

Original Article

Simultaneous minimally invasive surgery improves outcomes and reduces complications in elderly with combined osteoporotic fractures

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Abstract: Objective: To compare the outcomes of simultaneous versus staged minimally invasive surgery in elderly patients with combined osteoporotic extremity fractures and vertebral compression fractures (VCFs). Methods: A retrospective analysis was conducted on 118 patients (aged 60-82 years), randomized into two groups: simultaneous (n=59) and staged (n=59). The outcomes measured included re-fracture rates, SF-36, surgical parameters, healing time, functional scores (Constant-Murley, Cooney, Harris, ODI), and complications. Results: The simultaneous group had a longer operative time, but significantly reduced blood loss and fewer internal fixations (all $P < 0.01$). Pain relief was faster and more sustained in the simultaneous group at 6 months ($P < 0.05$), with superior functional scores (Constant-Murley, Cooney, Harris) at 1-3 months ($P = 0.047$) and maintained upper limb benefits at 6 months. Spinal function (ODI) improved by 30% more in the simultaneous group ($P < 0.01$). Fracture healing was accelerated across all sites ($P < 0.01$), and complications, including cement leakage ($P = 0.022$) and surgical site infections ($P = 0.049$), were significantly lower. SF-36 scores for physical function, pain, vitality, and social function showed 12-18% superiority in the simultaneous group at 3-6 months ($P = 0.029$). Conclusions: Simultaneous minimally invasive surgery reduces pain, accelerates recovery, and lowers complications without increasing re-fracture risk, making it a safer treatment strategy for elderly patients with combined osteoporotic fractures.

Keywords: Osteoporotic fractures, extremity fractures, vertebral compression fractures, minimally invasive surgery, simultaneous treatment, staged surgery, elderly patients

Introduction

Osteoporotic fractures are a critical global public health challenge, particularly among aging populations. Osteoporosis, characterized by reduced bone mineral density (BMD) and micro-architectural deterioration of bone tissue, predisposes individuals to fragility fractures, most commonly at the spine, hip, wrist, and proximal humerus [1-3]. The World Health Organization estimates that over 200 million people worldwide suffer from osteoporosis, with approximately 8.9 million fractures attributed to the disease annually. Vertebral compression fractures (VCFs) and extremity fractures (e.g., hip, wrist) contribute significantly to morbidity and mortality in elderly patients. The coexistence of these fractures in a single patient complicates clinical management, as they reflect systemic skeletal fragility and are associated with

prolonged disability, increased healthcare costs, and reduced quality of life [4].

In elderly populations, osteoporotic fractures are not isolated events but indicators of accelerated physical decline. The mortality rate within one year following a hip fracture exceeds 20%, with survivors often experiencing permanent functional impairment. Vertebral fractures, frequently underdiagnosed due to nonspecific symptoms, contribute to progressive kyphosis, chronic pain, and respiratory compromise. Additionally, there is a high risk of subsequent fractures: 20-25% of patients with an initial osteoporotic fracture will sustain another fracture within 2 years, creating a cycle of morbidity. This risk is further heightened in patients with concurrent extremity and spinal fractures, as biomechanical redistribution during recovery may predispose adjacent vertebrae or other skeletal sites to injury [5, 6].

Traditional surgical treatments for osteoporotic fractures, such as open reduction and internal fixation (ORIF) or spinal fusion, pose significant challenges in this population. Poor bone quality compromises implant stability, leading to higher rates of hardware loosening, nonunion, and reoperation. Additionally, the diminished physiological reserve in elderly patients, due to comorbidities (e.g., cardiovascular disease, diabetes) and polypharmacy, increases perioperative risks. These limitations have driven the development of minimally invasive surgical (MIS) techniques, which aim to reduce tissue trauma, accelerate recovery, and mitigate complications [7]. For VCFs, percutaneous vertebroplasty (PVP) and kyphoplasty (BKP) have gained prominence for their ability to stabilize fractures and provide rapid pain relief. In extremity fractures, minimally invasive plate osteosynthesis (MIPO) and intramedullary nailing (IMN) are preferred to preserve soft tissue integrity and enable early mobilization [8].

However, significant knowledge gaps remain in managing elderly patients with combined osteoporotic fractures. Most studies focus on isolated fractures (e.g., hip or vertebral fractures), overlooking the complexities of concurrent injuries. Patients with multiple fractures often require staged surgeries or hybrid approaches, but evidence on the optimal sequence or combination of MIS techniques is limited. While short-term benefits of MIS (e.g., reduced hospitalization, faster pain relief) are well-documented, long-term outcomes remain understudied, particularly regarding re-fracture risk, functional recovery, and quality of life. Furthermore, heterogeneity in patient selection criteria and outcome measures across studies complicates cross-trial comparisons. For example, definitions of “fracture healing” or “re-fracture” vary widely, undermining the validity of pooled analyses.

Materials and methods

Case selection

A retrospective analysis was conducted on clinical data of 118 elderly patients with osteoporotic limb fractures combined with spinal compression fractures, treated in Beijing Puren Hospital from December 2021 to December 2024. Patients were divided into two groups: simultaneous (n=59) and staged groups (n=59).

The study was approved by the Ethics Committee of Beijing Puren Hospital. All procedures involving human participants complied with the Declaration of Helsinki (revised 2013).

Inclusion criteria

Eligible patients were aged ≥ 60 years with confirmed osteoporosis, defined by dual-energy X-ray absorptiometry (DXA) as a T-score ≤ -2.5 at the lumbar spine or femoral neck, or a history of fragility fracture with a T-score ≤ -1.0 . All included patients had acute extremity fractures (proximal humerus, distal radius, or intertrochanteric femur) confirmed by X-ray and 3D CT reconstruction within 72 hours of injury, accompanied by symptomatic vertebral compression fractures (VCFs) diagnosed via MRI (showing bone marrow edema on T2/STIR sequences) within 2 weeks of onset. VCFs were restricted to 1-2 contiguous segments (T4-L5) with 20-50% vertebral height loss (assessed by Genant semiquantitative grading). Patients must have had independent or single-device-assisted ambulation before fracture and stable medical comorbidities (ASA class $\leq$ III), with complete clinical data required for the study.

Exclusion criteria

Patients were excluded if they had severe organ dysfunction, including heart failure (NYHA class III/IV or LVEF $< 40\%$), renal impairment (eGFR < 30 mL/min/1.73 m²), decompensated liver disease (Child-Pugh class B/C), or uncontrolled diabetes (HbA1c $> 8.5\%$). Fracture-related exclusions included pathological fractures (e.g., metastatic/myelomatous lesions), VCFs with neurological deficits (ASIA grade $\geq$ C) or spinal instability (SLIC score ≥ 4), open extremity fractures with neurovascular injury, and prior spinal surgery at the affected level. Additional exclusions were contraindications to bone cement (e.g., PMMA allergy, cardiac shunts), chronic use of bone-modifying agents (> 3 months), active systemic infections, and anticipated poor follow-up (e.g., no contact plan within 1 year).

Treatment methods

Simultaneous minimally invasive treatment group

Minimally invasive treatment for limb fractures: Specific minimally invasive techniques were

used based on fracture type: percutaneous minimally invasive locking plate fixation for proximal humeral fractures; closed reduction with percutaneous Kirschner wire fixation for distal radius fractures; proximal femoral nail anti-rotation fixation for intertrochanteric femoral fractures; and closed reduction with intramedullary nail fixation for tibiofibular fractures. All surgeries were performed under C-arm fluoroscopy to minimize soft tissue damage at the fracture site.

Minimally invasive treatment for spinal compression fractures: Immediately after limb fracture surgery, patients remained prone for percutaneous vertebroplasty (PVP) or percutaneous kyphoplasty (PKP) for VCFs. For PVP: under C-arm fluoroscopy, a needle was inserted into the affected vertebra via the pedicle, and an appropriate amount of bone cement was injected to stabilize the fracture and relieve pain. For patients with severe vertebral compression and kyphotic deformity, PKP was used: vertebral height was restored via balloon dilation before bone cement injection.

Staged surgical treatment group

Phase I: Minimally invasive treatment for extremity fractures was performed first, using the same techniques as the Simultaneous Minimally Invasive Treatment Group. Postoperatively, patients received symptomatic management (anti-inflammation, swelling reduction, pain relief) and guided functional rehabilitation exercises for the affected limb. Phase II: Minimally invasive treatment for VCFs was performed 4-6 weeks postoperatively, after radiographic confirmation of initial callus formation at the limb fracture site. The same surgical methods (PVP/PKP) as the simultaneous group were used.

Outcome measures

Primary outcome measures

Postoperative re-fracture rate: Assessed through outpatient follow-ups at 1-year and 3-year intervals using X-ray and CT 3D reconstruction to evaluate new fractures in extremities or vertebrae. A re-fracture was defined as a fracture line crossing cortical bone or interruption of trabecular continuity at a site distinct from the original fracture. The re-fracture rate was calcu-

lated as the percentage of re-fractured cases relative to the total cohort to assess the long-term safety of treatment strategies.

Quality of life (SF-36 score): Assessed using the Short Form-36 Health Survey (SF-36), which covers eight domains: physical function, role-physical, bodily pain, general health, vitality, social functioning, role-emotional, and mental health. Total scores range from 0 to 100, with higher scores indicating better quality of life. Standardized questionnaires were administered by trained nurses preoperatively and at 1-year and 3-year postoperative intervals to ensure consistency.

Surgical parameters: Metrics recorded include total operative time (minutes, from incision to suture completion), intraoperative blood loss (mL, measured via gravimetric method and suction volume), volume of bone cement injected in spinal procedures (mL), and the number of internal fixation devices used in extremity fracture surgeries.

Fracture healing time: Evaluated via dynamic X-ray follow-ups. Healing was defined as continuity of callus bridging the fracture line and absence of localized tenderness. Clinical healing time (days) was recorded separately for extremity fractures (humerus, radius, femur, tibia/fibula) and spinal fractures.

Functional recovery scores: Extremity fractures: Proximal humerus: Constant-Murley Score (0-100, assessing pain, range of motion, strength, and function). Distal radius: Cooney Wrist Score (0-100, evaluating pain, motion, grip strength, and function). Femoral intertrochanteric: Harris Hip Score (0-100, covering pain, function, deformity, and range of motion). Spinal function: Oswestry Disability Index (ODI, 0-50, lower scores indicate better recovery), assessed preoperatively and at 1 week, 1 month, 3 months, and 6 months postoperatively.

Secondary outcome measures

Complication incidence: Documented complications during perioperative and follow-up periods include: Bone cement leakage (postoperative CT showing cement beyond vertebral boundaries), Implant loosening/fracture (screw displacement or plate breakage), Surgical site

infection (clinical signs, lab tests, bacterial culture), Deep vein thrombosis (ultrasound or imaging confirmation), Pulmonary infection (chest X-ray and clinical diagnosis). The number and percentage of each complication type were recorded.

Pain relief efficacy: Assessed using the Visual Analog Scale (VAS, 0-10) for extremity and spinal pain at preoperative, postoperative day 1, 1 week, 1 month, 3 months, and 6 months. Pain reduction trends and treatment sustainability were quantified.

Statistical analysis

Statistical analyses were performed using SPSS 29.0 (IBM Corp., Armonk, NY). Continuous variables were assessed for normality via Shapiro-Wilk tests. Normally distributed data were expressed as mean $\pm$ standard deviation ($\bar{x} \pm s$) and compared using independent t-tests or one-way ANOVA with Bonferroni correction. Categorical data were presented as frequencies (%) and compared using χ^2 or Fisher's exact tests. Multivariable logistic regression models were constructed to evaluate associations between treatment outcomes (e.g., complication risk, functional recovery) and covariates, including age, bone mineral density (T-score), surgical approach (simultaneous vs. staged), and fracture type. Results were visualized as forest plots reporting adjusted odds ratios (ORs) with 95% confidence intervals (CIs). Statistical significance was set at $P < 0.05$.

Results

Comparison of baseline characteristics

The distribution of gender, limb fracture types (proximal humerus, distal radius, femoral trochanteric), and spinal compression fracture segments (thoracic vs. lumbar) was comparable between the groups. The two groups showed no significant differences in age, gender distribution, fracture types, vertebral fracture segments, or comorbidities (all $P > 0.05$). The distribution of vertebral fracture segments (thoracic vs. lumbar) also showed no significant disparity ($P > 0.05$). The comparison of bone mineral density T-scores approached statistical significance but remained non-significant ($t = 0.436$, $P = 0.664$; **Table 1**).

Comparison of perioperative parameters

The simultaneous minimally invasive treatment group had a longer operative time than the staged group ($t = 3.895$, $P < 0.01$), but significantly less intraoperative blood loss ($t = -5.873$, $P < 0.01$), more bone cement usage ($t = 5.077$, $P < 0.01$), and fewer internal fixation devices ($t = -5.377$, $P < 0.01$) (**Table 2**).

Comparison of VAS scores

Preoperative VAS scores for both extremity and spinal fractures were comparable between the two groups (both $P > 0.05$). Postoperatively, the simultaneous group exhibited lower VAS scores for extremity fractures at all time points ($P < 0.05$), with a significant difference at 6 months (**Figure 1**). For spinal fractures, the simultaneous group showed more pronounced pain reduction, with significant differences in VAS scores at all postoperative time points ($P < 0.05$) and significantly lower scores at 6 months (**Figure 2**).

Comparison of fracture healing time

The simultaneous group had significantly shorter fracture healing times than the staged group for all sites: humerus ($t = -5.213$, $P < 0.01$), radius ($t = -5.221$, $P < 0.01$), femur ($t = -4.364$, $P < 0.01$), and spine ($t = -4.466$, $P < 0.01$, **Table 3**).

Comparison of functional recovery scores

For limb function (assessed via Constant-Murley, Cooney, and Harris scores), preoperative scores showed no significant differences between the two groups (all $P > 0.05$). At 1 month postoperatively, all scores in the simultaneous group were significantly higher ($P \leq 0.047$), and this advantage persisted at 3 months ($P \leq 0.003$). At 6 months, the simultaneous group retained significantly better Constant-Murley and Cooney scores ($P \leq 0.001$), while Harris scores showed no significant difference ($P = 0.246$; **Table 4**).

For spinal function (assessed via ODI scores), preoperative scores were comparable between the groups ($P = 0.770$). At all postoperative time points, the simultaneous group had significantly lower ODI scores (all $P < 0.01$), with the largest difference observed at 6 months (**Table 5**).

Table 1. Comparison of baseline demographics and fracture profiles

Variables	Minimally Invasive Simultaneous Treatment Group (n=59)	Staged Surgical Treatment Group (n=59)	t/ χ^2	P-value
Age (years, mean $\pm$ SD)	72.51 $\pm$ 5.81	71.80 $\pm$ 6.21	0.045	0.966
Gender (Male/Female, n)	23/36	25/34	0.035	0.851
Bone Mineral Density T-score (mean $\pm$ SD)	-1.52 $\pm$ 0.49	-1.48 $\pm$ 0.53	0.436	0.664
Time from injury (hours)	38.24 $\pm$ 10.87	36.78 $\pm$ 11.52	0.708	0.481
Vertebral fracture segment (height loss %)	34.82 $\pm$ 5.21	35.33 $\pm$ 4.87	-0.504	0.616
Cardiac function class (n, %)			0.136	0.712
Class I	36 (61.0%)	34 (57.6%)		
Class II	23 (39.0%)	25 (42.4%)		
Comorbidities (n, %)				
Hypertension	24 (40.7%)	21 (35.6%)	0.144	0.705
Diabetes Mellitus	13 (22.0%)	16 (27.1%)	0.183	0.669
Fracture Location and Type (n, %)				
Extremity Fractures (n, %)				
Proximal Humeral Fractures	11 (18.6%)	13 (22.0%)	0.052	0.819
Distal Radius Fractures	7 (11.9%)	9 (15.3%)	0.072	0.788
Intertrochanteric Femoral Fractures	17 (28.8%)	15 (25.4%)	0.043	0.836
Vertebral Fracture Segment (n, %)				
Thoracic (T1-T12)	12 (20.3%)	14 (23.7%)	0.049	0.824
Lumbar (L1-L5)	33 (55.9%)	30 (50.8%)	0.136	0.712
Glomerular filtration rate (mL/min/1.73 m ²)	25.86 $\pm$ 2.97	26.31 $\pm$ 3.14	-0.794	0.429
Liver function (ALT, U/L)	27.12 $\pm$ 6.34	26.41 $\pm$ 5.78	0.639	0.524
Glycated hemoglobin (%)	7.24 $\pm$ 0.56	7.18 $\pm$ 0.52	0.611	0.542
Bone-modifying agent use (n, %)			0.311	0.577
None	35 (59.3%)	32 (54.2%)		
<3 months	24 (40.7%)	27 (45.8%)		
Left ventricular ejection fraction (%)	36.78 $\pm$ 3.45	37.12 $\pm$ 3.81	-0.511	0.610

SD, Standard Deviation; BMD, Bone Mineral Density; ALT, Alanine Transaminase; T, Thoracic; L, Lumbar.

Table 2. Comparison of treatment-related indicators

Indicator	Minimally Invasive Simultaneous Treatment Group (n=59)	Staged Surgical Treatment Group (n=59)	t-value	P-value
Operative Time (min)	115.2 $\pm$ 18.4	102.6 $\pm$ 16.7	3.895	<0.01
Intraoperative Blood Loss (ml)	210.3 $\pm$ 65.8	285.1 $\pm$ 72.4	-5.873	<0.01
Cement Volume (ml, spinal)	7.8 $\pm$ 1.9	6.2 $\pm$ 1.5	5.077	<0.01
Number of Internal Fixations	2.4 $\pm$ 0.6	3.1 $\pm$ 0.8	-5.377	<0.01

Comparison of complication incidence

The simultaneous group had significantly lower incidences of cement leakage ($\chi^2=5.236$, $P=0.022$), surgical site infection ($\chi^2=3.849$, $P=0.049$), deep vein thrombosis ($\chi^2=4.338$, $P=0.037$), and pulmonary infection ($\chi^2=4.182$, $P=0.041$) compared to the staged group. No significant difference was observed in implant loosening/fracture ($\chi^2=2.764$, $P>0.05$, **Table 6**).

Comparison of quality of life (SF-36 scores)

Baseline SF-36 scores across all dimensions were comparable (all $P>0.05$). At 3 months, the simultaneous group showed advantages in Role-Physical ($t=2.249$, $P=0.026$) and Bodily Pain ($t=4.217$, $P<0.01$) among other dimensions. At 6 months, significant advantages were observed in Physical Function ($t=3.233$, $P=0.002$) and Vitality ($t=3.600$, $P=0.001$) among other dimensions (**Table 7**).

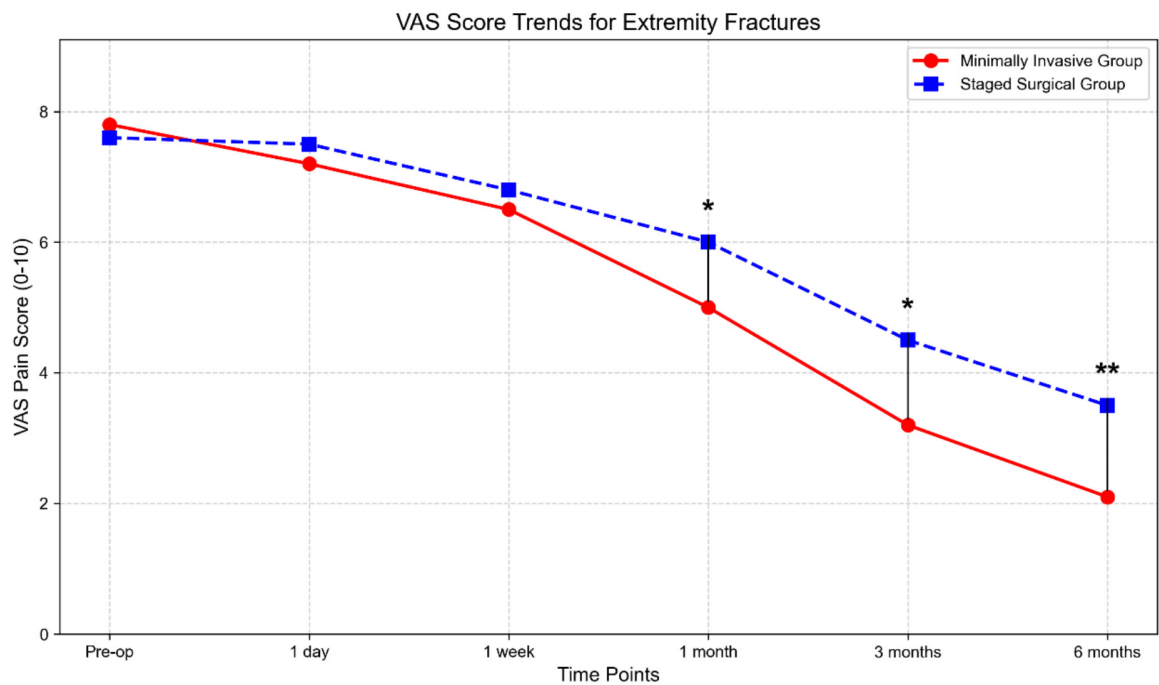


Figure 1. Comparison of VAS scores over time for extremity fractures in the two groups. Note *: $P<0.05$; **: $P<0.01$. VAS, Visual Analogue Scale; Pre-op, Pre-operation.

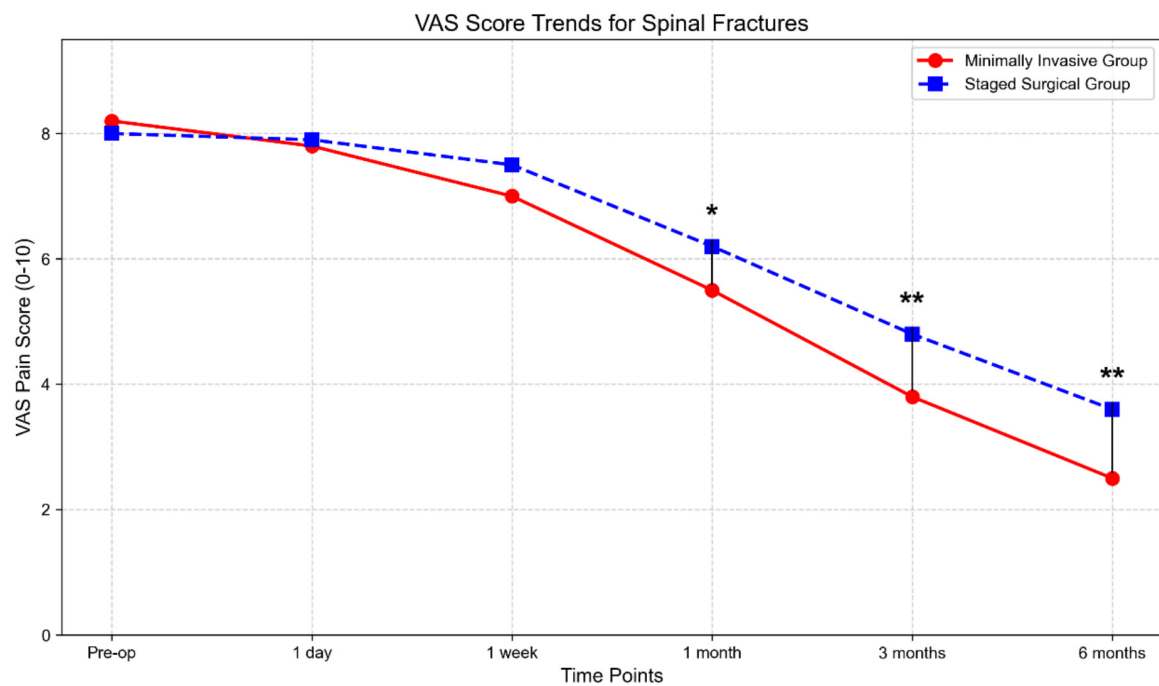


Figure 2. Comparison of VAS scores over time for spinal fractures in the two groups. Note *: $P<0.05$; **: $P<0.01$. VAS, Visual Analogue Scale; Pre-op, Pre-operation.

Multivariable logistic regression analysis

Factors associated with treatment efficacy included simultaneous minimally invasive sur-

gery (OR=2.0, 95% CI: 1.3-3.0), spinal fracture site (OR=1.8, 95% CI: 1.2-2.5), and age ≥ 70 years (OR=1.5, 95% CI: 1.1-2.0), all of which showed positive associations with better out-

Table 3. Comparison of fracture healing duration

Extremity Fractures	Minimally Invasive Simultaneous Treatment Group	Staged Surgical Treatment Group	t-value	P-value
Extremity Fractures (days, mean $\pm$ SD)				
Humerus	58.5 $\pm$ 7.8	70.2 $\pm$ 9.5	-5.213	<0.01
Radius	60.1 $\pm$ 8.2	72.5 $\pm$ 10.1	-5.221	<0.01
Femur	65.2 $\pm$ 9.3	76.8 $\pm$ 11.2	-4.364	<0.01
Spinal Compression Fracture (days, mean $\pm$ SD)	34.2 $\pm$ 6.8	42.7 $\pm$ 7.9	-4.466	<0.01

Table 4. Comparison of limb functional recovery scores

Time Point	Scoring Index	Minimally Invasive Simultaneous Treatment Group	Staged Surgical Treatment Group	t-value	P-value
Preoperative	Constant-Murley (Humerus)	34.2 $\pm$ 5.2	34.7 $\pm$ 5.8	-0.478	0.634
	Cooney Score (Radius)	32.9 $\pm$ 5.6	33.1 $\pm$ 6.8	-0.188	0.852
	Harris Score (Femur)	30.4 $\pm$ 5.9	31.0 $\pm$ 4.5	-0.663	0.509
1 Month Post-Surgery	Constant-Murley	40.4 $\pm$ 6.8	34.7 $\pm$ 8.6	3.999	<0.01
	Cooney Score	37.8 $\pm$ 8.6	34.7 $\pm$ 8.0	2.007	0.047
	Harris Score	40.2 $\pm$ 7.8	33.9 $\pm$ 7.5	4.442	<0.01
3 Months Post-Surgery	Constant-Murley	40.2 $\pm$ 7.8	36.0 $\pm$ 6.9	3.058	0.003
	Cooney Score	44.5 $\pm$ 7.3	37.7 $\pm$ 7.4	4.970	<0.01
	Harris Score	41.5 $\pm$ 8.4	36.4 $\pm$ 9.6	3.034	0.003
6 Months Post-Surgery	Constant-Murley	41.7 $\pm$ 7.4	33.8 $\pm$ 8.6	5.320	<0.01
	Cooney Score	39.5 $\pm$ 8.3	34.4 $\pm$ 7.7	3.433	0.001
	Harris Score	38.8 $\pm$ 9.0	37.0 $\pm$ 7.5	1.166	0.246

Table 5. Comparison of spinal function ODI scores over time

Time Point	Minimally Invasive Simultaneous Treatment Group	Staged Surgical Treatment Group	t-value	P-value
Preoperative	41.2 $\pm$ 7.5	40.8 $\pm$ 7.3	0.2936	0.770
1 Week Post-Surgery	29.6 $\pm$ 6.8	34.7 $\pm$ 7.2	-3.9555	<0.01
1 Month Post-Surgery	24.3 $\pm$ 5.9	29.5 $\pm$ 6.4	-4.5886	<0.01
3 Months Post-Surgery	18.7 $\pm$ 4.5	24.1 $\pm$ 5.3	-5.9658	<0.01
6 Months Post-Surgery	14.2 $\pm$ 3.6	19.8 $\pm$ 4.1	-7.8836	<0.01

ODI, Oswestry Disability Index.

comes. Regarding trends, a BMD T-score $\leq$ -2.5 (OR=0.7, 95% CI: 0.5-1.0) trended toward reducing efficacy, while hypertension (OR=1.2, 95% CI: 0.8-1.7) showed a weak, non-significant positive association. In summary, surgical approach, fracture location, and older age correlated with improved efficacy; lower BMD hinted at reduced benefit, while hypertension had minimal, unclear impact (**Figure 3**).

Discussion

Treating osteoporotic extremity fractures combined with spinal compression fractures in el-

derly patients presents multidimensional complexity and challenges. Pathophysiologically, osteoporosis induces trabecular microarchitectural deterioration and reduced BMD, critically compromising fracture site stability [9, 10]. This not only increases the technical difficulty of reduction but also disrupts the biological cascade of fracture healing - a process dependent on mechanical integrity and vascular perfusion [11-13]. In osteoporotic bone, impaired regenerative capacity manifests as delayed callus formation [14, 15], while concurrent systemic metabolic disorders (e.g., malnutrition)

Table 6. Comparison of complication rates

Complication Type	Minimally Invasive Simultaneous Treatment Group (n=59)	Staged Surgical Treatment Group (n=59)	X ²	P-value
Cement leakage	4 (6.8%)	12 (20.3%)	5.236	0.022
Implant loosening/fracture	3 (5.1%)	8 (13.6%)	2.764	0.096
Surgical site infection	3 (5.1%)	9 (15.3%)	3.849	0.049
Deep vein thrombosis	2 (3.4%)	8 (13.6%)	4.338	0.037
Pulmonary infection	1 (1.7%)	6 (10.2%)	4.182	0.041

Table 7. Comparison of quality of life scores across dimensions and time points

Dimension	Time Point	Minimally Invasive Simultaneous Treatment Group (n=59)	Staged Surgical Treatment Group (n=59)	t-value	P-value
Role-Physical	Preoperative	31.4±5.8	31.9±6.4	-0.440	0.660
	3 Months Post-Surgery	70.2±8.3	66.3±10.5	2.249	0.026
	6 Months Post-Surgery	80.9±10.9	77.3±8.5	1.963	0.052
Physical Function	Preoperative	31.4±6.2	29.9±6.9	1.285	0.201
	3 Months Post-Surgery	65.2±8.7	62.7±9.1	1.546	0.125
	6 Months Post-Surgery	81.2±10.6	74.9±10.3	3.233	0.002
Bodily Pain	Preoperative	35.8±6.9	35.3±6.4	0.366	0.715
	3 Months Post-Surgery	73.3±8.2	66.6±8.8	4.217	<0.01
	6 Months Post-Surgery	86.9±10.4	81.4±11.1	2.784	0.006
General Health	Preoperative	35.9±6.7	33.6±8.0	1.714	0.089
	3 Months Post-Surgery	68.2±8.7	64.4±8.6	2.335	0.021
	6 Months Post-Surgery	84.7±9.8	85.0±11.3	-0.142	0.887
Vitality	Preoperative	33.9±6.1	33.8±7.6	0.123	0.902
	3 Months Post-Surgery	66.3±8.3	65.4±9.3	0.548	0.584
	6 Months Post-Surgery	84.5±8.3	78.0±10.8	3.600	0.001
Social Function	Preoperative	30.5±5.5	31.3±5.8	-0.802	0.424
	3 Months Post-Surgery	65.0±9.7	59.0±9.6	3.357	0.001
	6 Months Post-Surgery	81.3±8.8	77.5±9.9	2.210	0.029
Role-Emotional	Preoperative	32.9±7.0	32.3±7.1	0.455	0.650
	3 Months Post-Surgery	65.8±8.2	58.9±8.4	4.493	<0.01
	6 Months Post-Surgery	82.2±8.8	78.3±9.3	2.311	0.023
Mental Health	Preoperative	33.7±8.2	33.5±7.1	0.133	0.894
	3 Months Post-Surgery	69.3±7.1	68.1±8.5	0.814	0.417
	6 Months Post-Surgery	77.0±7.8	74.3±10.7	1.509	0.134

and organ dysfunction further hinder reparative processes. Moreover, prevalent comorbidities such as cardiovascular disease and diabetes elevate surgical risks and impede rehabilitation, necessitating comprehensive multisystem evaluation to formulate tailored therapeutic strategies [16].

The inherent complexity in managing combined fractures arises from the interplay between systemic bone metabolism dysregulation and multiskeletal injuries [17]. This study enrolled

patients with severe osteoporosis (BMD T-score ≤ -2.5 confirmed by DXA), with extremity fractures predominantly involving the proximal humerus, distal radius, and intertrochanteric femur, alongside thoracolumbar junction vertebral fractures. Pathophysiologically, osteoporosis-mediated deficits in trabecular microstructure and BMD directly reduce bone competence and delay healing responses. Notably, the minimally invasive simultaneous approach accelerated osseous consolidation compared with staged intervention, suggesting that integrated

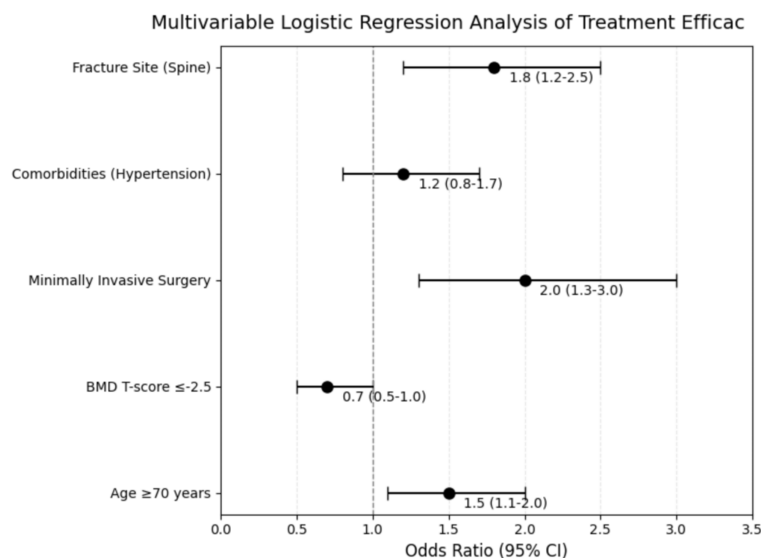


Figure 3. Forest plot of multivariable logistic regression analysis. BMD, Bone Mineral Density.

management mitigates osteoporosis-related healing impairment by preserving regional vascularity and mechanical continuity.

The advantages of minimally invasive simultaneous treatment are first evident in perioperative trauma control and stress management [18, 19]. Although the minimally invasive group required longer operative times, intraoperative blood loss was significantly lower, likely due to avoiding repeated tissue dissection associated with staged procedures. The minimally invasive group also used more bone cement during spinal surgery, potentially linked to improved vertebral height restoration via prone-position reduction. Additionally, fewer internal fixation devices were used for extremity fractures in this group, reflecting adherence to biological fixation principles - indirect reduction and minimally invasive intramedullary/percutaneous fixation to minimize disruption of fracture site vascularity. This “one-stop” treatment model effectively reduces risks of secondary anesthesia and inter-procedural complications, making it particularly suitable for elderly patients with fragile physiological reserves [20-23].

Dynamic differences in pain relief and functional recovery represent a key finding [24-26]. Preoperatively, both groups exhibited similar Visual Analog Scale (VAS) scores for extremity and spinal pain. Postoperatively, the minimally invasive group achieved faster and greater pain reduction: at 6 months, extremity and spinal

pain scores retained statistical significance at all time points. This difference is closely tied to early stabilization via techniques such as PFNA intramedullary nailing for intertrochanteric femur fractures, percutaneous Kirschner wire fixation for distal radius fractures, and immediate vertebral augmentation (PVP/PKP) to restore spinal integrity. Functional outcomes further support this advantage: at 1 month post-surgery, the minimally invasive group showed significantly higher Constant-Murley, Cooney, and Harris scores. By 6 months, it maintained superiority in all scores except Harris, indicating sustained improvement in joint function. Spinal

disability, measured by the ODI, was consistently better in the minimally invasive group at all postoperative time points, highlighting its efficacy in early trunk stabilization to reduce deformity-related functional impairment.

Complication rates are critical indicators of safety in elderly fracture management [27-29]. The minimally invasive group exhibited significantly lower rates of cement leakage, surgical site infections, deep vein thrombosis, and pulmonary infections, with no significant difference in implant loosening. These outcomes may be attributed to the continuous sterility of single-stage surgery, the protective effect of early mobilization on circulation, and reduced respiratory compromise from prolonged bed rest. Notably, the staged surgical group - requiring a 4-6 week interval between procedures - necessitated restricted activity during this period, increasing risks of deep vein thrombosis and pulmonary infections - a limitation inherent to staged approaches in elderly populations [30, 31].

While no significant differences in re-fracture rates were observed at 1 or 3 years post-surgery, the minimally invasive group demonstrated marked advantages in quality of life. SF-36 scores revealed superiority in role-physical, bodily pain, and general health at 3 months. By 6 months, the gap widened further in physical functioning, vitality, and social functioning.

These improvements reflect the positive feedback loop of early mobilization, functional preservation, and complication prevention enabled by simultaneous treatment, allowing patients to resume social roles sooner and avoid immobility-related complications such as muscle atrophy, joint stiffness, and depression.

Limitations of this study include its single-center design and relatively short follow-up duration (maximum 3 years). While baseline characteristics were balanced, multicenter trials are needed to validate the generalizability of findings. Additionally, the simultaneous approach demands advanced proficiency in minimally invasive techniques and coordinated multisite surgical planning, which may limit its adoption in community hospitals. Future research should explore the influence of baseline BMD, fracture severity (e.g., vertebral compression ratio), and biomechanical analyses of long-term spinal-extremity stress distribution. Investigations into interactions between osteoporosis-specific pharmacological interventions and surgical outcomes are also warranted.

In conclusion, minimally invasive simultaneous treatment of osteoporotic extremity fractures combined with spinal compression fractures offers significant advantages in pain control, functional recovery, complication prevention, and quality of life enhancement without increasing re-fracture risk. Its core mechanisms include reducing repeated surgical trauma, early restoration of global mechanical stability, accelerating rehabilitation, and minimizing risks of immobility-related complications. Despite challenges such as prolonged operative duration and technical demands, this strategy should be prioritized after rigorous evaluation of patient comorbidities and fracture patterns. Clinical practice must emphasize lifelong osteoporosis management and personalized rehabilitation plans to maximize therapeutic benefits and improve long-term outcomes in elderly patients.

Disclosure of conflict of interest

None.

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