**Table 1.** MIS surgical techniques, including percutaneous instrumentation, tubular retractors, mini-open, and endoscopic/thoracoscopic techniques.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Author, Year** | **N** | **Technique** | **OT****(minutes)** | **EBL****(cc)** | **LOS****(days)** | **CR****(%)** | **F/U****(month)** | **Outcomes** | **Findings** |
| **I. Percutaneous Stabilization** |  |  |  |  |  |  |  |  |  |
| 1. Kwan et al., 2016[59](#_ENREF_59)
 | 50 | Percutaneous screwsMini-open | 186 | 1400 | NA | 2% | NA | * Decreased VAS pain score (p<0.001)
* Of those with deficit, 70% displayed improvement of one Frankel grade and 5% had an improvement of 2 Frankel grades
* Average time to ambulation was 3.4±1.8 days
* Mean overall survival time 11.3 months (range 2–51)
 | * All 50 cases with pathological fractures
* 37/50 (74%) required decompression
* Single complication was implant failure
* Tomita score <8 had significantly longer survival
 |
| 1. Liu et al., 2016[30](#_ENREF_30)
 | 5 | Percutaneous screws | 413 | 160 | 7.6 | 0% | 13.2 mean | * No neurological deficits, wound complications, or hardware failure
* VAS pain scores all improved at 6 months
* 3/5 died at 15, 16, 20 months each
 | * Iliac screws placed in all patients
* All patients with metastatic lumbosacral disease
* All constructs spanned L1-ilium
* Mean time to adjuvant therapy was 2.8 weeks
 |
| 1. Versteeg et al., 2016[11](#_ENREF_11)
 | 101 | Percutaneous screws | 122 | 100 | NA | 18% | NA | * 88 pts (87%) ambulated within first 3 days after surgery
* Median survival of 11.0 months (range 0–70)
* 78% alive 3 months after surgery; breast and melanoma significantly better survival
* Lack of postop chemotherapy negatively associated with 3-month survival
* 18/101 (18%) experienced 30 complications including infection, neurologic worsening, hardware failure, screw malposition
 | * Increased operative time independently associated with increased risk of complications
* EBL based only on 41 pts
* >5 bodies fused in 65 pts (64%) pts, 4 levels in 9 pts (9%), 3 levels in 27 pts (27%)
* Vertebroplasty performed in 6 patients (6%), kyphoplasty in 10 patients (10%), and vertebral body stenting in 19 patients (19%)
* Cement augmentation of pedicle screws performed in 3 pts (3 %)
* One pt experienced complete paraplegia after medial placement of a pedicle screw
* Cement extravasation lead to incomplete ASIA C injury that recovered fully to ASIA E
 |
| 1. Moussazadeh et al., 2015[60](#_ENREF_60)
 | 44 | Percutaneous screwsCement augmentation | NA | NA | NA | 9% | 6 med, 9 mean | * Pts w/ severe pain decreased from 86% to 0%
* 65% reported no mechanical pain postoperatively
* No neurologic declines
* Complications included 1 adjacent fracture, 1 asymptomatic screw pullout, 2 additional decompressions needed
 | * All screws placed with cement augmentation
 |
| 1. Park et al., 2015[61](#_ENREF_61)
 | 12 | Percutaneous screwsMini-open | 72 | 73 | 9.6 | 17% | 7.4 mean | * No early complications or perioperative mortalities
* Significant decrease in VAS pain scores (p=0.003)
* 91.8% pts (11/12) experienced improvement in their ECOG score post operatively
* Mean ambulation time 196.9 days
* Mean overall survival time 249.9 days (95% CI, 145.3–354.4 days; median, 176 days).
* Two complications were transient weakness and wound complication
 | * 1/12 (8.3%) patients with mini-open procedure
 |
| 1. Zairi et al., 2015[62](#_ENREF_62)
 | 44 | Percutaneous screws | 85 | 100 | 5.2 | 2% | NA | * Pain significantly improved postoperatively (p<0.001)
* No neurologic worsening
* No hardware complications
* 1 patient required additional decompression due to tumor recurrence
 | * All 44 patients underwent long-segment percutaneous fixation
* All patients underwent postoperative radiation in approximately 2 weeks
 |
| 1. Rao et al., 2014[9](#_ENREF_9)
 | 8 | Percutaneous screwsMini-open | 268 | 680 | 12.6 | 13% | 29 median | * Survival in all patients was 3, 11 13, 28, 30, 41, 43 months
* In three patients, strength improved from 2 to 4; 1 patient improved from 0 to 4; remaining 4 patients unchanged
* Single complication was wound infection
 | * Three techniques recommended, with increasing levels of invasiveness depending on Tokuhashi survival: <6 months, 6-12 months, >12 months
* Percutaneous instrumentation used in all techniques
* 5 patients underwent mini-open procedure; 3/5 with expandable cage placement
 |
| 1. Schwab et al., 2011
 | 14 | Percutaneous screws Tubular retractor | NA | 128 | NA | NA | 9 mean | * 7 pts (29%) unable to ambulate prior to surgery; all 14 pts ambulating within 2 to 3 days postoperatively (p=0.01)
* Change in VAS pain was 2.8 to 1.0 (p=0.001)
 | * 14/24 (58%) patients with metastastic disease
* Kyphotic deformities improved by 10° and 9°; scoliosis improved by 13°
 |
| **II. Tubular Retractors** | **N** | **Technique** | **OT****(minutes)** | **EBL****(cc)** | **LOS****(days)** | **CR****(%)** | **F/U****(month)** | **Outcomes** | **Findings** |
| 1. Harel et al., 2015[12](#_ENREF_12)
 | 5 | Tubular retractorPercutaneous screwsCement augmentation | 134 | Minimal | 4-10 | 0% | 5 mean | * No complications
* Improvement in neurological status, function, and pain scores
* Admission: 2 ambulatory, 2 with assistance, 1 wheelchair; at discharge, 3 ambulatory, 2 with assistance, 0 wheelchair.
* Improvements seen in ASIA, VAS, Karnofsky score though no statistics reported
 | * Five patients underwent surgery w/ thoracic or lumbar metastases
* Procedure was unilateral decompression with expandable tubular retractor followed by screw on contralateral side with bilateral instrumentation one level above and below
* Cannulated fenestrated screws used in conjunction with injected cement to prevent screw pullout.
 |
| 1. Massicotte et al., 2012
 | 10 | Tubular retractorPercutaneous screwsCement augmentation | NA | 335 | NA | NA | 13 median(range 3-18) | * Local control observed in 7 of the 10 pts
* Improvements in VAS, ODI and QOL were improved post-SBRT
 | * MASS – tubular retractors followed by radiotherapy
* Median time to SBRT treatment planning was 6.5 days; median time to SBRT treatment 7 days.
 |
| 1. Zairi et al., 2012[32](#_ENREF_32)
 | 10 | Tubular retractorPercutaneous screws | 170 | 400 | 6 | 10% | 10.1 mean | * Eight patients (80%) improved at least 1 Frankel grade
* Pain improved in all pts; mean VAS decreased from 5.5 (range 2–9) to 2 (range 0–5)
* 1 complication was benign UTI
 | * All 10 patients underwent transpedicular corpectomy with expandable retractor
 |
| 1. Deutsch et al., 2008[14](#_ENREF_14)
 | 8 | Tubular retractor | 132 | 227 | 4 | 0 | NA | * No complications reported
* Improvement of at least 1 grade on Nurick scale noted in 5 of 8 (63%) patients
* Pain improved in 5 of 8 (63%) on numeric pain score
* One-year survival was 38%
* Two pts able to ambulate independently immediately after surgery despite significant paraparesis preoperatively.
 | * 8 thoracic mets
* Posterior decompression and partial vertebrectomy performed in all cases with use of tubular retractors
* No report of percutaneous screw placement
* No new kyphosis or instability in any patients
 |
| **III. Mini-open** | **N** | **Technique** | **OT** **(minutes)** | **EBL****(cc)** | **LOS****(days)** | **CR****(%)** | **F/U****(month)** | **Outcomes** | * **Findings**
 |
| 1. Dabravolski et al., 2015[63](#_ENREF_63),[64](#_ENREF_64)
 | 78 | Mini-openCavity/coblationPercutaneous screwsCement augmentation | 30-120 | 5-130 | NA | 15% | NA | * Cement escaped laterally in 38 cases without clinical relevance
* 188 patients since died due to new tumor manifestation
* Average reduction in VAS postoperatively by 6-8 points
* 151/229 survived at year for 66% 1-yr survival rate
* 0% local recurrence rate
 | * With percutaneous cavity/coblation technology, tumor tissue disrupted through plasma panel, tumor denatured and converted to gaseous state.
* Cement introduced in VB space after tumor coagulated and removed
* Of the total 250 patients, 21 patients with primary hemangiomas
* Cavity/coblation technique done in 229 patients in conjunction with:
	+ Vertebroplasty/kyphoplasty (172)
	+ Mini-open percutaneous screw placement (59)
	+ Mini-open decompression (19)
* Total of 78 patients underwent mini-open approach
* Percutaneous cavity/coblation safe, minimally invasive, with good short- and long-term results and lower complication rates.
 |
| 1. Lau et al., 2015[15](#_ENREF_15)
 | 21 | Mini-openPercutaneous screws | 452 | 918 | 7.4 | 9.5% | All f/u >6m; 35/49 had >6m f/u | * No difference in operative time between mini-open and open group
* Trend toward a lower perioperative complication rate in the mini-open group (9.5%) compared with the open group (21.4%); but not statistically significant (p = 0.27).
* No significant differences in ASIA grade (p = 0.342), complication rate after the 30-day postoperative period (p = 0.999), or need for surgical revision (p = 0.803).
* Higher infection rate in open group (17.9% vs. 9.5%); but not statistically significant (p = 0.409).
* Single complication in MIS group was a UTI
 | * Compared mini-open to traditional open corpectomy
 |
| 1. Miscusi et al., 2015[16](#_ENREF_16)
 | 23 | Mini-openPercutaneous screws | 132 | 240 | 7.2 | 4% | NA | * No difference in neurologic recovery and complications between mini-open and open groups
* MIS group decreased blood loss, operative time, and bed rest time
* Postoperative pain and the opioid administration also significantly less in the MIS group.
* Results from the EORTC QLQ-C30 and QLQ-BM22 scales showed better improvement in quality of life at follow-up in the MIS group.
 | * Compared mini-open to traditional open approach
* Patient-reported outcome measures showed improvement in quality of life measures in mini-open group.
 |
| 1. Fang et al., 2012[34](#_ENREF_34)
 | 24 | Mini-open Cement augmentationRetractor | 175 | 1058 | NA | 29% | 24.8 mean | * Improvement in 1 ASIA grade in 97.2% pts
* 68.4% of non-ambulatory pts became ambulatory again, including 84.6% after mini-open corpectomy and 33.3% after posterior total en bloc spondylectomy (p > 0.05).
* Operative time (p<0.001), EBL (p<0.001), and VAS pain (p<0.001) significantly improved in mini-open group
* Local tumor recurrence lower in mini-open corpectomy group (p < 0.05)
* Postop survival rates similar in both groups
* Complication rate in the mini-open corpectomy group (29.2%) was higher than that in the TES group (11.8%) but not statistically significant (p = 0.185)
 | * Comparison to total en bloc spondylectomy
* Retractor system used but not tubular
* Slight subsidence (< 3 mm) of the mesh cage was observed with a successful fusion in 3/17 patients (17.6%) in the TES group; no subsidence of in the mini-open group
 |
| 1. Tancioni et al., 2012[65](#_ENREF_65)
 | 25 | Mini-openPercutaneous screwsCement augmentation | NA | NA | 6 | 0% | 9 median | * Pain remission in (96%)
* Improved neurologic deficit seen in 88%
* No major morbidity or perioperative mortality occurred
* Local recurrence occurred in (8%)
* Median survival was 10 (range, 6–24) months
* 1-year survival was 43% and 2-year survival 15%.
 | * MIS followed by radiotherapy
* Non-tubular retractor system used
 |
| 1. Uribe et al., 2010[66](#_ENREF_66)
 | 21 | Mini-openLateral approach | 117 | 291 | 2.9 | 5% | 21 mean | * 2 pts (10%) residual tumor; 2 pts (10%) died during study
* VAS improved from 7.7 to 2.9 postoperatively
* ODI improved from

52.7% to 24.9% to last f/u* 1 (5%) perioperative complication was a pneumonia
* No injury to lung, vascular structures, infections, or hardware failure
 | * 24% presented with neurologic deficits that improved post-operatively
* 62% required corpectomy
* Portion of rib resected in all patients
 |
| 1. Payer and Sottas, 2008[67](#_ENREF_67)
 | 11 | Mini-openAnterior approachRetractor  | 188 | 711 | NA | 18% | Followed until 1 year | * Mean VAS 1.7 at 6 months postoperatively, 1.4 at 12 months, and 1.0 at 24 months.
* No hardware failure at 6 months
* Dural tear and infection in 2/11 pts (22%)
* 4 pts (36%) reached 12-months; 1 pt (9%) died after 6-month f/u
 | * Anterior approach in all patients
* Table-mounted retractor system used
 |
| 1. Huang et al, 2006
 | 29 | Mini-open Lateral approachCement augmentation | 179 | 1100 | NA | 24% | Followed until 1 year | * Complication rate, 1-year and 2-year survival rates comparable between both groups
* Dural tear 7%, femoral fracture 3%
* 1 year survival rate 66%; 2 year survival rate 41%; overall survival 27.4 months in MIS group
 | * Compared mini-open to open lateral approach
* Rib resected, approach through chest, collapse of right lung.
 |
| **IV. Thoracoscopy /Endoscopy** | **N** | **Technique** | **OT** **(minutes)** | **EBL****(cc)** | **LOS****(days)** | **CR****(%)** | **F/U****(month)** | **Outcomes** | **Findings** |
| 1. Kan and Schmidt, 2008[17](#_ENREF_17)
 | 5 | Thoracoscopy | 258 | 610 | 6.3 | 0% | 6 median | * No complications
* All patients improved preoperative symptoms and neurologic status measured with VAS and Frankel grade respectively
 | * Ventral decompression and corpectomy, interbody reconstruction with expandable cage and anterolateral plating system
* Performed in thoracic spine and thoracolumbar junction
 |
| 1. McLain, 2001[35](#_ENREF_35)
 | 8 | Endoscopy | 360 | 1677 | 6.5 | 0% | 3-36 range | * 6/8 patients with neurologic deficits improved to full strength
* All 8 patients mild or no back pain
* Two patients died of disease 8 and 14 months post-op; remaining 6 were living
 | * Endoscope used to assist with corpectomy in 8 patients
* Posterior screws placed but not percutaneously
 |
| 1. Huang et al, 1997[68](#_ENREF_68)
 | 7 | Thoracoscopy | 155 | 1050 | NA | 11% | NA | * 1 pt converted to open due to pleural adhesion
* Complications included 2 transient intercostal neuralgia, 1 infection, and 1 one residual pneumothorax.
 | * Combo of video-assisted thorascopic surgery (VATS) and traditional, 3 portal or 2 portal approach
* 7 of 12 patients with metastatic lesions
 |
| 1. Dickman et al., 1996[69](#_ENREF_69)
 | 5 | Thoracoscopy | 306 | 1120 | NA | 20% | 8 mean (range 3-20) | * 60% improved at least one neurologic Frankel grade, 40% were stable; 0% deteriorated
* 2 complications were postop MI on POD2 leading to death, and a transient intercostal neuralgia
* Overall comparison showed improved OT, EBL, chest tube days, ICU stay, hospital stay, and narcotic use in the thoracoscopy group, but this was not statistically significant
 | * Part of a larger cohort of 17 patients including fractures and infections
* VATS used for each case
* Compared to 7 patients with open thoracotomy, though not all were tumor
 |
| 1. Mcafee et al., 1995[70](#_ENREF_70)
 | 7 | Thoracoscopy | 333 | 993 | 6.7 | 10% | NA | * Single complication of atelectasis that responded to pulmonary therapy
* 5/7 pts (71%) improved Frankel level from D to E, remaining 2 were stable at D
 | * Stabilization options included rib and fibular autograft, iliac crest, facet plates, and PMMA
 |

**Table 2.** Separation surgery.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Author, Year** | **N** | **Study Description** | **F/U** | **Neurologic** | **Complications** | **Local Recurrence** | **Overall Survival** | **Findings** |
| 1. Bate et al., 2015[41](#_ENREF_41)
 | 21 | Separation surgery | 13.7 median | 81% stable Frankel grade; 14% improved Frankel grade; 5% decline Frankel due to cervical radiculopathy | 2 durotomiesasymptomatic | * 3/21 patients local failure
* Median time to recurrence 8.4 months
 | * 1/3 with failure alive
* mean survival in remaining 2 patients 24.1 months from surgery
 | * 57 patients with 69 lesions; 21 lesions with surgery followed by SRS, remaining 48 lesions treated with SRS alone
 |
| 1. Tatsui et al., 2015[39](#_ENREF_39)
 | 11 | Laser interstitial thermotherapy (LITT) | 4.7 median | VAS 6.18 to 2.8 at 60 days (p<0.05); VAS quality of life improved from 60% to 70% (p>0.05) | None | At median f/u of 4.7 months, 1 patient underwent open surgery, 1 stable, all others had favorable response.  | NA | * High-dose hypofractionated (24–30 Gy in 3 fractions) therapy provided a benefit in local tumor control compared with low-dose (18–36 Gy in 5 to 6 fractions) hypofractionated adjuvant therapy; average procedure length 8 hours; 8/11 pts (73%) started SRS in <4 days
 |
| 1. Al-Omair et al., 2013[40](#_ENREF_40)
 | 80 | Separation surgery | 8.3 median | NA | 9 vertebral compression fractures; 3 GI toxicity; 3 GU toxicity; 7 worsening pain; 1 hardware failure w/ reoperation | 26% local failures at 1 year1 year local control rate was 84%Median time to local failure 6.9 months | 64% overall survival rate | Significant predictors of local control were treatment with 18 – 26 Gy in 1 or 2 fractions (p=0.02) and a postoperative epidural disease grade of 0 or 1 (p=0.003) as significant predictors of LC.  |
| 1. Laufer et al., 2013[37](#_ENREF_37)
 | 186 | Separation surgery | 11 median | No neurologic complications | 4 pts reoperation due to hardware failure; no neurologic complications | 16.4% local recurrence 1 year after SRS | NA | Improvement with high dose postop SRS, significant improvement in local control with high-dose hypofractionated SRS (4.1% cumulative incidence of local progression at 1 year, HR 0.12, p=0.04) as compared with low-dose hypofractionated SRS (22.6% local progression at 1 year). |