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Minimal Access Surgery for Spinal Metastases: Prospective Evaluation of a Treatment Algorithm Using Patient Reported Outcomes

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Abstract

Background: Minimal access surgery (MAS) allows early return to systemic and radiation therapy in patients with cancer leading to its increasing utilization in the treatment of spinal metastases. Systematic examination of surgical indications resulted in the development of an algorithm for implementation of MAS in the treatment of spinal metastases. The object of this study was to evaluate a spine tumor MAS treatment algorithm using patient-reported outcomes in cancer patients undergoing treatment of spinal metastases.

Methods: A prospective cohort study. Patients who underwent spinal percutaneous instrumented stabilization with the addition of MAS cord or nerve root decompression and/or kyphoplasty when indicated at a tertiary cancer center between December 2013 and August 2016 were included. Validated patient reported outcome (PRO) measures including the Brief Pain Inventory (BPI) and the MD Anderson Symptom Inventory – Spine module (MDASI-sp) were utilized. PROs were collected and compared at baseline, 3 month and long-term follow up (4.5–12 months).

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• No part of the contents of this work has been presented or published elsewhere.

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Results: Fifty-one patients were included. MAS resulted in a statistically significant decrease in the severity of pain, and improved activity, ability to work and enjoyment of life ($P<0.001$). The improvement was reported at the short- and long-term follow-up time points.

Conclusions: We present our treatment algorithm for MAS implementation in the treatment of thoraco-lumbar spinal metastases. Prospectively collected data demonstrate that using this algorithm, MAS surgery for the treatment of spinal metastases results in significant decrease in pain severity and symptom interference with daily activities.

Keywords

MAS; PRO; Spine; Minimally Invasive; Tumor

Introduction:

The growing implementation of minimal access surgery (MAS) in the treatment of degenerative and traumatic spinal disorders has led to the exploration of MAS role in the treatment of spinal deformity and tumors. Since patients with spinal tumors generally require a combination of surgical, radiation and systemic therapies, expeditious post-operative healing and return to treatment is of paramount importance. Surgical indications for the treatment of spinal metastases include restoration of mechanical stability and decompression the spinal cord or nerve roots⁹. These goals may be achieved using a variety of techniques including combination of posterior and anterior instrumentation, corpectomy, laminectomy and separation surgery, with MAS techniques having been described for all of these surgical options. Combination of surgery with post-operative high-dose conformal radiation has improved local tumor control and has diminished the role of aggressive tumor excision⁸.

We previously published our initial experience with percutaneous instrumented stabilization with cement augmentation for the treatment of neoplastic spinal instability²⁹. Our encouraging results with percutaneous spinal instrumentation lead us to explore the additional role of MAS techniques in decompression of the spinal cord and nerve roots. Our experience with MAS spine tumor surgery led to the development of an algorithm to facilitate the selection of appropriate MAS techniques (Figure 1). Patient reported outcome (PRO) data were collected in order to define the effect of MAS surgery on spine tumor-related symptoms and to validate this treatment algorithm

Methods:

Study Design:

This is a prospective, single center, observational cohort study involving a large tertiary cancer center. This study was approved by the IRB at our hospital with a waiver for informed consent.

Population:

The study population included metastatic cancer patients who were treated with MAS surgery between December 2013 and August 2016. Patients who underwent “open”

decompression and fusion or those who underwent cement augmentation without pedicle screw fixation were excluded. Patients who did not complete pre-operative and post-operative quality of life surveys were excluded. Patients whose pre-operative evaluation was conducted more than 30 days prior to surgery were also excluded. Fifty-one patients met inclusion for the current evaluation.

Treatment:

Figure 1 outlines the algorithm used for selection of MAS procedure in the treatment of patients with thoracolumbar fractures due to metastatic tumors. The principal surgical indications among patients with spinal metastases include mechanical instability and spinal cord compression due to radioresistant tumors. The utilization of metastatic epidural spinal cord compression (ESCC) score¹⁰ facilitates description of the degree of epidural tumor extension, with scores of 2 (spinal cord displacement) and 3 (absence of CSF around the spinal cord due to tumor extension) representing patients with high-grade epidural disease. Patients with ESCC scores of 2 and 3 due to radioresistant tumors generally require decompression. Below the spinal cord, mechanical radiculopathy serves as the primary indication for decompression, as has been shown to consistently respond to stabilization and decompression²⁷. Post-operative stereotactic body radiation therapy (SBRT) provides durable and consistent local control irrespective of tumor volume or tumor histology²⁴, therefore the primary goal of decompression was to provide circumferential spinal cord decompression in order to optimize SBRT dosimetry, and cytoreductive surgery with the purpose of gross tumor excision was not performed. The Spinal Instability Neoplastic Score (SINS)¹⁷ facilitates the recognition of spinal instability, with movement-associated pain in the setting of a vertebral fracture representing the most frequent indication for stabilization.

Stabilization with Decompression—The two indications for surgical decompression include metastatic epidural spinal cord compression (MESCC) due to radioresistant tumors and mechanical radiculopathy.

- A. Radioresistant tumors require SBRT treatment in order to achieve durable local tumor control⁵. In the setting of high-grade MESCC, adequate SBRT dose cannot be delivered to the entire tumor volume without risking spinal cord toxicity. Therefore patients with high grade MESCC due to radioresistant tumors require surgical decompression and instrumented stabilization⁷ in order to permit optimal SBRT dosing to the tumor while sparing the spinal cord from dangerous radiation doses. In the current series spinal cord decompression was performed using “mini-open” laminectomy and transpedicular ventral epidural decompression with transfascial instrumented stabilization. (Figure 2)
- B. Patients with lumbar burst fractures with extension into pedicle and joint frequently experience mechanical radiculopathy, i.e radicular pain felt to be due to instability associated with metastatic disease as evidenced by the onset of radicular pain with axial loading and/or ambulation²⁷. Mechanical radiculopathy additionally corresponds to high-intermediate or unstable SINS. In the current study, mechanical radiculopathy was treated with percutaneous instrumented stabilization with screw cement augmentation, kyphoplasty at the level of the

burst fracture and MAS facetectomy with pedicle excision for decompression of the affected nerve root. The MAS facetectomy was carried out using an expandable retractor inserted on the side ipsilateral to the radiculopathy, usually through one of the incisions made for screw placement. (Figure 3)

Stabilization without Decompression—Patients without MESCC due to radioresistant tumors and without mechanical radiculopathy did not undergo surgical decompression and underwent stabilization alone for treatment of mechanical instability. Cement augmentation of the screws was carried out for all short segment constructs.

- C. Patients with mechanical instability due to fractures caused by radiosensitive tumors such as lymphoma, multiple myeloma or breast and prostate adenocarcinoma underwent percutaneous instrumented stabilization alone when they had significant epidural tumor or fracture extension. Balloon kyphoplasty was not attempted at the level of the fracture in order to avoid the risk of exacerbation of the epidural disease. The stabilization was followed by conventional external beam radiation therapy (cEBRT) within a week of surgery. (Figure 4)
- D. Patients with mechanical instability due to fractures without significant epidural extension, and that either had extensive cortical destruction or fracture extension into the posterior elements, underwent percutaneous instrumented stabilization combined with balloon kyphoplasty. Kyphoplasty was performed at the level of the fracture. The percutaneous instrumentation, with screws one level above and one level below, was added due to inability to obtain adequate cement fill in the setting of extensive cortical destruction or in order to provide additional stability to the posterior column in the setting of fractures with extension into the pedicles and joints. (Figure 5)
- E. Patients with mechanically unstable fractures without significant epidural extension, extensive cortical destruction or posterior element involvement were treated with balloon kyphoplasty. These patients were excluded from analysis since the focus of the current study is on surgical decompression and/or instrumented stabilization. (Figure 6)

Our method for percutaneous spinal stabilization with cement augmentation has been previously described²⁹. In short, patients were placed in prone position under general anesthesia. Intraoperative imaging was used, either a navigation system (i.e O-Arm CT with Stealth Navigation (Medtronic, USA)) or standard fluoroscopy, both for localization and incision planning as well as for cannulation of pedicles and screw placement. The pedicle screws were placed using standard muscle sparing techniques. Fenestrated screws became available in the USA in 2016 and were used for all of the patients who underwent surgery subsequent to their approval. Following verification of proper placement, poly-methyl-methacrylate (PMMA, i.e “bone-cement”) augmentation was preformed through fenestrated screws. Prior to 2016, cement was injected into the vertebral body after the screw trajectory was tapped and prior to placement of the screw, using the previously described technique²⁹. Next, when possible, kyphoplasty was performed at the site of the fracture. Lastly, sub-

fascial, interconnecting rods were placed and secured. When indicated, decompression of the spinal cord or exiting nerve roots at the index level was performed, typically using an expandable tubular retractor. For a midline decompression a separate midline skin was made, the retractor was placed in the spino-laminar intersection and a minimally invasive laminectomy was carried out in standard fashion. In cases of lumbar radiculopathy, one or both previous skin incisions for instrumentation were used to place an expandable retractor on the facet joint and the joint was removed using a high-speed drill. To ensure adequate nerve root decompression, we typically decompressed the nerve root up to the dorsal root ganglion.

Patient Reported Outcomes:

PROs were collected using the brief pain inventory (BPI) and the MD Anderson symptom inventory (MDASI). PROs were collected at baseline; 3 months post-operatively and at long term follow up (i.e. 4.5–12 months, median 188 days). Data were collected electronically when possible and hand-written surveys were provided when required and were then manually transferred to the electronic database. All data were kept in accordance with HIPAA regulations.

BPI questionnaires included 12 individual items. Four pain items; worst pain, least pain, average pain, right now pain, and 8 interference items; general activity, mood, walking ability, normal work, relations, sleep, enjoyment of life and relief. Combining the 4 pain items generated a pain construct, combining the interference items generated an interference construct and combining all individual items generated a patient pain experience construct.

MDASI questionnaires included 13 core symptom items; pain, fatigue, nausea, sleep, distress, shortness of breath, memory, appetite, drowsiness, dry mouth, sadness, vomiting and numbness. When combined they generate a core symptom construct. Six disease interference items were analyzed; general activity, mood, work, relations, walking, enjoyment of life. When combined, these items generated a disease interference construct. Five spine tumor specific items were also included; spine pain, leg weakness, bowel/bladder control, bowel patterns and sexual activity and when combined generated a spine tumor specific construct.

Statistical Analysis:

Descriptive statistics such as frequencies, medians, means, and standard deviations were utilized for characterizing the cohort. Preoperative and postoperative individual items from the BPI (n=12) and MDASI (n=24) were compared using the Wilcoxon Signed-Rank test for matched pairs. Three BPI and three MDASI constructs were composed as described above using means for each individual. A majority of each construct's individual items must have been answered; otherwise, the construct was not calculated for that patient. Constructs were also compared preoperatively to postoperatively using the Wilcoxon Signed-Rank test for matched pairs. All p-values were two-sided with an alpha level of significance of <0.05, with the exception of the individual pain items. For the individual pain items (n=36), Bonferroni correction was used for statistical significance (<0.0014 considered statistically significant).

The primary endpoint was the comparison of preoperative to postoperative PROs, where postoperative time-point was defined as 2 to 4.5 months following surgery. The secondary endpoint was the comparison of preoperative to postoperative delayed PROs, where the postoperative time-point was defined as 4.5 months to 12 months following surgery.

All statistical analyses were done in SAS (version 9.4, Cary, NC).

Results:

Baseline characteristics:

Of the 51 patients included, 31 (61%) were female. The most common tumor histologies included lung, breast and multiple myeloma. The majority of patients had good pre-operative neurologic function with ASIA impairment scores of D and E only and 68% of the cohort presented in good functional status (Eastern Cooperative Oncology Group 1 (ECOG)). The majority of patients (80%) presented with high spinal instability neoplastic scores (SINS) of 10–18, suggesting impending or frank instability. Patient and tumor characteristics are summarized in Table 1.

All surgeries were performed in the thoracic or lumbar spine. Thirty-eight patients underwent percutaneous stabilization alone and 13 patients underwent percutaneous stabilization along with surgical decompression. Treatment variables including length of construct and number of levels decompressed are summarized in Table 1.

Brief Pain Inventory:

An analysis of the BPI individual items revealed statistically significant improvement in; worst pain, average pain, general activity, mood, walking ability, normal work and enjoyment of life ($P = 0.001$) at 3-month follow up (primary endpoint). At long term follow up; worst pain, average pain, general activity, normal work and enjoyment of life remained statistically significantly improved ($p < 0.001$).

When combining individual items into constructs, all 3 BPI constructs (i.e. pain severity, interference and patient pain experience) were statistically significantly improved at 3 months ($P < 0.0001$) with a durable improvement in long term follow up seen for all 3 constructs ($P < 0.001$). (Figure 7)

MD Anderson Symptom Inventory

An analysis of the MDASI individual items showed statistically significant improvement in; pain, spine pain, general activity, walking and enjoyment of life ($P = 0.001$) of life at 3 month follow up (primary endpoint). At long term follow up pain, general activity, walking and enjoyment of life remained statistically significantly improved ($p < 0.01$).

When combining individual items into constructs, all 3 MDASI constructs (i.e. MDASI core symptoms, spine tumor specific symptoms and diseases interference improved statistically significantly at 3 months with a durable improvement in long term follow up for MDASI core symptoms and disease interference constructs ($P < 0.05$). (Figure 7)

Complications

There were no complications requiring re-operation in this cohort. One patient had an asymptomatic screw fracture. This screw had fractured at the intersection of the shaft and the screw head. As this screw had been cement augmented, there was no apparent lucency surrounding it. No cases of infection requiring surgical intervention or hardware mal-positioning requiring re-operation were noted.

Discussion:

This study evaluated the utilization of an MAS decision-making algorithm in patients with thoracolumbar metastases and utilized PRO instruments to measure the impact of MAS on patient-reported outcomes. Our data show significant and durable improvement in multiple PRO items demonstrating that MAS techniques, predominantly percutaneous stabilization, improves pain and disease interference, ultimately improving quality of life in cancer patients with spinal instability.

Minimal access spine techniques for the treatment of cancer are gaining popularity as they entail limited perioperative morbidity, allow for quick recovery and rapid return to normal activity^{20,21}. Current MAS techniques for the treatment of spinal metastases include percutaneous instrumentation, mini-open approaches for decompression and tumor removal with or without tubular/expandable retractors and thoracoscopy/endoscopy. Studies have shown decreased blood loss, transfusion rates and hospitalization length with MAS stabilization techniques^{20,21,23,35}. Moreover, these less invasive procedures allow for rapid continuation of systemic treatment which is a crucial step in optimizing cancer treatment. Concomitant radiation can sometimes be started within 1 week of MAS surgery, unlike open surgeries where the risk of wound complications frequently delay radiation therapy^{14,39}. Recent reports continue exploring these innovative strategies describing MAS stabilization with additional techniques for spinal cord and nerve root decompression¹⁵. As technology continues to improve^{37,30} it is likely that MAS techniques will become more widespread over time. A recent systematic literature review highlights the fact that although some studies have shown superiority of outcomes using MAS techniques, especially using “mini open” decompression, the available data are still of low quality and strong recommendations cannot be made⁴¹.

With the introduction of modern technologies and next generation cancer therapies, the management of patients with spinal metastases has gained complexity. At our institution all patients are evaluated by a multidisciplinary team including; neurosurgeons, radiation and medical oncologists, interventional radiologists and pain specialists. Patients are managed using a decision-making framework “NOMS”²⁵. This framework assesses four sentinel factors; Neurologic (i.e. myelopathy or radiculopathy but primarily the degree of epidural spinal cord compression^{10,19}), Oncologic (i.e. the predicted tumor response to current available treatments, primarily tumor radiosensitivity), Mechanical (i.e. assessment of the mechanical stability of the spine as facilitated by SINS¹⁸) and Systemic (i.e. a risk assessment of the patient’s ability to withstand the proposed treatment). Application of the NOMS principles to decisions for selection of MAS techniques resulted in the development of the treatment algorithm for thoracolumbar MAS spine stabilization and decompression

for spinal metastases. Currently, patients with high-grade spinal cord compression due to radioresistant tumors are considered for surgical decompression. The open technique for separation surgery, where the spinal column is stabilized using instrumentation and circumferential spinal cord decompression is carried out has been previously described²⁴. In the current series we employed the “mini-open” approach, described by Chou et al.,¹² in order to carry out the stabilization and decompression, however none of our patients underwent a corpectomy. Others have described case series demonstrating the safety and efficacy with minimal access approaches using tubular and expandable retractors^{15,40}.

Mechanical instability represents the second surgical indication in patients with metastatic spinal tumors. Current evidence strongly supports kyphoplasty for symptomatic compression fractures due to metastatic disease^{6,26,31}. However, fractures with evidence of posterior element disease often require augmentation of the posterior tension band through the use of pedicle screws, since cement cannot be injected into the posterior elements. Percutaneous pedicle screw placement technique provides spinal stabilization with preservation of muscle attachments and expeditious healing. A combination of vertebral cement augmentation and percutaneous instrumentation provides stabilization of both the anterior and posterior columns of the spine. However, in patients with pathologic fractures resulting in high-grade spinal cord or cauda equina impingement or compression secondary to either radiosensitive tumor or bone, percutaneous pedicle screws are placed without supplemental vertebral body cement augmentation at the index level due to concern of further retropulsion into the spinal canal. Finally, patients who present with mechanical radiculopathy due to lumbar burst and pedicle fractures typically require decompression of the nerve root in addition to stabilization²⁸. These patients often benefit from percutaneous stabilization with instrumentation and cement along with a facetectomy and pedicle resection that can be carried out using an expandable or tubular retractor. Since the majority of cancer patients have poor bone quality, we routinely employ pedicle screw cement augmentation, as screw pullout or pedicle fracture in a short construct can be potentially catastrophic¹¹. Complication rates from surgery for metastatic spine disease range from 2.6% to 16% as described by a recent systematic review⁴ while others have reported severe complications as high as 19%³⁴ and even 34% with 10% 30 day mortality for wide decompressive surgery with stabilization³². The most common reported complications in surgery for metastatic spine are wound infections or dehiscence. To note, overcoming poor bone quality has typically been achieved via open surgeries with long constructs and hardware failure requiring surgical revision in cancer patients has previously been reported to be as low as 1.9%³³- 2.8%¹. These long constructs require long incisions, increasing the likelihood of wound complications. Our current series utilizing MAS techniques compares favorably to prior publications as there were no wound or hardware complications requiring re-operations.

The MDASI spine tumor module^{2,13} and the BPI^{3,16,38}, which were used in this current study, are examples of validated, disease specific, PRO tools used in the evaluation of spine cancer patients^{22,36}. We collected PRO data utilizing the MDASI-sp and BPI in order to evaluate the effect of MAS spine surgery on patients with spinal metastases. Our current data demonstrate significant and durable improvement in pain, ambulation and the degree of disease interference spine cancer patients experience following MAS surgery using validated

PRO measures. These findings support the principle that the need for spine stabilization serves as an independent surgical indication regardless of the need to decompress the spinal cord or nerve roots and that this can be achieved with limited morbidity. As previously mentioned, MAS allows for short hospitalization time, and rapid return to oncologic treatment^{20,21}. Our current data further support these approaches as they show substantial and lasting improvement in the HrQOL of this patient population. A significant limitation of this study is the lack of comparison cohort. The authors intention is to present our treatment algorithm and encouraging PRO data which evaluate the use of this algorithm in this cohort. The current study does not compare MAS surgery to open surgery, and future studies are necessary to elucidate outcome differences between the two surgical techniques.

Conclusions:

We present our treatment algorithm for MAS implementation in the treatment of thoracolumbar spinal metastases. These prospectively collected data demonstrate that MAS surgery for the treatment of spinal metastases result in a significant decrease in pain severity and symptom interference with daily activities. These findings should facilitate early referral for surgical evaluation and treatment for cancer patients with spinal metastases, especially since MAS surgery requires minimal delay in radiation and systemic therapy.

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Abbreviations:

MAS	Minimal Access Surgery
PRO	Patient Reported Outcomes
BPI	Brief Pain Inventory
MDASI	M.D. Anderson Symptom Inventory
ESCC	Epidural Spinal Cord Compression
SINS	Spinal Instability Neoplastic Score
SBRT	Stereotactic Body Radiation Therapy
MESCC	Metastatic Epidural Spinal Cord Compression cEBRT, Conventional External Beam Radiation Therapy
HrQOL	Health-related Quality of Life

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Highlights:

We present our treatment algorithm for MAS implementation in the treatment of thoracolumbar spinal metastases.

Prospectively collected PRO data demonstrate that using this treatment algorithm, MAS surgery for the treatment of spinal metastases results in a significant decrease in pain severity and symptom interference with daily activities.

Figure 1: MAS Treatment Algorithm for Metastatic Thoraco-Lumbar Disease.

Suggested treatment algorithm using minimal access surgery for metastatic thoraco-lumbar spine disease.

Figure 2: Percutaneous stabilization with minimal access decompression

70 year old male presented with progressive bilateral lower extremity weakness and back pain due to newly diagnosed stage IV non-small cell lung carcinoma.. MRI demonstrated a T9 metastases with high grade spinal cord compression. The patient underwent separation surgery using mini-open midline T9 exposure and transmuscular instrumented stabilization using a midline skin incision. A. Sagittal T1-weighted MRI demonstrating the T9 metastasis B. Axial T1-weighted gadolinium-enhanced MRI demonstrating high-grade epidural spinal cord compression C. Postoperative x-ray showing the multi-level percutaneous stabilization with cement augmentation.

Figure 3: Percutaneous stabilization with unilateral facetectomy

59-year-old female with high-grade leiomyosarcoma, presented with movement related lower back pain radiating to the right hip and knee. MRI demonstrated a L2 lesion with predominantly right-sided foraminal stenosis. The patient underwent percutaneous L1-L3 stabilization, L2 kyphoplasty and a right-sided minimally invasive hemilaminectomy, facetectomy. A. Sagittal T1-weighted MRI demonstrating the L2 metastasis. B. Axial T1-weighted gadolinium-enhanced MRI demonstrating foraminal stenosis secondary to tumor infiltration. C. Post-operative CT scan showing the unilateral facetectomy.

Figure 4: Percutaneous stabilization (pedicle screws and rods)

27-year-old male who presented with interscapular pain exacerbated by movement due to newly diagnosed small cell lung cancer (SCLC). Imaging revealed a T5 burst fracture with posterior element involvement and retropulsion of the tumor into the spinal canal causing spinal cord compression. Since SCLC represents a radiosensitive tumor, the patient did not require surgical decompression, however he had signs and symptoms of mechanical instability and required spinal stabilization. Cement augmented, fenestrated percutaneous pedicle screws and connecting rods were placed. Due to the cord compression with posterior displacement of the tumor into the spinal canal, kyphoplasty was not performed. The patient commenced radiation therapy 5 days following spinal stabilization. A. Sagittal T2-weighted MRI demonstrating the T5 metastasis with associated fracture. B. Axial T1-weighted gadolinium-enhanced MRI demonstrating high grade epidural tumor extension. C. Post-operative x-ray scan showing the cement augmented pedicle screws and rods.

Figure 5: Percutaneous stabilization with kyphoplasty

61-year-old male with multiple myeloma who presented with movement-related lower back pain due to L3 burst fracture without significant epidural extension. The right-sided pedicle was infiltrated with tumor. On the basis of mechanical instability with posterior element involvement and no radiculopathy or cord compression he underwent percutaneous stabilization with cement augmented pedicle screws and rods along with L3 kyphoplasty. A. T2-weighted MRI of the lumbar spine demonstrating an L3 burst fracture B. Axial T2-weighted MRI demonstrating no canal stenosis at the fracture level, small bone fragment with no tumor invading the canal posteriorly C. AP x-ray demonstrating the cement augmented pedicle screws and kyphoplasty D. Lateral x-ray demonstrating the cement augmented pedicle screws and kyphoplasty.

Figure 6: Kyphoplasty

57-year-old female presented with multiple osseous lesions and no known primary cancer. An L3 lytic lesion was demonstrated and suspected to be the source of her pain. No epidural extension, no posterior element involvement noted and no clinical signs of mechanical radiculopathy. On this basis, the patient underwent L3 kyphoplasty and biopsy for tissue diagnosis. A. Sagittal T1 MRI demonstrating the L3 lesion B. Axial non-contrast CT showing the lytic lesion C. Sagittal x-ray demonstrating the bone cement filling the lytic lesion. A. MRI T1 sagittal non-contrast image demonstrating the L3 metastasis B. Axial non-contrast CT at L3 demonstrating a lytic lesion in the vertebral body C. Post kyphoplasty x-ray showing the “bone cement” filled vertebral body.

Figure 7:

Mean pre vs post-operative scores for BPI and MDASI constructs at 3 month post-operative follow up and at long term follow up (4.5–12 months). (* = $P < 0.05$)

Table 1:

Patient demographics and clinical characteristics

Variable	Category	N	%	Median	Mean	SD
Age	--	51	100	62.9	61.4	12.7
Sex	Female	31	61			
	Male	20	39			
Histology	Lung	15	29			
	Breast	10	20			
	Multiple myeloma/plasmacytoma	7	14			
	Renal	4	8			
	Prostate	3	6			
	Sarcoma	3	6			
	Others	9	17			
Preoperative SINS		48	94	11	11.7	2
	7–9 (low intermediate)	7	14			
	10–12 (high intermediate)	20	39			
	13–18	21	41			
	n/a due to previous kyphoplasty	3	6			
Preoperative ECOG		51	100	1	1.4	0.8
	0	1	2			
	1	37	74			
	2	6	11			
	3	6	11			
	4	1	2			
Preoperative MRC	3	2	4			
	4	5	10			
	5	44	86			
Preoperative ASIA score	D	5	10			
	E	46	90			
Length of Stay (days)	--	51	100	4	5.3	4.6

Table 2:

Treatment associated variables

Variable	Category	N	%
Procedure site	Thoracic	16	31
	Thoraco-lumbar	4	8
Tumor resection	Lumbar	31	61
	No	39	76
	Yes	12	24
Number of levels decompressed	0	38	75
	1	10	19
	2	1	2
	3	2	4
Kyphoplasty (concurrent at treatment level)	No	8	16
	Yes	43	84
Length of construct (spinal levels)	3	43	84
	4	6	12
	5	2	4
Prior radiation at treatment level	Yes	19	37
	No	32	63
Prior Spinal procedure at treatment level	Yes	7	14
	No	44	86

Survey	Individual Item	Preoperative Survey				3 month Postoperative Survey				P-value	Long-term Postoperative Survey				P-value
		Mean Score	SD	N	%	Mean Score	SD	N	%		Mean Score	SD	N	%	
BPI	Worst pain	7.7	2.4	50	98	4.3	2.8	37	73	<0.0001	4.8	3	26	51	0.0004
	Least pain	3.1	2.6	50	98	1.8	1.9	37	73	0.02	1.7	1.7	26	51	0.02
	Average pain	5.7	2.3	50	98	3.2	2.2	37	73	<0.0001	3.4	2.2	26	51	0.0003
	Right now pain	4.6	2.9	50	98	2.6	2.2	37	73	0.007	3	2.6	26	51	0.06
	General activity	7.8	2.6	47	92	3.0	2.6	36	71	<0.0001	3.8	2.9	25	49	<0.0001
	Mood	5.7	3.6	46	90	2.8	2.7	36	71	0.001	3.2	3.1	25	49	0.007
	Walking ability	6	3.3	47	92	3.5	3.0	36	71	<0.0001	3.4	2.8	25	49	0.002
	Normal work	7.7	2.9	47	92	4.3	3.3	36	71	<0.0001	4.1	3.2	23	45	<0.0001
	Relations	4	3.8	49	96	2.3	3.0	35	69	0.17	2.8	2.9	25	49	0.21
	Sleep	5.5	3.4	49	96	2.9	2.8	35	69	0.002	3	2.8	25	49	0.009
	Enjoyment of life	7.4	3.2	49	96	3.4	3.1	35	69	<0.0001	3.5	2.9	25	49	<0.0001
	Relief	58.2%	26.3%	49	96	55.2%	37.0%	29	57	0.53	58.7%	30.5%	23	45	0.62
MDASI	Pain	8.1	2.3	49	96	4.4	3.1	36	71	<0.0001	5.2	3.3	26	51	<0.0001
	Fatigue	6	3.3	48	94	4.9	2.9	35	69	0.04	5.1	3.1	26	51	0.32
	Nausea	1.6	2.5	48	94	2.1	2.8	35	69	0.39	1.2	2.1	26	51	0.61
	Sleep	5.1	3.3	48	94	3.3	3.1	36	71	0.01	3.4	2.9	26	51	0.12
	Distress	5.1	3.3	48	94	3.3	3.1	36	71	0.002	3.8	3.2	26	51	0.07
	Shortness of breath	2.4	3	49	96	1.7	2.4	36	71	0.47	1.9	2.9	26	51	0.49
	Memory	2.1	2.7	49	96	2.8	2.7	36	71	0.29	2.7	2	26	51	0.89
	Appetite	4	3.4	49	96	2.9	2.9	36	71	0.63	3.3	3.2	26	51	0.66
	Drowsy	4.1	3.6	47	92	3.5	2.8	37	73	0.73	3.8	2.9	26	51	0.42
	Dry mouth	4.7	3.7	49	96	2.2	2.9	37	73	0.009	3.2	3.3	25	49	0.03
	Sadness	3.7	3.5	47	92	2.9	2.8	37	73	0.17	3.2	2.6	26	51	0.39
	Vomiting	0.6	1.8	49	96	0.9	2.5	37	73	0.47	0.8	1.9	26	51	0.44
	Numbness	2.9	3.1	48	94	2.5	2.9	37	73	0.49	2.5	2.9	25	49	0.37
	Spine pain	6	3.7	47	92	3.2	3.4	37	73	<0.0001	3.7	3.2	25	49	0.01
	Limb weakness	3.9	3.5	47	92	2.8	3.0	37	73	0.25	2.6	3	24	47	0.15

Survey	Individual Item	Preoperative Survey				3 month Postoperative Survey				P-value	Long-term Postoperative Survey			
		Mean Score	SD	N	%	Mean Score	SD	N	%		Mean Score	SD	N	%
	Bowel/Bladder control	1.1	2.8	49	96	0.8	2.1	37	73	0.77	1	1.7	25	49
	Bowel pattern	3.7	4	46	90	2.2	2.7	37	73	0.14	2.6	3.3	25	49
	Sexual function	2.2	3.8	45	88	2.8	4.0	35	69	0.43	2.5	3.8	24	47
	General activity	7.4	2.8	47	92	4.2	2.9	36	71	<0.0001	4.3	3.1	23	45
	Mood	5.7	3.5	47	92	3.0	2.9	37	73	0.0018	3.8	3.3	24	47
	Work	7.3	3.1	46	90	4.6	3.5	36	71	0.002	4.1	3.3	24	47
	Relations	3.8	3.5	47	92	2.5	3.0	37	73	0.19	2.7	2.6	25	49
	Walking	6.1	3.4	45	88	3.7	3.2	37	73	0.001	3.6	2.6	24	47
	Enjoyment of life	7.2	2.9	47	92	3.5	3.2	36	71	<0.0001	4.1	3.2	24	47