

A cost minimization analysis comparing minimally-invasive with open reduction surgical techniques for pelvic ring fracture

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Abstract. The aim of the present study was to compare the in-hospital direct medical costs of patients with pelvic fracture treated with minimally invasive surgery (MIS) or open reduction and internal fixation (ORIF). A retrospective, single-center, cohort, and comparative study was performed. Administrative information and clinical results, in addition to cost data, were collected and analyzed. A cost minimization analysis method was used to evaluate the costs of two different surgical techniques. A total of 128 patients diagnosed with pelvic fracture were included in this study; 62 were treated with MIS and 66 underwent ORIF. No significant difference was observed between the 2 groups in terms of patients' clinical baseline characteristics. The operative time, length of incision, intra-operative blood loss, and post-operative length of stay in the MIS group were significantly different compared with those in the ORIF group. The cost-minimization analysis demonstrated that the cost effectiveness of MIS was better than ORIF as the MIS was associated with a significantly lower total in-hospital direct medical cost (\$8,900 vs. \$5,786, $P=0.032$), compared with ORIF. The cost-minimization analysis demonstrated that for similar clinical baseline characteristics as well as outcomes, there were differences in direct hospitalization cost of two surgical techniques, and MIS had a lower cost on average than ORIF.

Introduction

Economic evaluations of health care interventions are assuming increasing importance. There has been continued growth of medical expenses in China over the past decade, and attention has been increasingly focused on evaluating the cost-effectiveness of medical treatments that patients received. The National Health and Family Planning Commission (NHFPC) of the People's Republic of China requested in 2016 that the growth of national health expenditure should be less than 10% by the end of 2017. For that reason, it is not surprising that there has been considerable interest in reducing medical expenses by adopting more cost-effective medical treatments including surgical techniques.

Although traumatic disruption of the pelvic ring is uncommon and accounts for about 3 to 8% of all skeletal injuries, it has often carried a relatively high risk of mortality with current estimates ranging from 5 to 35%, and up to 50%, based on the severity of the associated injury patterns (1-6). These injuries are predominantly the result from high energy blunt trauma such as falling from a height, crushing by heavy loads at the workplace, and motor vehicle collisions (7-10). Severe associated injuries and multiple trauma are prevalent in patients with pelvic ring fracture, which has increased the complexity of surgical treatment, and also the hospitalization costs. A previous study showed that the direct hospitalization cost per patient with a pelvic fracture was \$12,012 (US dollars) between 1999 to 2006 in the United States. This amount was just lower than for hip fracture and multiple fractures (11).

Apart from the relatively high expenses, the hospitalization costs among patients with pelvic fractures vary greatly. On the one hand, it is because the severity of the injury of the patients with pelvic fracture are heterogeneous (12-15); on the other hand, the surgical treatments of pelvic fracture do vary (16-19). Both these facts play an important role in the length of stay and health care costs in hospital, which contribute significantly to the overall hospitalization costs of these patients.

There is no doubt that the in-hospital medical costs increase with the increase in injury severity of patients with pelvic fracture (20,21). Among all the surgical techniques of the pelvis, open reduction and internal fixation has been commonly used

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Abbreviations: CMA, cost minimization analysis; MIS, minimally-invasive surgery; ORIF, open reduction and internal fixation

Key words: cost minimization analysis, minimally-invasive surgery, open reduction and internal fixation, pelvic ring fracture, sensitivity analysis

to treat fracture of the pelvic ring for decades. Traditionally, ORIF procedures can be performed successfully with either small or large locking compression or fragment reconstruction plates and screws (22). Although ORIF is considered as sophisticated and widely applicable, many surgeons prefer to choose minimally invasive techniques such as a subcutaneous pedicle screw-rod fixation system for their patients instead (23). This is mainly because both ORIF and MIS can achieve similar short-term clinical outcomes and long-term treatment results, as a number of studies have reported. In addition, MIS had superior results to ORIF in terms of the operation time, length of incision, blood loss during operation, and length of stay (24,25).

However, there is still no consensus on whether MIS or ORIF is more cost-effective in the treatment of traumatic pelvic ring fractures. Additionally, no relevant studies have compared the cost effectiveness of MIS and ORIF for pelvic fracture treatment so far. Therefore, it is necessary to make an economic evaluation and to compare the cost effectiveness of these two types of surgical techniques for the treatment of pelvic fractures.

There are four types of economic evaluation methods which can be used to gather evidence and compare the expected costs and outcomes of different surgical techniques (26).

i) A cost-utility analysis (CUA) is characterized by analysis of utility-based outcomes such as the quality-adjusted life years following treatment; ii) A cost-benefit analysis (CBA) is concerned with the consequences expressed in monetary units and is commonly used to evaluate distribution of resources to diverse areas of health care; iii) A cost-effectiveness analysis (CEA) is characterized by analysis of both costs and clinical or physiological outcomes, where the outcomes of alternative treatments might be different in magnitude; and iv) A cost-minimization analysis (CMA), which is a form of cost-effectiveness analysis, is used when outcomes of different treatments are equivalent and the aim is to identify which alternative has the lowest cost (26).

To determine the most appropriate economic evaluation approach in this study, a literature review was first conducted to ascertain whether the clinical outcomes between MIS and ORIF were equivalent. Based on reviewing the relevant studies we found that although MIS resulted in slightly better scores than ORIF on post-operative outcomes such as functional score, imaging score, reduction quality, and complication rate, the statistical difference between these two kinds of surgical techniques was barely significant (22,24,25,27,28). Because both methods achieved equivalent outcomes according to the literature studied, cost-minimization analysis (CMA) could be an appropriate economic evaluation form.

We hypothesize that the cost effectiveness of MIS is better than ORIF for the treatment of pelvic fracture because the units of blood transfusion, nursing workload, antibiotics consumption, and post-operative length of stay are expected to be reduced for the patients treated with minimally invasive pelvic surgery.

The main aim of this study was to determine whether there were any differences in the cost effectiveness of pelvic fracture treatment by MIS or ORIF. Additionally, all the cost data were analyzed to evaluate the composition of hospitalization costs of different surgical techniques.

Materials and methods

Patient selection. This retrospective study involved a single-center series of patients who were diagnosed with pelvic fractures according to the International Classification of Diseases (ICD-10) codes at Shanghai General Hospital from January 2012 to December 2016. Pelvic fractures included all fracture types affecting the following bony anatomy region: Acetabulum, pubis, sacrum, ilium, ischium, and coccyx.

The inclusion criteria were as follows: i) patients aged between 18 and 90 years old (because there is controversy on whether pediatric pelvic fractures are different injuries from adults) (14); ii) patients who failed to accept conservative treatment and had to undergo surgical treatment for pelvic fracture.

The exclusion criteria were as follows: i) patients who had undergone surgeries for other parts of the body besides the pelvis; ii) patients who had received closed reduction and external fixation (CREF) or fixation removal surgery; iii) patients who were diagnosed with severe comorbidities (including cancers, cardiovascular and cerebrovascular diseases, and coagulation disorders) or acute associated injuries (especially severe open pelvic fracture and multiple organ failure); and iv) patients who were lost to follow-up (either by being lost to contact or by other socioeconomic factors).

Data collection. The demographic and physiological data of patients on admission including age, gender, mechanism of injury, systolic blood pressure, heart rate, respiratory rate, temperature, consciousness, need for ICU on admission, and units of blood transfused within the first 24 h post injury were obtained from the hospital's routine nursing records.

Injury-specific data were extracted from the hospital's electronic clinical records. These data included fracture type, whether associated with internal organ injury, the need for pelvic digital-subtraction angiography (DSA), and whether it was an isolated or multiple pelvic fracture (more than 3 sites of pelvic fractures). In addition, the American Society of Anesthesiologists score was recorded, which is an overall score that assesses the physical status of patients before surgery and ranges from 1 to 5, corresponding to 'normal healthy patient' to 'moribund patient who is not expected to survive', and the number of consultations before the operation. The types of pelvic fracture were classified separately by two resident physicians according to all the available radiological data and using Tile's classification system adopted by the Orthopedic Trauma Association (OTA). Type A fractures are vertically and rotationally stable; Type B fractures are vertically stable but rotationally unstable; Type C fractures are vertically and rotationally unstable (29). Cases that were undecided were discussed in regular weekly meetings held by the department director to minimize inter-observer bias.

The surgery-related data including the type of surgical procedure, duration of operation, length of incision, intra-operative bleeding volume, and post-operative length of hospital stay were collected from the paper-based operative notes. Moreover, the incidence rate of peri-operative complications were gathered from medical records and the Majed postoperative functional outcome scores were obtained from follow-up records. The follow-ups were performed and pelvic radiographs were taken to evaluate the reduction and the

osseous union. The Majeed functional score of all patients were evaluated at 6 and 12 months after the operation.

The data of direct medical costs in hospital including medical tests, medical materials, surgical services, medications, blood production, nursing care, ward-bed occupation, and miscellaneous items were identified by accessing the hospital's financial records.

Surgical technique. The criteria were classified into 2 groups by the pattern of surgeries they received. One group underwent open reduction and internal fixation (ORIF), and the other group underwent minimally invasive surgery (MIS). All surgeries were performed under general anesthesia.

In the open reduction and internal fixation (ORIF) group, patients were placed in the supine position, a midline vertical incision was made, then a 4.5 mm locking compression plate with 9-12 holes was bent and placed closely to the bone surface with 2-3 holes remaining on each side, and then screws were inserted and tightened on each end of the plate.

In the minimally invasive surgery (MIS) group, all patients underwent percutaneous pedicle screw-rod fixation (PSRF). From 2 to 4 pedicle screws (60-80 mm long and 7 mm wide) were inserted into the bilateral supra-acetabular bone through small incisions which spanned the fractured pelvic ring by interconnecting the left and right hemipelvis with an appropriate length curved titanium or stainless steel rod.

Financial analysis. For each patient, hospitalization costs were extracted from the hospital financial information system. Direct medical costs in hospital were based on a fixed internal hospital fee schedule for services and consisted of medical test costs (laboratory test and imaging investigation), materials (consumables and implants), surgical services (procedure and anesthesia), medications (antibiotics and non-antibiotic drugs), inpatient costs (nursing service and ward-bed occupation), blood production, and miscellaneous items costs. Direct non-medical costs, which include the expenditure caused by transportation and food for patients and their relatives during hospitalization, were not included in the study. Indirect medical costs (30), which mostly refer to the loss of income due to absenteeism and intangible costs caused by pain and suffering were also excluded. All cost data were obtained in CNY (¥), and subsequently converted to USD (\$), with ¥1 equivalent to \$0.1452 according to the international exchange rate on May 16, 2017.

Cost minimization analysis (CMA) was used to determine which kind of surgery method was more cost-effective because evidence was found that the treatment alternatives have identical outcomes. In other words, the comparison of cost effectiveness was equivalent to the comparison of the mean cost between the different groups (31). The cost structure of the 2 kinds of surgical techniques was also analyzed. This was done to clarify the relationship between each part of the hospitalization costs and related surgical technique. In addition, one-way sensitivity analyses were used to test the robustness of the conclusions as well as broaden the generalizability of the results.

Statistical analysis. Descriptive statistics were presented as mean \pm standard deviation (SD) or median and interquartile

range (IQR) for all continuous variables depending on the distribution of the data while number with percentages (%) were reported for all categorical variables.

Bivariate analysis was performed by using t test (normal distribution) or Mann Whitney U-test (abnormal distribution) whenever appropriate to compare the mean for all the continuous variables between the 2 groups. Chi-Square test or Adjusted Chi-Square test, as appropriate (depending on the sample size), were used to compare the proportions of all the categorical variables between the 2 groups. Results with P-values less than or equal to 0.05 were considered to be statistically significant.

The software SPSS version 20.0 (IBM Corp., Armonk, NY, USA) was used for data management as well as statistical analysis.

Ethics statement. This study was reviewed and approved by the Institutional Review Board of the Shanghai General Hospital affiliated to Shanghai Jiao Tong University. The study was carried out in accordance with the principles of the World Medical Association's Declaration of Helsinki. The application of the exemption for informed consent was approved by the Ethics Committee of Shanghai General Hospital since the study did not involve any identifying patient information.

Results

Baseline characteristics. During the study period, 324 adult patients were diagnosed with pelvic fracture and received surgical treatment (ICD-10 code: S32.801), among whom 274 patients received surgery for the pelvis without surgery for other parts of the body. There were 118 patients excluded for receiving a nonspecific method of surgery and 8 patients were excluded because of severe comorbidities or acute associated injuries. Moreover, 20 patients were lost to follow-up due to invalid contact information provided or referral to local hospitals where these patients lived. After the selection process, 66 patients with a mean age of 44 years who underwent ORIF surgery, and 62 patients with a mean age of 41 years who underwent MIS were finally included in this study. The follow-up rate was 85.7% in the ORIF group and 87.3% in the MIS group, respectively. A detailed flow chart of patient selection is presented in Fig. 1.

Because different surgical treatments were based on the clinical condition of patients, all baseline data of the 2 groups of patients including demographic information, preoperative clinical characteristics, severity of the illness, types of the pelvic fracture, and other factors were compared to ensure that the 2 groups were comparable in this study. According to the statistical results, patients in the MIS group showed no differences in baseline characteristics from the ORIF group. The results are summarized in Tables I and II.

Operation records and outcomes. Differences in length of incision were significant (Table III). The median incision length in the MIS and ORIF group was 14 and 6 cm respectively ($P < 0.001$). A significant difference was observed regarding duration of operation ($P = 0.001$; Table III), which was shorter in the MIS group than the ORIF group (103 min vs. 152 min). The MIS group had significantly less

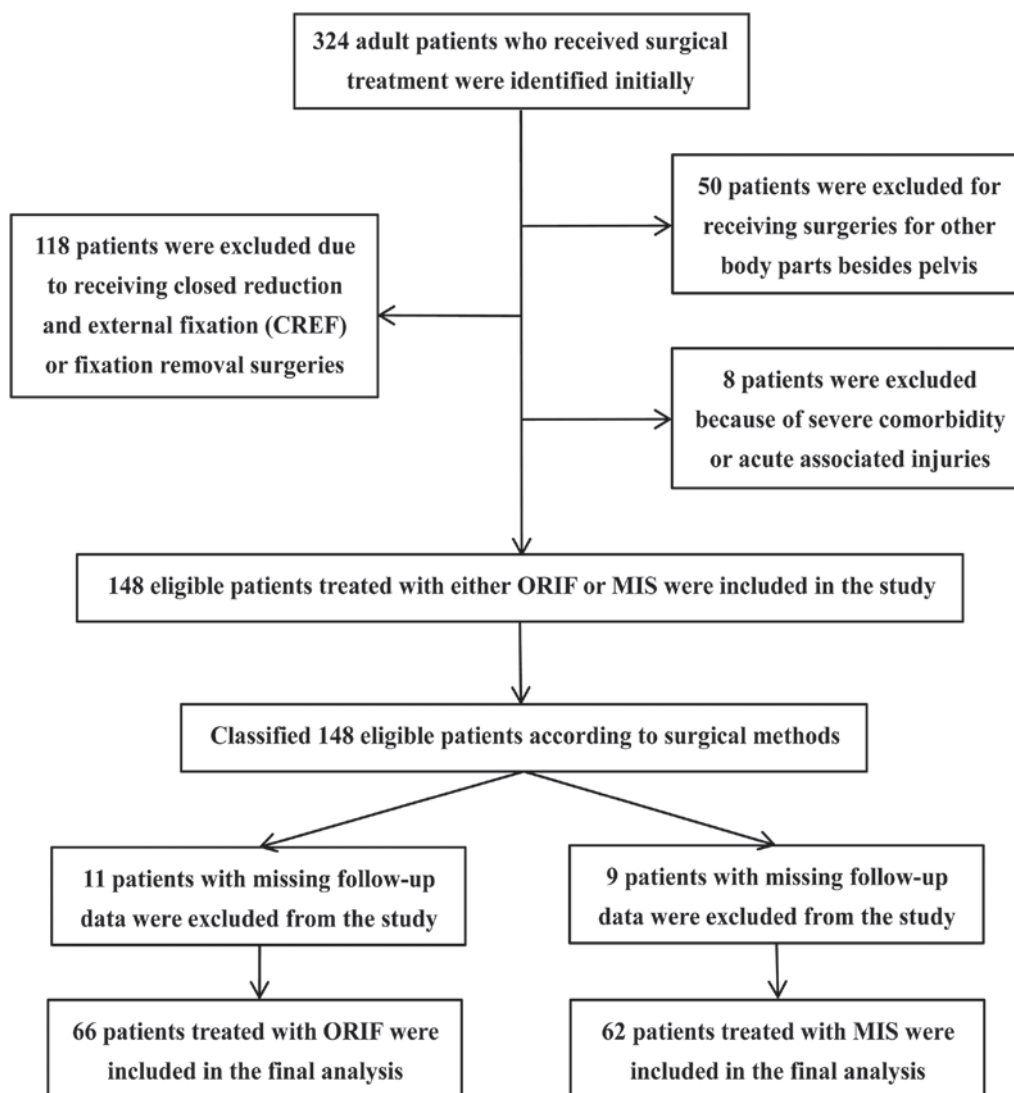


Figure 1. Detailed flow diagram of patient selection. ORIF, open reduction and internal fixation; MIS, minimally invasive surgery.

intra-operative bleeding volume (50 vs. 250 ml) than the ORIF group ($P<0.001$; Table III).

There was also a statistically significant difference in the post-operative length of stay between the 2 groups, with a median stay of 8 days and 15 days in the MIS and ORIF group, respectively ($P<0.001$; Table III).

We found no statistically significant difference in the Majeed functional scores between the 2 groups at the final follow-up ($P=0.614$; Table IV). The average evaluation score was 79.6 points with an excellent rate of 77.4% in the MIS group vs. 81.4 points with an excellent rate of 75.8% in the ORIF group ($P=0.825$; Table IV). With regard to complications, in the ORIF group, there were 2 patients with surgical site infection, 2 patients treated with unplanned re-operation due to hardware failure, and 1 patient was reported as having malunion. By comparison, 3 patients who underwent MIS were found to have infection at the surgical site. Even though the complication rate in the ORIF group (7.6%) was higher than that in MIS group (4.8%), the difference was not statistically significant ($P=0.719$; Table IV). Furthermore, no patients died in either the ORIF or the MIS group. Because both groups achieved equivalent outcomes according to the

statistics ($P<0.05$), cost-minimization analysis (CMA) is the most appropriate form of economic evaluation for this study because the CMA assumes that outcomes are equivalent while seeking the least expensive alternative (26).

Hospitalization costs. For all subjects, the average total hospital direct cost was estimated to be \$6,178.4 in the MIS group vs. \$9,227.7 in the ORIF group and a significant difference was observed between the 2 groups ($P=0.032$). All the details of the costs are summarized in Table V.

Most of the hospital direct cost in both groups was due to the direct cost of medical materials which consist of disposable medical consumables (\$1,248.0 vs. \$646.4, $P<0.001$) and surgical implants (\$4809.0 vs. \$3,351.8, $P=0.149$). The medical materials cost in the MIS group and ORIF group was \$6,057.0 and \$3,998.2 respectively, and the difference between the 2 groups was statistically significant ($P=0.029$).

A significant difference was also found between the 2 groups in the surgical services cost, which includes anesthesia (\$226.4 vs. \$212.6, $P=0.451$) and operating room occupation and staff labor (\$777.3 vs. \$602.9, $P<0.001$). The surgical services cost in the ORIF group was much higher, by

Table I. Demographic and physiological data of patients with pelvic fracture.

Patient variables	ORIF, n=66	MIS, n=62	P-value
Sex, n (%)			0.965
Male	37 (56.1)	35 (56.5)	
Female	29 (43.9)	27 (43.5)	
Age (years, mean \pm SD)	43.76 \pm 13.43	44.14 \pm 13.19	0.408
Mechanism of injury, n (%)			0.280
High fall	11 (16.7)	14 (22.6)	
Motor vehicle collision	37 (56.1)	26 (41.9)	
Crush injury	8 (12.1)	6 (9.7)	
Stumble fall	10 (15.1)	16 (25.8)	
Physiological indicators on arrival			
Systolic blood pressure (mm Hg, mean \pm SD)	125.72 \pm 14.96	120.73 \pm 15.34	0.122
Heart rate (bpm, median and IQR)	77 (76, 80)	78 (76, 80)	0.273 ^b
Respiratory rate (bpm, median and IQR)	20 (18, 20)	19 (18, 20)	0.595 ^b
Temperature ($^{\circ}$ C, median and IQR)	36.9 (36.6, 37.0)	37.0 (36.7, 37.0)	0.574 ^b
Consciousness on arrival, n (%)			0.128 ^a
GCS \geq 9	55 (83.3)	58 (93.5)	
GCS<9	11 (16.7)	4 (6.5)	
Need for ICU on arrival, n (%)			0.114
Yes	17 (25.8)	8 (14.5)	
No	49 (74.2)	54 (85.5)	
Blood transfused within the first 24 h after admission (Units, median and IQR)	0 (0, 1)	0 (0, 1.5)	0.776 ^b

GCS, Glasgow coma scale; SD, standard deviation; IQR, interquartile range. ^aAdjusted Chi-square test. ^bMann-Whitney U test.

Table II. Pre-operative injury-severity factors of patients with pelvic fracture.

Patient factors	ORIF, n=66	MIS, n=62	P-value
Tile's classification, n (%)			0.499
A type	20 (30.3)	14 (22.6)	
B type	37 (56.1)	41 (66.1)	
C type	9 (13.6)	7 (11.3)	
Internal organ injury, n (%)			0.758
Yes	12 (18.2)	10 (16.1)	
No	54 (81.2)	52 (83.9)	
Need for DSA, n (%)			0.249 ^a
Yes	8 (12.1)	3 (4.8)	
No	58 (87.9)	57 (95.2)	
Multiple pelvic fractures, n (%)			0.234
Yes	23 (34.8)	28 (45.2)	
No	43 (65.2)	34 (54.8)	
Preoperative consultation (times, median and IQR)	1 (0, 1)	1 (0, 1.5)	0.977 ^b
ASA score (mean \pm SD)	2.20 \pm 0.72	1.91 \pm 0.68	0.055

DSA, digital subtraction angiography; ASA, American Society of Anesthesiologists; SD, standard deviation; IQR, interquartile range.

^aAdjusted Chi-square test. ^bMann-Whitney U test.

an average of \$189, than the MIS group (\$1,003.7 vs. \$815.4) (P<0.001).

The medication cost in the MIS group and ORIF group was \$646.4 and \$1,112.1, respectively, and the difference between

Table III. Surgery records of patients with pelvic fracture.

Surgery records	ORIF, n=66	MIS, n=62	P-value
Surgery times (min, median & IQR)	152 (105, 168)	103 (90, 118)	0.00 ^a
Length of incision (cm, median & IQR)	14 (10, 16)	6 (5, 8.5)	<0.00 ^a
Estimated blood loss (ml, median & IQR)	250 (200, 800)	50 (20, 100)	<0.00 ^a

LOS, length of stay; SD, standard deviation; IQR, interquartile range. ^aMann-Whitney U test.

Table IV. Comparison of outcomes between the MIS and ORIF group.

Outcomes	ORIF, n=66	MIS, n=62	P-value
The Majeed functional score (mean ± SD)	81.4±7.7	79.6±9.0	0.614
Excellent reduction n (%)	50 (75.8)	48 (77.4)	0.825
Perioperative complications n (%)	5 (7.5)	3 (4.8)	0.719 ^a
Surgical site infection	2	3	/
Unplanned re-operation	2	0	/
Malunion	1	0	/

^aFisher's exact test.

Table V. Comparison of direct medical costs of patients with pelvic fracture.

Direct medical cost	ORIF, n=66 (mean ± SD)	MIS, n=62 (mean ± SD)	P-value ^a	Mean difference (ORIF minus MIS)
Medical test (\$)	344.2±133.1	342.8±189.5	0.984 ^b	+1.7
Laboratory test	185.3±91.3	198.3±97.2	0.765 ^b	-13
Imaging investigation	158.8±84.3	144.5±105.5	0.725 ^b	+14.3
Medical materials ^c (\$)	6,057.0±2,010.9	3,998.2±901.2	0.029 ^b	+2058.8
Consumables ^c	1,248.0±1,036.4	646.4±128.4	<0.001	+601.6
Implants	4,809.0±2,187.4	3,351.8±889.0	0.149 ^b	+1457.2
Surgical service ^c (\$)	1,003.7±267.4	815.4±23.4	<0.001	+188.3
Anesthesia	226.4±103.7	212.6±21.7	0.451	+13.8
Operating room occupation and staff labor ^c	777.3±240.1	602.9±3.9	<0.001	+174.4
Medication ^c (\$)	1,112.1±654.5	646.4±128.4	<0.001	+465.7
Antibiotics ^c	257.9±478.4	88.4±34.6	0.021	+169.5
Non-antibiotics ^c	854.2±347.2	558.0±113.0	0.009	+296.2
Blood production ^c (\$)	117.0±311.8	33.4±74.7	<0.001	+83.6
Nursing care ^c (\$)	140.8±199.7	57.8±29.6	0.014	+83.0
Ward bed occupation ^c (\$)	189.5±207.1	113.8±74.2	0.018	+75.6
Miscellaneous items (\$)	263.4±169.1	170.6±26.2	0.233	+92.8
Total in-hospital direct costs ^c (\$)	9,227.7±3,107.3	6,178.4±1,087.8	0.032 ^b	+3049.3

^at²-test. ^bt-test. ^c¥1 equal to \$0.1452. ^cP<0.05. ORIF, open reduction and internal fixation; MIS, minimally invasive surgery.

the 2 groups was statistically significant ($P<0.001$). It is notable that the cost of antibiotics in the ORIF group was 2.9 times than that in the MIS group (\$257.9 vs. \$88.4, $P=0.021$). With regard to non-antibiotics, the cost was also much higher in

the ORIF group compared with that in the MIS (\$854.2 vs. \$558.0, $P=0.009$). Other costs that were statistically higher in the ORIF group included the cost of nursing care service (+\$83.0, $P=0.014$) and ward-bed occupation (+\$75.6, $P=0.018$).

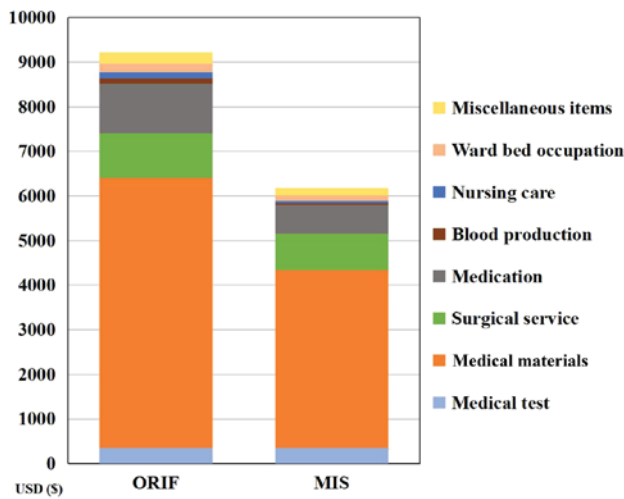


Figure 2. Summary of cost categories in US dollars for ORIF and MIS. Eight different colors in both bars indicate cost of medical test, medical materials, surgical service, medication, blood production, nursing care, ward bed occupation, and miscellaneous items from bottom to top. ORIF, open reduction and internal fixation; MIS, minimally invasive surgery.

No significant difference was observed in the cost of medical tests. The cost of various imaging tests such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound testing (UT), and the cost of laboratory tests such as for blood, urine, and other body fluid did not differ between the 2 groups, with a cost of \$344.2 in the MIS group vs. \$342.8 in the ORIF group ($P=0.984$).

Cost structure. Fig. 2 shows the composition of hospitalization costs per patient for the 2 different kinds of surgical methods. As can be seen from the figure, in the ORIF group, medical materials accounted for 68.1% of the cost, followed by medication taking up 12.1%, and surgical service 10.9%. These 3 major components were responsible for a great proportion of the total cost, which was similar to the situation in the MIS group, although medical materials accounted for 69.1%, surgical service 14.1%, and medication cost 11.2%.

The cost proportion of surgical service was quite similar in both groups as well, with a percentage of 14.1% in the MIS group and 11.3% in the ORIF group by comparison. Furthermore, similarity was also found between the 2 groups with regard to miscellaneous items, which accounted for 3.0% in both groups.

Blood production, nursing care and ward-bed occupation were the 3 smallest cost areas in both groups, altogether amounting to only 3.5 and 5.0% of the total cost in the MIS and ORIF group, respectively.

With regard to medical tests, the cost proportion in the MIS group (5.9%) was about 1.5 times greater than that in the ORIF group (3.9%), which was the biggest difference between the 2 groups in this study (Fig. 2).

Sensitivity analyses. One-way sensitivity analyses were performed to simulate different possible scenarios and test the robustness of the results, by changing only one variable in a reasonable range while keeping all the other variables constant and then observing the change of the new outcomes. In the

Table VI. Sensitivity ranges of key variables.

Variables	Base value	Sensitivity range
Discount rate	0%	-10%-10%
Surgeon's fee for surgical service	\$601.1	\$300.6-\$901.7
Daily hospitalization cost	\$414.3	\$207.2-\$621.5
Implants cost		
Locking compression plate	\$1,707.6	\$853.8-\$2,561.3
Titanium surgical screw	\$819.5	\$409.8-\$1,229.3
Titanium surgical rod	\$327.9	\$163.9-\$491.8

current study, the sensitivity analyses included the following parameters: Discount rate, surgeon's fee for surgical service, daily hospitalization cost and implants cost. The sensitivity range of each variable was obtained by varying the lower and upper limit by 50% of the base value (except the discount rate, which ranged from -10% to 10% in light of actual conditions in the real world) (Table VI). The surgeon's fee for surgical service refers to the labor costs of surgeons incurred by performing surgeries, and the daily hospitalization cost includes medications and bed and nursing charges. In addition, the implants included the locking compression plate (used in the ORIF group), titanium surgical screw (used in both groups) and rod (used in the MIS group). All the outcomes of sensitivity analyses are presented in Fig. 3A-F. It should be noted that the variations in each selected key variable did not affect the original conclusion within the sensitivity range, which means our results are robust to these changes.

Discussion

The incidence of pelvic ring injuries is estimated to be 19-37 per 100,000 people/year according to the published relevant literature (4) and has been reported to make up from 3 to 8% of all skeletal injuries (12). With the recent decades of rapid economic development and urban construction in China, pelvic fractures caused by motor vehicle accidents and industrial injuries in the workplace have gradually become more prevalent, which constitutes a major cause of death as well as economic burden on national healthcare in contemporary society (32).

The economic burden on patients with pelvic fracture injury is heavy, not only for the immediate reconstructive surgery but may also involve rehabilitation training or assisted living placement resulting from loss of functional status. Alessandro Aprato *et al* (30) reported that the median direct and indirect cost of pelvic fracture is €33,710 with the interquartile range from €23,266 to €51,012. They concluded that the most direct cost of pelvic fracture was accrued in the sector of surgical intervention, which amounted to a median of €8,279 with the interquartile range from €5,674 to €14,365. However, different surgical techniques are expected to result in different direct hospitalization costs. Johnsen *et al* (33) reported that the average direct medical cost of surgery for patients with

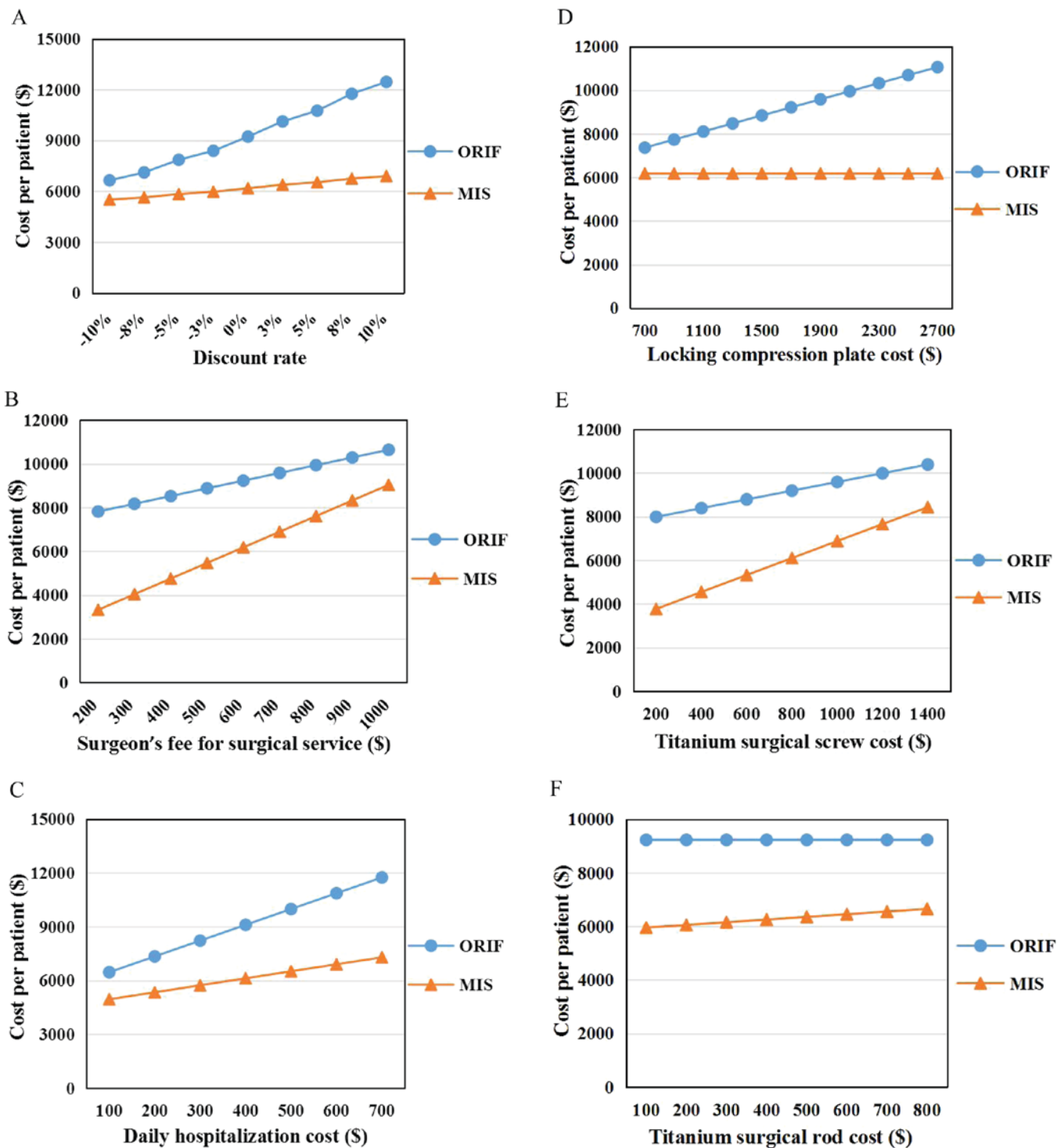


Figure 3. One-way sensitivity analyses of six selected variables on the cost comparison of ORIF and MIS. Selected variables include (A) discount rate; (B) surgeon's fee for surgical service; (C) daily hospitalization cost; (D) locking compression plate; (E) titanium surgical screw; and (F) titanium surgical rod. Lines labeled with blue dot represent ORIF; lines labeled with orange triangle represent MIS. ORIF, open reduction and internal fixation; MIS, minimally invasive surgery.

pelvic fracture urethral-disruption injuries varied from \$16,907 to \$19,925 with different surgical intervention strategies. As a consequence of the significant resources expended on the treatment of pelvic fracture injuries, the cost of various pelvic procedures should be evaluated comprehensively and systematically.

However, few previous studies have compared the cost effectiveness between different surgical treatment methods

for pelvic fracture injuries, and most of the existing research focused on the comparison of biomechanical characteristics and clinical outcomes in either the short or long term because surgeons are more concerned with clinical effect than the medical cost of a surgical technique (16,25,28). To the best of our knowledge, this is the first study to make an economic comparison between MIS and ORIF techniques for pelvic fracture from a cost-minimization perspective.

The selection of surgical technique plays either an extremely or very important role in direct medical cost for patients. In this study, we analyzed the inpatient hospital costs associated with the MIS and ORIF procedures thoroughly. The results are consistent with the initial hypothesis that the MIS is a more cost-effective alternative.

Patients in the MIS group had a shorter operation time, less intra-operative bleeding volume, smaller incision, and shorter post-operative length of stay than patients in the ORIF group. These clinical factors accounted for most of the difference in the hospitalization costs between the 2 groups and explained the higher total cost in the ORIF group compared with the MIS group.

For example, the shorter duration of surgery required a shorter anesthesia time, shorter occupation time of the operating room, and less workload for surgeons, which decreased the charge and cost of surgical services with a net difference of \$188.3 (\$1,003.7 for ORIF vs. \$815.4 for MIS). The MIS procedure is often associated with a significantly smaller incision. For these patients, the antibiotic consumption could be reduced significantly with a lower probability of surgical site infection, which leads to a lower cost of medication with a net difference of \$465.7 (\$1,112.1 for ORIF vs. \$646.4 for MIS). Less intra-operative bleeding volume definitely contributed to a lower cost of blood production for patients who were treated with MIS and the net difference was \$83.6. In addition, patients in the MIS group had a significantly shorter post-operative length of stay than those who were treated with open reduction surgery, which lowered the costs of ward-bed occupation as well as nursing care for the MIS group with a net difference of \$75.6 and \$83.0, respectively. Shortening the length of stay in the hospital can also effectively accelerate bed turnover and significantly improve the operating capacity.

It should be noted that the surgical implants can be rather expensive and always make up a large proportion of any orthopedics operation. In the current study, the cost of implants accounted for more than half of the total medical direct cost in both the ORIF (54.0%) and MIS (57.9%) group, and the proportion of the cost was similar. Specifically, 4 to 16 screws with 1 to 6 locking compression plates or reconstruction plates were used in an ORIF surgery; by comparison, 2 to 6 screws with a titanium or stainless steel rod were employed in a MIS. It is clear that the MIS procedure typically used fewer implants than the ORIF. The mean difference of implant cost between the 2 groups was relatively large at the amount of \$1,457.2, even though the difference was not statistically significant ($P=0.149$, Table V).

Although the differences of patients' clinical baseline characteristics between the 2 groups were not statistically significant in this study, the indication and contraindication of different surgical techniques are not identical. It is unlikely that all kinds of injury patterns of the pelvis could be treated successfully with only one universal surgical approach, and the optimal operative technique is still controversial. Therefore, the choice of surgical methods in practice should always depend on the specific condition of the patients. The ORIF is indicated for pure ligamentous pubic dislocations, parasymphseal, or ramii fractures, with plate fixation spanning the anterior column (23). Many surgeons prefer the ORIF because of its accurate reduction. Elzohairy and Salama (27)

reported that ORIF achieved an 80% rate of excellent and good reductions in a series of patients with unstable posterior pelvic-ring disruptions. Lindsay *et al* (22) reported that 57 out of 60 patients who had unilateral unstable pelvic-ring injuries and were treated with ORIF obtained excellent and good outcomes of reduction. With regard to the MIS procedure, the pedicle screw-rod fixator is based on the same principles as the 2 pin external fixator but is applied subcutaneously (25). It combines the advantages and avoids the disadvantages of ORIF and external fixation, and is often indicated for unstable unilateral or bilateral osseous and osseoligamentous injuries of the anterior pelvic ring associated with rotational or overall instability of the posterior segment of the pelvis. The pedicle screw-rod fixator is also indicated for unstable injuries of the anterior pelvic ring in morbidly obese patients and patients with severe soft tissue injuries (23).

The minimally invasive pedical screw-rod system for pelvic fracture fixation has been introduced and gradually been substituted for the traditional open reduction and internal fixation with plates since January 2014. Therefore, in the current study, the patients who were admitted to our hospital during the first half of the study period (from January 1, 2012 to December 31, 2013) were all treated by ORIF, while the other patients who were admitted during the second half of the study period (from January 1, 2014 to December 31, 2016) were all treated by MIS, which ensured that all patients were distributed in each group randomly and reduced the selection bias that could be introduced by surgeons' preferences for the surgical treatment of pelvic fractures.

This study focused on an individual large-scale general hospital rather than a sample of cases across the entire population in China. In order to minimize the selection bias, this study was based on a single surgical team who were experienced at performing both kinds of procedures. However, this could limit the generality of the results since the surgical technique levels of surgeons are varied, which could affect certain clinical parameters such as blood loss, operation time, postoperative pain, medical materials consumption, and length of hospital stay. All the factors mentioned above may have an impact on the total direct medical cost in a hospital, and any specific figure presented in this study should not be extrapolated directly to other areas. Thus, more samples from other medical centers with different MIS technique levels should be collected and analyzed in further studies.

The data of direct non-medical costs (such as the expenditure caused by transportation and food for patients and their family members during hospitalization) and indirect cost (especially the absenteeism caused by injury) were not considered. This was because of the heterogeneous socioeconomic levels of patients which may affect the reliability of the evaluation results as the sample size was relatively small. In addition, a larger sample size from different geographic areas with various social-economic levels should be involved.

This study was also limited by several factors inherent to the retrospective analysis, even though the nature of the retrospective method allowed us to match our cohorts based on patients' clinical baseline characteristics. In the current study, some data were collected retrospectively, which may have had an impact on the data completeness.

As a large-scale tertiary general hospital in Shanghai, China, patients admitted to our hospital were not only from the local area but also from across the nation, which made it a great challenge to collect follow-up data from all the patients and resulted in some missing data. A prospective evaluation with well documented follow-up records should be done in the future as part of the continuous optimization and improvement of the information management system in our hospital.

In addition, although the baseline characteristic differences between the 2 groups were not statistically significant, the criteria that we chose to reflect the severity of injury of patients with pelvic fracture did not include the Injury Severity Score (ISS) due to the limitations of our database. Therefore, American Society of Anesthesiologists (ASA) scores, fracture types classified by the Tile classification system, and a series of physiological indicators on admission which reflect associated injuries condition of patients were added to substitute for the value of ISS, which may have introduced some unknown confounding bias into this study.

Despite the limitations mentioned above, we believe that this study provides valuable references regarding cost-effectiveness between minimally invasive surgery (MIS) and open reduction and internal fixation (ORIF) surgery for patients with pelvic fracture.

In conclusion, In light of the concept of the biopsychosocial medical mode (34), treatment decisions should be made not only based on the clinical basis of an individual patient but also from an economic aspect. The results of this study illustrated that MIS performed by subcutaneous pedicle screw-rod fixator is a cost-minimizing surgical technique for pelvic injury compared with the technique of ORIF. Further thorough and systematic economic evaluations concerning the cost effectiveness analyses of other pelvic-surgery techniques are still required.

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Availability of data and materials

The data sets used or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

YZ designed the study. QW performed the pelvic surgery and provided the original data. YC collected data. LiM and LeM analyzed the data and wrote the manuscript. YJ was responsible for the statistical analysis and quality control of the original data. The final version of the manuscript was read and approved by all authors.

Ethics approval and consent to participate

The present study was approved by the Institutional Review Board of the Shanghai General Hospital affiliated to Shanghai Jiao Tong University (approval number: 2015KY155). The application of the exemption for informed consent was approved by the Ethics Committee of Shanghai General Hospital since the study did not involve any identifying information of patients.

Patient consent for publication

Not applicable.

Competing interests

All authors declare that they have no competing interests.

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