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

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| **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 screws  Mini-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 screws  Cement 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 screws  Mini-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 screws  Mini-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 retractor  Percutaneous screws  Cement 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 retractor  Percutaneous screws  Cement 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 retractor  Percutaneous 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-open  Cavity/coblation  Percutaneous screws  Cement 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-open  Percutaneous 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-open  Percutaneous 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 augmentation  Retractor | 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-open  Percutaneous screws  Cement 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-open  Lateral 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-open  Anterior approach  Retractor | 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 approach  Cement 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.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **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 durotomies  asymptomatic | * 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 year  1 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). |