed to verify this conclusion. In clinical practice, the conservative approach could be preferred due to the invasiveness and cost of the surgical approach. Overall, the above findings suggested that the most appropriate treatment decision should be based on the patient's current physical condition and clinical findings.

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### Availability of data and materials

The data generated in the present study are included in the figures and/or tables of this article.

### Authors' contributions

AGA and ED collected the data. ED analyzed and interpreted the results. AGA and ED wrote the final version of the manuscript and revised it. AGA and ED confirmed the authenticity of all raw data. Both authors have read and confirmed the final version of the manuscript.

### Ethics approval and consent to participate

The current study was approved by the İnönü University Medical School Ethics Committee (Battalgazi, Türkiye; approval no. 2013/10). All patients in the surgery group provided written informed consent for their data to be used in the research. Patients provided written informed consent for publication of their data to be used/published for scientific research purposes.

### Patient consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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