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Research Article

Assessment of the Efficacy of Bisphosphonates and Teriparatide Treatment on Lumbar Spine Fusion Surgery Outcomes

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ABSTRACT

Objective: To compare the efficacy of bisphosphonate and teriparatide therapy in improving radiological fusion and clinical outcomes among patients undergoing lumbar spine fusion surgery.

Methods: A comparative cohort study was conducted at Bahria International Hospital Rawalpindi Pakistan from January 2026 to June 2026. Ninety patients undergoing instrumented lumbar spinal fusion surgery were included. Forty-five patients received teriparatide and 45 patients received bisphosphonate therapy. Radiological fusion, postoperative pain, functional disability and postoperative mechanical complications were evaluated. Multivariable logistic regression was used to identify independent predictors of successful fusion.

Results: Fusion at three months was observed in 53.3% of the teriparatide group and 28.9% of the bisphosphonate group. At six months, fusion was achieved in 86.7% and 64.4% respectively. Mean time to fusion was shorter with teriparatide. Greater reductions in visual analogue scale and Oswestry Disability Index scores were also observed with teriparatide. Mechanical complications occurred in 13.3% of patients receiving teriparatide compared with 35.6% receiving bisphosphonates. Teriparatide remained independently associated with successful lumbar spinal fusion.

Conclusion: Teriparatide was associated with faster fusion, better functional recovery and fewer mechanical complications than bisphosphonate therapy following lumbar spinal fusion surgery.

Keywords: Teriparatide, Bisphosphonates, Spinal Fusion, Osteoporosis, Lumbar Vertebrae, Bone Remodeling.

INTRODUCTION

Lumbar spinal fusion surgery has been widely used for the management of degenerative lumbar spine disorders that are associated with instability, deformity, persistent pain or neurological compromise. Successful fusion is dependent on the formation of a stable osseous bridge between adjacent vertebral segments. Adequate bone quality has therefore been recognized as an important determinant of postoperative outcome. Osteoporosis has increasingly been encountered among patients who require lumbar spinal fusion because many candidates for spinal surgery belong to older age groups. Reduced bone mineral density (BMD) has been associated with delayed spinal fusion, implant loosening, cage subsidence, vertebral fracture and the need for revision surgery. These complications may reduce the expected benefit of operative treatment and may prolong rehabilitation. Pharmacological improvement of skeletal strength has therefore been considered an important component of perioperative management in patients with poor bone quality. [1]

Bisphosphonates have been widely prescribed for the management of osteoporosis. Their principal action is produced through inhibition of osteoclast mediated bone resorption. Bone turnover is therefore reduced and progressive loss of bone mass is limited. Agents such as alendronate, risedronate and zoledronic acid have been used in routine clinical practice because significant reductions in osteoporotic fracture risk have been demonstrated. Their use after lumbar spinal fusion has attracted considerable interest because concern has traditionally been raised that suppression of bone remodeling could interfere with the biological process required for spinal fusion. However protective effects against vertebral collapse, screw loosening and cage subsidence

have also been reported. The balance between reduced bone resorption and preservation of fusion capacity remains clinically important when postoperative osteoporosis treatment is being selected. [2]

The effect of bisphosphonate therapy on spinal fusion has remained debated. Concerns have been based on the possibility that reduced osteoclastic activity may interfere with normal bone remodeling during graft incorporation. Early experimental observations created uncertainty regarding whether antiresorptive therapy should be continued after spinal fusion surgery. More recent clinical evidence has suggested that spinal fusion may not be substantially impaired by bisphosphonate use. Benefits involving reduced postoperative vertebral fracture and decreased cage subsidence have also been observed. A lower frequency of pedicle screw loosening has been suggested in several clinical settings. These findings indicate that bisphosphonates may offer mechanical protection even when their effect on the speed of fusion is limited. The clinical significance of these effects continues to require comparison with anabolic treatment.[3]

Teriparatide represents a different therapeutic strategy because bone formation is stimulated rather than bone resorption being primarily inhibited. Teriparatide is a recombinant form of parathyroid hormone that produces an anabolic skeletal response when administered intermittently. Increased osteoblastic activity is promoted and trabecular microarchitecture is improved. Greater interest has therefore been directed toward its use in patients undergoing spinal fusion. Improved pedicle screw fixation and faster bone formation have been described in osteoporotic individuals receiving teriparatide during the perioperative period. Enhanced fusion has also been suggested because active formation of new bone may support incorporation of graft material and stabilization of the operated segment. These biological properties have made teriparatide an important potential option for patients in whom compromised bone quality may threaten surgical success.[4]

The achievement of solid lumbar spinal fusion is influenced by several biological and mechanical factors. Advanced age, poor bone mineral density, smoking, metabolic disease, nutritional status and the number of fused levels may influence healing. Surgical technique and implant design may also alter the probability of union. When osteoporosis is present the mechanical environment becomes less favorable because fixation strength may be reduced. Microfracture around screws may be produced and early implant movement may interfere with the developing fusion mass. Pharmacological treatment may therefore affect outcomes through both systemic improvements in bone metabolism and local improvement in the quality of fixation. An effective osteoporosis strategy could potentially improve radiological fusion while reducing complications related to poor skeletal strength.[5]

Teriparatide has been increasingly evaluated as a method for improving fusion outcomes in patients with osteoporosis. Faster fusion and stronger fixation have been reported in several observational studies and controlled investigations. The anabolic response induced by teriparatide may be particularly valuable during the early postoperative period when newly formed bone is required around the fusion bed. Increased bone formation may improve the interface between vertebral bone and implanted hardware. A lower incidence of screw loosening has also been described after postoperative teriparatide treatment. These findings have supported the concept that anabolic therapy may be more suitable than antiresorptive therapy when rapid spinal fusion is desired. However, variation in treatment duration and patient selection has limited uniform interpretation of available evidence. [6]

Clinical outcomes after lumbar fusion are not determined by radiographic union alone. Pain reduction, functional recovery, neurological improvement and return to daily activity are also important measures of treatment success. A patient may demonstrate acceptable radiological fusion while persistent disability continues because of preoperative nerve injury, adjacent segment disease or other musculoskeletal conditions. Conversely meaningful symptom relief may be experienced before complete radiographic fusion has been demonstrated. Evaluation of osteoporosis treatment after lumbar spinal fusion should therefore include both structural and clinical outcomes. Measures of pain, disability, mobility, hardware stability and postoperative complications may provide a more comprehensive assessment than fusion status alone. A broader evaluation is required when bisphosphonates and teriparatide are compared in routine surgical practice. [7]

Direct comparison between bisphosphonates and teriparatide has remained limited despite

increasing use of both drug classes in patients undergoing spinal fusion. Considerable evidence has been generated through retrospective studies, small prospective cohorts and selected randomized investigations. However substantial heterogeneity has been present in patient age, osteoporosis severity, surgical technique, fusion level and duration of treatment. Different imaging criteria have also been applied for determination of union. In some studies, plain radiography has been used while computed tomography has been preferred in others. Treatment initiation has varied from the preoperative period to several weeks after surgery. These methodological differences have restricted the ability to determine which pharmacological strategy provides the most reliable improvement in lumbar spinal fusion outcomes. [8]

An important research gap is also present in relation to patients treated within South Asian health care settings. Most available evidence has been obtained from populations in East Asia Europe or North America. Differences in nutritional status, vitamin D exposure, osteoporosis screening patterns, comorbidity burden and access to long term therapy may influence treatment response. Local data regarding postoperative pharmacological management of osteoporotic patients undergoing lumbar spinal fusion remain limited. The practical selection between bisphosphonate and teriparatide may also be influenced by cost treatment adherence and availability. These factors are particularly relevant in resource constrained settings where extended anabolic therapy may not be feasible for every patient. Comparative evidence from local clinical practice is therefore required. [9]

Another uncertainty concerns the timing and duration of treatment. Teriparatide may provide greater benefit when therapy is started before surgery and continued during the early fusion period. Bisphosphonates may provide stronger protection against later fragility fracture and mechanical complications. The optimal sequence of these agents has not been firmly established. Some patients may benefit from initial anabolic treatment followed by antiresorptive therapy while others may receive only one pharmacological class. Reliable comparison of short term fusion outcomes remains necessary before broader treatment strategies can be developed. Evaluation of early postoperative radiological union together with pain and functional recovery may help identify the treatment approach that provides the greatest clinical advantage. [10]

Despite growing interest in osteoporosis management during spinal fusion surgery, a clear consensus regarding the superior medication for promotion of lumbar spinal fusion has not been established. Existing studies have frequently involved limited samples and inconsistent therapeutic schedules. Direct assessment of bisphosphonate therapy against teriparatide therapy has been less frequently performed than comparison against untreated control groups. Clinical outcomes and radiological outcomes have also not always been evaluated together. The need for further comparative research is therefore evident. Evidence generated from a defined surgical population may help guide perioperative bone health management and may support more individualized treatment selection for patients at increased risk of impaired fusion.

The present study was designed to assess the efficacy of bisphosphonate therapy and teriparatide therapy in patients undergoing lumbar spinal fusion surgery at Bahria International Hospital, Rawalpindi Pakistan. Radiological fusion and postoperative clinical outcomes were intended to be compared between treatment groups. Treatment related differences in pain improvement, functional recovery and spinal fusion associated complications were also intended to be evaluated. The objective of the study was to determine whether teriparatide or bisphosphonate therapy was associated with better lumbar spinal fusion surgery outcomes and to identify the treatment approach that could provide greater postoperative benefit in patients requiring pharmacological management of reduced bone strength.

MATERIALS AND METHODS

Study Design and Setting

A comparative cohort study was conducted at Bahria International Hospital, Rawalpindi, Pakistan. The study included patients who underwent lumbar fusion surgery and received pharmacological treatment for reduced bone strength during the six-month period from January 2026 to June 2026. The study was designed to compare postoperative outcomes between patients treated with bisphosphonate therapy and those treated with teriparatide therapy. Clinical records, operative notes, radiological investigations, and follow-up

assessments were reviewed using a structured data collection method. Eligible cases treated during the defined study period were screened according to prespecified criteria.

Study Population and Sample Size

A total of 90 patients were included in the final analysis. Patients were categorized according to the anti-osteoporosis treatment prescribed during the perioperative or postoperative period. One cohort consisted of patients receiving bisphosphonate therapy while the second cohort consisted of patients receiving teriparatide therapy. Consecutive sampling was used to include eligible patients with complete clinical and radiological information. Only cases with sufficient follow-up for assessment of fusion status and postoperative recovery were entered into the analysis.

Inclusion Criteria

Patients aged 50 years or older who underwent instrumented lumbar spinal fusion for degenerative lumbar spine disease, spinal instability, spondylolisthesis, spinal stenosis or related indications were eligible. Reduced bone mineral density or osteoporosis was required to have been documented by dual-energy X-ray absorptiometry (DEXA) or recorded clinical assessment. Patients receiving either bisphosphonate therapy or teriparatide therapy were included. Baseline clinical information, operative documentation, postoperative imaging and follow-up data had to be available for assessment of fusion, pain, function and complications.

Exclusion Criteria

Patients were excluded when fusion had been performed for acute traumatic fracture, active spinal infection, primary or metastatic spinal malignancy or severe congenital deformity. Previous fusion at the same lumbar level was also an exclusion criterion. Patients who received both bisphosphonate and teriparatide during the same observation period were excluded because treatment effects could not be separated. Severe renal impairment, uncontrolled metabolic bone disease other than osteoporosis, chronic high-dose corticosteroid exposure, major systemic illness affecting bone healing, incomplete records, unavailable follow-up imaging and documented treatment nonadherence were additional exclusion criteria.

Treatment Exposure

Bisphosphonate therapy was prescribed according to routine clinical practice. Oral or intravenous bisphosphonate treatment was accepted when the drug and duration were documented. Teriparatide was administered by subcutaneous injection according to the standard regimen used for osteoporosis. Timing of treatment initiation and duration were recorded. Treatment was selected by the responsible clinical team according to bone health status, contraindications, patient preference and treatment feasibility. The investigators did not alter therapy for research purposes.

Surgical Procedure and Perioperative Management

All patients underwent instrumented lumbar spinal fusion surgery by experienced spine surgeons using standard posterior or transforaminal approaches as clinically indicated. Pedicle screw fixation was used for stabilization and interbody support was provided when required. The number of fused levels and use of bone graft material were documented. Routine antibiotic prophylaxis, analgesia, mobilization, and rehabilitation protocols were followed. Calcium and vitamin D supplementation were recorded when prescribed. Surgical indication, fusion technique, number of levels and immediate postoperative complications were collected because these variables could influence fusion.

Outcome Assessment

The primary outcome was radiological evidence of lumbar spinal fusion. Fusion status was assessed on postoperative radiographs and computed tomography when available as part of routine follow-up. Successful fusion was defined by continuity of trabecular bone across the intended fusion area without radiological features of pseudarthrosis or pathological movement. Implant loosening, cage subsidence, adjacent vertebral fracture, and hardware failure were also recorded. Secondary outcomes included postoperative pain improvement and functional recovery. Pain was assessed through the visual analogue scale when documented. Functional status was evaluated using the Oswestry Disability Index or an equivalent recorded assessment. Changes from baseline were compared between the treatment groups.

Data Collection Procedure

A structured proforma was used for data extraction. Demographic variables included age, sex, body mass index, smoking status and major comorbidities. Bone health variables included bone mineral density findings, osteoporosis status, treatment type, treatment duration and supplementation. Operative variables included diagnosis, fusion level, number of fused segments, operative approach and implant information. Follow-up variables included pain score, disability score, radiological fusion, implant-related complications, vertebral fracture, reoperation and other relevant adverse outcomes. Records were checked for completeness before statistical entry.

Control of Bias and Confounding

Eligibility criteria were applied consistently to both treatment groups and consecutive sampling was used to reduce selection bias. Baseline characteristics and recognized factors affecting spinal fusion were recorded. These included age, sex, smoking status, bone mineral density, diabetes, number of fused levels and surgical technique. Multivariable analysis was planned to determine whether treatment type remained associated with successful fusion after adjustment for clinically important confounding variables.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 26. Continuous variables were summarized as mean and standard deviation when normally distributed and as median with interquartile range when non-normal. Categorical variables were presented as frequencies and percentages. The independent samples t test was used for normally distributed continuous variables while the Mann-Whitney U test was used for non-normal variables. The chi-square test or Fisher exact test was applied to categorical variables. Changes in pain and disability scores were evaluated through appropriate paired and between-group tests. Logistic regression was used to assess predictors of successful fusion after adjustment for relevant covariates. Effect estimates were reported with 95% confidence intervals. A p value below 0.05 was considered statistically significant.

Ethical Considerations

The study was conducted in accordance with accepted ethical principles for clinical research. Approval was obtained from the institutional ethical review committee of Bahria International Hospital, Rawalpindi before data analysis. Patient confidentiality was maintained through anonymized data collection and restricted access to study records. No identifying information was included in the analysis or manuscript. Treatment had been prescribed as part of routine clinical care and no alteration of standard management was undertaken for research purposes.

RESULTS

Patient Demographic and Baseline Characteristics

A total of 90 patients who underwent lumbar spinal fusion surgery were included in the final analysis. Forty-five patients received teriparatide therapy and 45 patients received bisphosphonate therapy. The overall mean age was 62.5 ± 7.8 years. The mean age was 62.8 ± 7.6 years in the teriparatide group and 62.2 ± 8.1 years in the bisphosphonate group. Females represented 57.8% of the total study population. Baseline demographic and clinical characteristics were comparable between both groups. No statistically significant differences were observed regarding age, sex, body mass index, smoking status, diabetes mellitus, hypertension or baseline bone mineral density. The mean lumbar spine T-score was -2.92 ± 0.48 in the teriparatide group and -2.87 ± 0.51 in the bisphosphonate group. This baseline comparability reduced the possibility that major demographic differences influenced subsequent fusion outcomes.

Table 1: Baseline Demographic and Clinical Characteristics of the Study Population

Variable	Teriparatide Group n=45	Bisphosphonate Group n=45	p-value
Mean age in years	62.8 ± 7.6	62.2 ± 8.1	0.718
Male	18 (40.0%)	20 (44.4%)	0.670
Female	27 (60.0%)	25 (55.6%)	0.670
Mean BMI kg/m²	26.8 ± 3.4	27.1 ± 3.7	0.689
Current smokers	8 (17.8%)	10 (22.2%)	0.598
Diabetes mellitus	13 (28.9%)	14 (31.1%)	0.818
Hypertension	21 (46.7%)	23 (51.1%)	0.673
Mean lumbar T-score	-2.92 ± 0.48	-2.87 ± 0.51	0.633

Surgical Characteristics and Distribution of Fusion Levels

Single-level lumbar spinal fusion surgery was performed in most patients. The L4-L5 level was the most frequently treated level in both groups followed by L5-S1. Multilevel fusion was performed in 23 patients overall. Transforaminal lumbar interbody fusion (TLIF) was the most frequently used operative technique. Posterior lumbar interbody fusion (PLIF) was used in the remaining patients according to surgical indication and anatomical requirements. The distribution of fusion levels and operative techniques did not differ significantly between treatment groups. Mean operative duration was also comparable. These findings indicated that both cohorts underwent broadly similar surgical procedures and therefore allowed a more reliable comparison of postoperative pharmacological effects.

Table 2: Surgical Characteristics and Fusion Levels

Surgical Variable	Teriparatide Group n=45	Bisphosphonate Group n=45	p-value
L4-L5 fusion	20 (44.4%)	18 (40.0%)	0.670
L5-S1 fusion	14 (31.1%)	15 (33.3%)	0.821
Multilevel fusion	11 (24.4%)	12 (26.7%)	0.808
TLIF procedure	31 (68.9%)	29 (64.4%)	0.653
PLIF procedure	14 (31.1%)	16 (35.6%)	0.653
Mean operative time in minutes	151.4 ± 26.3	154.7 ± 28.1	0.567

Radiological Fusion Outcomes

Radiological assessment demonstrated a greater fusion rate among patients treated with teriparatide. At three months after surgery successful radiological fusion was identified in 24 patients or 53.3% of the teriparatide group compared with 13 patients or 28.9% of the bisphosphonate group. This difference was statistically significant with a p-value of 0.018. By six months the fusion rate had increased in both groups. Successful fusion was documented in 39 patients or 86.7% receiving teriparatide compared with 29 patients or 64.4% receiving bisphosphonate. The difference remained statistically significant at six months with a p-value of 0.014. The mean estimated time to radiological fusion was also shorter among patients receiving teriparatide. These findings demonstrated more rapid and more frequent fusion in the teriparatide cohort.

Table 3: Comparison of Radiological Fusion Outcomes

Fusion Outcome	Teriparatide Group n=45	Bisphosphonate Group n=45	p-value
Fusion at 3 months	24 (53.3%)	13 (28.9%)	0.018
No fusion at 3 months	21 (46.7%)	32 (71.1%)	0.018
Fusion at 6 months	39 (86.7%)	29 (64.4%)	0.014
No fusion at 6 months	6 (13.3%)	16 (35.6%)	0.014
Mean time to fusion in months	5.1 ± 1.2	6.0 ± 1.5	0.002

Pain and Functional Outcomes

Clinical improvement was observed in both treatment groups following lumbar fusion. Baseline visual analogue scale scores were similar between the groups. At six months' greater pain reduction was observed among patients treated with teriparatide. The mean visual analogue scale score decreased from 7.3 ± 1.0 to 2.6 ± 1.1 in the teriparatide group. In the bisphosphonate group the score decreased from 7.2 ± 1.1 to 3.3 ± 1.3. The between-group difference at six months was statistically significant. Functional improvement measured through the Oswestry Disability Index followed a similar pattern. Mean disability scores improved substantially in both cohorts although significantly lower residual disability was observed among patients receiving teriparatide.

Table 4: Comparison of Pain and Functional Recovery

Clinical Outcome	Teriparatide Group	Bisphosphonate Group	p-value
Baseline VAS score	7.3 ± 1.0	7.2 ± 1.1	0.653
VAS score at 6 months	2.6 ± 1.1	3.3 ± 1.3	0.007

Mean VAS improvement	4.7 ± 1.3	3.9 ± 1.5	0.009
Baseline ODI score	54.8 ± 8.7	55.4 ± 9.1	0.750
ODI score at 6 months	22.9 ± 7.4	29.1 ± 8.6	<0.001
Mean ODI improvement	31.9 ± 9.2	26.3 ± 9.8	0.006

Postoperative Mechanical and Treatment Outcomes

Mechanical complications were less frequent in patients receiving teriparatide. Pedicle screw loosening was identified in three patients in the teriparatide group compared with nine patients receiving bisphosphonate therapy. Cage subsidence occurred in two and seven patients respectively. Adjacent vertebral fracture was documented in one patient receiving teriparatide and five patients receiving bisphosphonate treatment. Individual complications did not consistently reach statistical significance because of the limited number of events. However, the overall proportion of patients experiencing at least one mechanical complication was significantly lower in the teriparatide group. Reoperation was required in one patient in the teriparatide group and four patients in the bisphosphonate group.

Table 5: Postoperative Complications According to Treatment Group

Complication	Teriparatide Group n=45	Bisphosphonate Group n=45	p-value
Pedicle screw loosening	3 (6.7%)	9 (20.0%)	0.118
Cage subsidence	2 (4.4%)	7 (15.6%)	0.157
Adjacent vertebral fracture	1 (2.2%)	5 (11.1%)	0.203
Hardware failure	1 (2.2%)	3 (6.7%)	0.616
Reoperation	1 (2.2%)	4 (8.9%)	0.361
At least one mechanical complication	6 (13.3%)	16 (35.6%)	0.014

Predictors of Successful Lumbar Spinal Fusion

Multivariable logistic regression analysis was performed to determine independent predictors of successful fusion at six months. Treatment with teriparatide remained significantly associated with successful fusion after adjustment for age, sex, smoking status, baseline T-score, diabetes mellitus, and number of fused levels. Patients receiving teriparatide had approximately three times greater odds of achieving successful fusion compared with those receiving bisphosphonate therapy. Smoking was independently associated with reduced odds of fusion. A baseline T-score of -3.0 or lower also showed a negative relationship with fusion success. Multilevel surgery demonstrated a tendency toward reduced fusion probability although the association did not reach statistical significance.

Table 6: Multivariable Logistic Regression Analysis for Successful Spinal Fusion at Six Months

Predictor	Adjusted Odds Ratio	95% Confidence Interval	p-value
Teriparatide therapy	3.15	1.15-8.60	0.026
Age ≥65 years	0.72	0.27-1.91	0.511
Female sex	0.91	0.35-2.39	0.852
Smoking	0.31	0.10-0.96	0.042
Diabetes mellitus	0.66	0.24-1.82	0.425
T-score ≤-3.0	0.35	0.13-0.94	0.037
Multilevel fusion	0.51	0.18-1.45	0.205

Overall Treatment Comparison

Overall analysis demonstrated that both therapies were associated with substantial postoperative clinical improvement. However, teriparatide was associated with a higher proportion of radiological fusion at both three and six months. A shorter mean fusion time was also recorded in this group. Greater improvement in pain and functional disability was observed among patients receiving teriparatide. Mechanical complications were numerically less frequent and the combined complication rate was significantly lower in the teriparatide group. Multivariable analysis further demonstrated that the relationship between teriparatide treatment and successful lumbar spinal fusion remained significant after adjustment for important clinical factors. These

results suggest that teriparatide may provide a stronger early anabolic advantage for patients with reduced bone strength undergoing lumbar spinal fusion surgery while bisphosphonate therapy remained associated with meaningful postoperative improvement.

DISCUSSION

The present study compared teriparatide therapy with bisphosphonate therapy in patients undergoing lumbar spinal fusion surgery who had reduced bone strength. A higher rate of radiological fusion was observed in the teriparatide group at both three months and six months. The time required to achieve fusion was also shorter in patients who received teriparatide. Better improvement in pain and disability was demonstrated in the same group. Mechanical complications were less frequent after teriparatide treatment and the combined complication rate was significantly lower. These findings suggest that an anabolic treatment strategy may provide an important advantage during the early phase of bone healing after lumbar spinal fusion. The observed pattern is consistent with recent evidence showing that stimulation of osteoblastic activity may improve fusion biology in osteoporotic patients. [11]

The higher fusion rate found with teriparatide can be explained by its direct anabolic action on skeletal tissue. Intermittent stimulation of the parathyroid hormone receptor promotes osteoblast differentiation and increases new bone formation. This mechanism is particularly relevant after spinal fusion because formation of a stable osseous bridge depends on active remodeling and incorporation of graft material. A stronger early bone forming response may improve the environment around the fusion bed and may support more rapid maturation of the fusion mass. Recent comparative evidence has shown higher fusion rates among patients treated with teriparatide than among those managed with antiresorptive therapy or routine care. [12] The present findings therefore strengthen the view that perioperative bone metabolism should be considered an important component of surgical planning in patients with osteoporosis.

At three months' fusion was observed in more than half of the patients receiving teriparatide while less than one third of patients treated with bisphosphonate had achieved fusion. This difference was maintained at six months. A randomized comparative investigation published in recent literature also reported faster fusion when teriparatide was compared with zoledronate after posterior lumbar interbody fusion in postmenopausal patients with osteoporosis. [13] The similarity between those observations and the present results is clinically important. It suggests that the effect of teriparatide may be most prominent during the early healing interval. Accelerated early spinal fusion may reduce the duration during which instrumentation carries most of the mechanical load. Earlier biological stability may consequently decrease the risk of micromotion and delayed union.

Bisphosphonate therapy was also associated with a substantial fusion rate in the present study. Almost two thirds of patients receiving bisphosphonate treatment had achieved spinal fusion by six months. This finding should not be interpreted as evidence that bisphosphonate therapy is detrimental to spinal fusion. Modern clinical studies have generally shown that bisphosphonates do not prevent successful union after instrumented lumbar spinal fusion surgery. Their effect may differ from that of teriparatide because bone resorption is suppressed rather than new bone formation being directly stimulated. [14] Preservation of bone mass around implants may provide mechanical benefit even when the speed of fusion is not increased to the same degree. The present study therefore supports the continued role of bisphosphonates when teriparatide cannot be used or when long term antiresorptive treatment is required.

The shorter mean time to fusion observed in the teriparatide group has important practical implications. Delayed fusion can expose implants to prolonged mechanical stress. This may contribute to screw loosening and implant failure in patients with compromised bone quality. Osteoporosis has been identified as an important risk factor for mechanical complications after lumbar fusion. Recent systematic evidence has shown that poor bone quality is associated with cage subsidence, Screw loosening, Vertebral fracture and other fixation related complications. [15] Improvement of bone biology before or after surgery may therefore influence both the radiological and mechanical success of the procedure. The present reduction in fusion time may partly explain why fewer mechanical complications were observed in patients treated with teriparatide.

Pedicle screw loosening occurred less frequently in the teriparatide group than in the

bisphosphonate group. Although the individual difference did not reach statistical significance the numerical pattern favored anabolic therapy. This finding is compatible with published evidence showing improved fixation strength and reduced screw related problems after teriparatide use in osteoporotic spine fusion surgery. [16] Increased trabecular bone formation around the screw trajectory may improve the bone implant interface. Greater local bone quality can increase resistance to toggling and pullout forces. The relatively small number of complication events in the present study probably limited statistical power for individual mechanical outcomes. Nevertheless, the lower combined mechanical complication rate provides support for a clinically meaningful protective effect.

Cage subsidence was also less frequent among patients receiving teriparatide. Subsidence may occur when the vertebral endplate is unable to tolerate transmitted load. Reduced bone mineral density can increase this risk because structural support beneath the endplate is weakened. Anabolic treatment may improve the load bearing capacity of vertebral bone through enhancement of trabecular architecture. Bisphosphonates may also preserve vertebral strength by limiting excessive resorption. However, the biological response produced by teriparatide may be more suitable during the active healing period when rapid formation of new bone is required. Recent reviews of osteoporotic spinal fusion surgery have emphasized that bone health optimization can reduce the risk of mechanical failure and may improve the durability of spinal reconstruction. [17]

Adjacent vertebral fracture was uncommon in both groups but fewer events were documented among patients treated with teriparatide. This observation is consistent with the established fracture prevention effect of osteoporosis treatment. Teriparatide can improve vertebral strength through new bone formation while bisphosphonates reduce fracture risk through suppression of bone turnover. The difference observed in the present study may reflect the greater anabolic effect of teriparatide during the short follow up period. However, caution is required because only a small number of fractures occurred. Longer follow up would be necessary to determine whether the early difference persists. Evidence from broader osteoporosis research has demonstrated that teriparatide is effective in reducing vertebral fracture risk in high risk patients. [18]

Clinical improvement was demonstrated in both treatment groups. Pain scores decreased substantially after lumbar spinal fusion surgery and disability scores were also reduced. Greater improvement was recorded among patients receiving teriparatide. This pattern may be related to faster achievement of biological stability. Reduced micromotion at the operated level may contribute to earlier relief of mechanical pain. Improved confidence in mobilization may also facilitate rehabilitation. A recent meta-analysis of teriparatide in spinal fusion demonstrated favorable radiological results but did not consistently show a significant difference in disability outcomes. [19] The present findings therefore suggest a stronger clinical effect than has been demonstrated in some pooled analyses. Differences in follow up duration, Baseline disability, Surgical technique and rehabilitation may explain this variation.

The improvement in Oswestry Disability Index observed in the teriparatide group should be interpreted within the broader context of spinal recovery. Functional outcome after lumbar fusion is influenced by decompression of neural structures. Restoration of stability, Postoperative rehabilitation, Psychological factors and preexisting comorbidity. Pharmacological treatment alone cannot determine recovery. However successful fusion provides the structural foundation on which long term functional improvement depends. The association between higher fusion rates and better disability scores in the present study suggests that improved bone healing may contribute to a more favorable rehabilitation pathway. [20] Future studies should examine whether the functional advantage remains significant after longer follow up and after adjustment for baseline neurological status.

The multivariable analysis showed that teriparatide therapy remained independently associated with successful spinal fusion after adjustment for important clinical variables. This result strengthens the interpretation that treatment type itself contributed to the observed difference. Age and sex were not significant independent predictors in the adjusted model. Smoking was associated with lower odds of successful fusion. This finding is biologically plausible because nicotine exposure and other tobacco related factors may impair vascularity and osteoblast function. Smoking

has long been recognized as a modifiable risk factor for pseudarthrosis after lumbar spinal fusion. [21] The present findings reinforce the importance of smoking cessation as part of perioperative optimization in patients undergoing instrumented spinal fusion.

A baseline T-score of minus three or lower was also associated with reduced probability of successful fusion. This observation highlights the effect of severe osteoporosis on the biological and mechanical environment of spinal reconstruction. Very low bone mineral density can compromise fixation and may reduce the capacity for graft incorporation. Modern spine practice has increasingly emphasized preoperative assessment of bone quality because untreated osteoporosis can increase the risk of instrumentation related complications. [22] Screening by dual energy X ray absorptiometry remains important and additional imaging based measures may provide supplementary information when conventional assessment is unavailable. Recognition of severe osteoporosis before surgery may allow pharmacological optimization and modification of fixation strategy.

Multilevel fusion showed a tendency toward lower fusion success although the association was not statistically significant. A greater number of treated levels creates a larger biological demand and increases the mechanical complexity of the construct. More extensive surgery may also be associated with longer operative duration and greater blood loss. The limited sample size of the present study may have prevented detection of a modest effect. Patients with osteoporosis undergoing complex spinal reconstruction may require more intensive bone health optimization because consequences of mechanical failure can be substantial. Careful patient selection may therefore be particularly important when fusion across multiple segments is planned.

Another important finding was the overall similarity in baseline characteristics between treatment groups. Age, Sex, Body mass index, Smoking, Diabetes, Hypertension and baseline T-score were comparable. Operative characteristics were also broadly similar. This comparability supports interpretation of the observed postoperative differences as treatment related rather than simply the result of major baseline imbalance. Nevertheless, residual confounding cannot be excluded in a cohort design. Treatment selection may have been influenced by physician preference, Osteoporosis severity, Cost, Drug availability, Or patient willingness to receive regular injections. These factors may also influence adherence and follow up behavior.

The study has particular relevance for clinical practice in Pakistan where evidence regarding pharmacological optimization of osteoporotic patients undergoing lumbar spinal fusion remains limited. Teriparatide may provide an effective strategy when rapid fusion is considered essential and when the patient has severe osteoporosis or a high risk of mechanical failure. Bisphosphonates remain useful because they are familiar, Widely available and effective for long term fracture prevention. The greater cost of teriparatide and the need for regular subcutaneous administration may limit its routine use in some settings. Treatment decisions should therefore consider skeletal risk, Expected surgical complexity, Affordability, Adherence, Contraindications and the anticipated duration of therapy.

The findings should not be interpreted as showing that bisphosphonate treatment is ineffective. Significant clinical improvement occurred in both groups and most bisphosphonate treated patients achieved fusion during follow up. The principal difference was that fusion appeared to occur earlier and more frequently with teriparatide. This distinction is important because the therapeutic goals of the two drug classes are not identical. Teriparatide may be most valuable during the active fusion period while bisphosphonate therapy may remain important for long term maintenance of bone density and fracture prevention. [23] A sequential treatment strategy could therefore be clinically attractive in selected patients. However, such an approach was not evaluated in the present study and should be tested through dedicated prospective trials.

Several aspects of future research can be identified from these findings. Larger multicenter studies should be performed with standardized treatment timing and predefined radiological criteria for fusion. Computed tomography based assessment should be incorporated at uniform intervals when clinically justified. Treatment adherence should be recorded carefully and serum markers of bone turnover may help demonstrate the biological response to therapy. Longer follow up is required to determine whether the early advantage associated with teriparatide

translates into lower revision rates and better long term function. Cost effectiveness should also be evaluated because the financial burden of anabolic therapy may influence its practical value in routine care.

Overall the present findings indicate that both pharmacological strategies can be incorporated into the management of osteoporotic patients undergoing lumbar spinal fusion. Teriparatide was associated with a higher early fusion rate, Shorter time to union, Greater improvement in pain and disability and fewer overall mechanical complications. Bisphosphonate therapy also produced satisfactory clinical and radiological outcomes but progression of fusion was slower. These findings support a more individualized approach to perioperative bone health management in which anabolic treatment is considered for patients at greater risk of impaired fusion while antiresorptive treatment remains an important option for continuing osteoporosis care.

CONCLUSION

Teriparatide therapy was associated with faster lumbar spinal fusion and better postoperative functional recovery than bisphosphonate therapy. A higher fusion rate and fewer mechanical complications were observed among patients receiving teriparatide. Teriparatide may therefore be considered a valuable perioperative treatment option for osteoporotic patients undergoing lumbar spinal fusion surgery.

Limitations

The study was conducted at a single center and the sample size was relatively limited which may restrict wider generalizability. The follow up period was short and long term fusion durability and delayed mechanical complications could not be fully assessed. Potential confounding related to treatment selection and adherence could not be completely eliminated because a randomized design was not used.

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