

Table 8 (supplementary material): Study characteristics – baseline parameters

Author Year of publication Design Recruitment period	Procedure	FU N pts at start	N pts at FU	Osteoporosis status	Population pathology (In-and Exclusion criteria)
Cavagna JSDT 2008 "prospective series of patients" 2001-2002	PLF	2-4y 40 pts	39 (1 died)	all pts <-2.5 SD	Disabling chronic low back pain and radicular claudication in connection with a severe lumbar stenosis requiring surgical decompression based on scoliosis rotatory dislocation: 12, degenerative spondylolisthesis: 18, post-decompression instability (total arthroplasties): 6 kyphosis: 3
Chen Osteop Int 2016 RCT Oct 2011-Mar 2012	PLIF	1 year 79 pts	69 (3 expired, 2 deep wound infection, 5 withdrawal) zoledronic: 33, ctrl 36	all pts <-2.5 SD	Inclusion criteria single level degenerative spondylolisthesis with symptoms of low back pain and/or leg pain for ≥ 3 months, after failed nonoperative treatments plus diagnosis of osteoporosis with a BMD at the lumbar or femoral neck with -2.5 SD, measured w/ DXA Exclusion criteria: neoplasm, infection, acute vertebral fractures, history of lumbar surgery, history of antiosteoporosis medication, severe spinal deformities such as degenerative scoliosis, uncorrected bleeding diatheses, renal insufficiency, other metabolic disorders.
Ohtori Spine 2013 RCT Jan 2007 - April 2011	PLF	12 m 62 pts total teriparatide: 20 pts (25 levels) risedronate: 20 pts (26 levels) ctrl: 22 pts (30 levels)	62 pts total teriparatide: 20 pts risedronate: 20 pts ctrl: 22 pts	osteoporosis acc. to Japanese criteria [ref18], BMD measurement	Osteoporotic patients (acc. to Japanese criteria) with lumbar degenerative spondylolisthesis with spinal stenosis Inclusion criteria: (1) more than 5% slip of vertebra in a neutral position or (2) more than 3 mm translation between flexion and extension positions on radiographical evaluation Exclusion criteria: previous spinal surgery, spinal tumor, infection, trauma
Delank Orthopäd 2010 retrospective case series 2002 - 2007	long distance spondylodesis (3 segments or more)	29.4m SD 5.4 70 pts	64 pts	"concomitant osteoporosis" (no details)	Degenerative spine condition with concomitant osteoporosis

Cho ESJ 2015 prospective comparative study with no information on method of group allocation Mar 2011-Nov 2012	PLIF w/ PEEK cage	Teriparatide group: 24.7m SD 2.0 Bisphosphonate group: 29.9m SD 8.1 47 pts	47 Bisphosphonate group: 24 (28 level) Teriparatide group : 23 (27 level)	all pts <-2.5 SD	Inclusion criteria (1) osteoporosis diagnosed by BMD (T-score<-2.5), (2) spinal stenosis, and (3) degenerative spondylolisthesis. Exclusion criteria (1)>three-level surgery, (2) revision surgery after previous lumbar fusion, (3) pathological conditions of the lumbar spine (trauma, tumor, or infection), (4) renal disease, and (5) a long period of steroid use.
Tu JSR 2014 retrospective matched cohort study Jan 2007 - April 2010	PLIF w/ PEEK cage	2y 64 pts (32 pts per group)	64 Zolendronate: 41 level in 32 pts control: 40 level in 32 pts	<u>Zolendronate group:</u> -3.1 ± 0.59 (- 2.5 to -4.9) <u>Control group:</u> -2.9 ± 0.5 (- 2.5 to -4.3)	Included: Patients with diagnosis of osteoporosis based on the WHO criteria (T-score : <-2.5 SD) additional diagnosis of lumbar degenerative spondylolisthesis with spinal stenosis according to x-ray and magnetic resonance imaging Excluded: Patients with previous spinal surgery or spinal tumor, infection, or trauma
Matsumura Spine 2006 retrospective comparative April 2000 - March 2002	pedicles screws combined with PLIF or TLIF	Fenestrated Tube (FT): 34.5m SD 9.6 Open Box (OB): 32.7m SD 4.8 FT: 30 pts OB: 45 pts	Fenestrated Tube (FT): 30 Open Box (OB): 45	Jikei [mean]: FT: 1.3 OB: 1.4	Inclusion criteria: 1) degenerative spondylolisthesis of the L4–L5 disc space, 2) TLIF only performed on the L4–L5 segment, and 3) pedicle screw instrumentation of only the L4 and L5 vertebrae. Exclusion criteria: 1) isthmic spondylolisthesis or 2) degenerative scoliosis
Nagahama JNS 2011 RCT nd	PLIF	12 m 40 pts	36 pts (total) alendronate: 19 control: 17 "Four patients were lost to follow-up because of cerebral hemorrhage, gastrointestinal adverse event due to alendronate, deep wound infection, or withdrawal from participation"	osteoporosis criteria: <70% of the young adult mean value (or <80% of the young adult mean value in postmenopausal women) or the presence of a vertebral fracture related to bone fragility	degenerative spondylolisthesis (29) foraminal stenosis (5) isthmic spondylolisthesis (2)

Wu AOTS 2012 RCT Jan 2004 - Jan 2009	posterior fusion w/ or w/o PLIF, 2 diff. screw designs	24m 157 pts in total: Expandable Pedicle Screws (EPS): 80 pts, 488 screws Conventional Pedicle Screws (CPS): 77 pts 464 screws	142/157 EPS group: 88.8% ==> 71 pts CPS group: 92.2% ==> 71 pts	BMD 2.5 SD or more below the young adult mean (T-score at or below -2.5).	Inclusion criteria: (1) patients having a history of neurogenic claudication or radicular leg symptoms for at least 12 weeks with confirmatory cross-sectional images showing lumbar spinal stenosis at one or more levels, and (2) BMD 2.5 SD or more below the young adult mean (T-score at or below -2.5). Exclusion criteria: (1) underwent surgery before, and (2) diagnosis included spondylolisthesis, spondylolysis, kyphosis, cancer, or pseudarthrosis.
Kim KH JNS 2010 retrospective cohort study Jan 2004 - Dec 2006	Pedicle screws with ALIF w/ and w/o VP	group I ALIF w/ (PSF) alone: 36m (25-42) group II instrumented ALIF w/ ant. PMMA: 34m (25- 58) 62 pts (total) group I ALIF w/ percutaneous Pedicle screw fixation (PSF) alone: 31 pts group II instrumented ALIF w/ anterior PMMA augmentation: 31 pts	<u>Clinical outcome:</u> group I ALIF w/ (PSF) alone: 31 pts group II instr. ALIF w/ ant PMMA [VP]: 30 pts <u>Radiological outcome:</u> group I ALIF w/ (PSF) alone: 24 pts group II instr. ALIF w/ant PMMA [VP]: 22 pts	<u>Mean T-score:</u> ALIF w/ PSF: -3.09 (-2.5 to -4.5) ALIF w/ PSF w/ PMMA: - 3.28 (-2.5 to -4.7)	Inclusion criteria: 1) spondylolisthesis was initially diagnosed; 2) mean T-score of BMD at L1-4 was below -2.5; 3) ASD was not apparent; and 4) patient was followed for more than 2 years. Exclusion criteria: 1) cases involving revision surgery or infection; 2) presence of lumbar disc herniation or stenosis not associated with olisthesis; 3) multilevel instrumentation; and 5) any radiological evidence of vertebral column compression fracture
Xie BMC MD 2011 retrospective cohort study Dec 2000 - Dec 2006	pedicle screws w/ or w/o PMMA augmentation	3.8y SD 1.4 N/A retrospective	31 pts in total PMMA group: 14 pts autograft group: 17 pts	diagnosed as osteoporosis according to the WHO criteria (T < - 2.5), mean T-score was - 3.03 ± 0.34 (-2.5 to -3.8).	degenerative lumbar scoliosis combined with osteoporosis
Jang Nmc 2013 retrospective comparative Mar 2002 - Dec 2005	TLIF w/ PEEK cage w/or w/o HA cement augmentation	2y 34 pts 17 pts in each group	34 pts augmented screws: 17 pts control: 17 pts	T-score < -2.5 augmented: -3.5 SD 0.6 control: -3.3 SD 0.7	Inclusion: spondylolisthesis grade I or II at L4-5 and concomitant osteoporosis

Piñera ESJ 2011 prospective study (?)/data collection Oct 2006 - Feb 2009	spinal fusion with PMMA augmented cannulated pedicle screw instrumentation	32m (20-49) 23 pts	23 pts "we augmented 103 cannulated screws of 58 cemented vertebrae in 23 pts"	All patients had osteoporotic fracture history or bone mineral density criteria for osteoporosis. Lumbar (DEXA) T- score: 2.4 (-1.8 to -4.1).	Included: lumbar degenerative spondylolisthesis with instability or lumbar stenosis requiring aggressive decompression excluded: revision surgery patients
Dai Clinics 2015 nd, consecutive patients June 2010 -Feb 2013	augmented pedicle screws	15.7m SD5.6 43	43 125 CICPSs (cement-injectable cannulated pedicle screw)	all pts <-2.5 SD	osteoporosis and a degenerative spinal disease such as degenerative lumbar spondylolisthesis, lumbar disc herniation/lumbar spinal stenosis, compression fractures and ankylosing spondylitis. All patients had lower back pain and varying degrees of neurogenic issues such as radiating pain, numbness, or muscle weakness in the lower limbs. Each patient had previously undergone at least six months of conservative treatment before surgery. Exclusion criteria included having a blood coagulation disorder, an allergy to any element of the implants and/or a normal BMD
Patil ESJ 2013 retrospective cohort study 2006-2011	Group 1: VP (w/o pedicle screws) Group 2 A: TPD w/ instrumentation Group 2 B: PSO w/ instrumentation Group 2 C: wide posterolateral decompression w/ mesh cage and bone graft w/ instrumentation	34m (12-62) 40 pts total 30 pts w/ instrumentation	40 pts total 30 pts w/ instrumentation	diagnosis OVCF	symptomatic un-united OVCFs, with fracture geometry unsuitable for cement augmentation due to spinal canal compression by fracture fragments

<p>Lee KJS 2011 retrospective case series Feb 2004 - Aug 20077</p>	<p>Posterior fusion with augmented screws (augmentation in vertebral body) w/ and w/o cage</p>	<p>12 m (10-23) NA, retrospective, (157 pts)</p>	<p>157 pts (947 pedicle screws) Group I: 67 pts (469 screws) Compression /burst fractures (62)and idiopathic scoliosis (5) ==> only 8 %2w/ idiopathic scoliosis; include this group because up to 10% "maverick" is allowed Group II: 90 pts (497 screws) Disc Herniation: 21 pts Stenosis w/ or w/o instability: 12 pts, Spondylolisthesis: 57</p>	<p>T-score lower than -3.0 determined by DEXA BMD examination, Group I: -3.93 Group II: -3.72</p>	<p>Group I: 67 pts compression /burst fractures (62)and idiopathic scoliosis (5) Group II: Disc Herniation: 21 pts Stenosis w/ or w/o instability: 12 pts Spondylolisthesis: 57 Included: various spinal diseases including spinal fractures accompanying severe osteoporosis Excluded: tumor or spinal metastasis cases</p>
<p>Yuan ESJ 2015 prospective Jan 2010 - Jan 2012</p>	<p>augmented pedicle screws</p>	<p>12 m 27 (149 screws)</p>	<p>26 (1 died of postoperative pneumonia)</p>	<p>QCT value <80 mg/cm³ which is equivalent to a DXA T-score of -2.5</p>	<p>Osteoporosis diagnosis by QCT and well-defined surgical indication such as relieving pain, neurological decompression and unstable spine fractures</p>
<p>Ayodogan JSDT 2009 retrospective case series 2003-2006</p>	<p>PSF w/VP</p>	<p>37m (24-48) 36 of 49 pts having minimum 2y FU</p>	<p>36 pts</p>	<p>T-Score < -2.5</p>	<p>pts with severe osteoporosis (T-Score < -2.5) who required spine surgery due to neurologic deficit with min. 2 y FU spinal stenosis and deformity: 26 pts vertebra fracture: 6 pts spondylolisthesis: 3 pts spinal tumor metastasis: 1 pt</p>

Hsieh BMS MD 2013 retrospective May 2006-Nov 2010	PLIF with special spacer (I-VEP)	12 m 22 pts in group 1 (short segment fixation with intervertebral expandable pillars (I-VEP)) 24 pts in group 2 <i>Vertebroplasty (not considered in this analysis)</i>	22 pts in group 1 (short segment fixation with intervertebral expandable pillars (I- VEP)) 24 pts in group 2 <i>Vertebroplasty (not considered in this analysis)</i>	no hard data, but indication "osteoporotic thoracolumbar VCF"	Inclusion: intractable back pain due to acute or chronic single level osteoporotic thoracolumbar VCF, pain refractory to nonsurgical treatment for more than 6 months, or bony cleft formation in the vertebral body. Exclusion: primary or metastatic lesions with vertebral fractures, an infectious origin or poor general condition with a high-risk requirement of general anesthesia
El Saman EJTES 2013 retrospective cohort study nd	posterior instrumentation (no interbody implant) w/ or w/o PMMA augmentation	430 days (44- 1467) 24 pts group 1 (no augmentation): 9 pts (86 screws) group 2 (PMMA augmentation): 15 pts (117 screws)	24 pts group 1 (no augmentation): 9 pts group 2 (PMMA augmentation): 15 pts	no details given	vertebral fractures of traumatic origin in the thoracolumbar junction or lumbar spine. [in introduction (aim of study) the fx are labeled osteoporotic, in discussion (first sentence) the population is also labeled osteoporotic]
Kim HS JKNS 2008 retrospective nd	augmented pedicle screws	15m (12-25) 20 pts	20	T-score: mean: -3.62	unstable thoracolumbar burst fractures with severe osteoporosis (T-score < -3.0) in neurologically intact patients, despite severe canal encroachment in the thoracolumbar burst fracture, and the loss of anterior body height exceeding 50% and with more than 20° of sagittal angulation.

Kim WJ CORR 2006 retrospective case series Sep 2001 - Nov 2004	anterior- posterior correction w/ or w/o vertebroplasty	more than 2 y 32 pts	32 pts in total 24 w/ vertebroplasty or pedicle augmentation (VP group) 8 w/o vertebroplasty or pedicle augmentation in patients with weak screw purchase in the time when it was reimbursed (non - VP group)	The fracture was considered an osteoporotic fragility fracture if the fracture was occult or developed with an everyday trauma in an osteoporotic spine with a BMD T-score of less than -2.5.	The inclusion criteria were symptomatic gross sagittal imbalance caused by osteoporotic fragility fractures including those caused by osteoporotic fractures occurring in the juxtafusional segments and within the previous instrumented segments. The fracture was considered an osteoporotic fragility fracture if the fracture was occult or developed with an everyday trauma in an osteoporotic spine with a BMD T-score of less than -2.5. Multiple fractures showing morphologic characteristics of osteoporotic fractures histories of diligent osteoporosis treatment after the discovery of the fragility fractures were considered fragility fractures even if the T-score was greater than -2.5. The exclusion criteria were acute osteoporotic fractures: deformities without gross sagittal imbalances; posttraumatic deformities from recallable high- energy injuries during the patients' youths; lack of substantial functional derangement caused by the sagittal plane deformities; deformities associated with infective complications of previous surgeries; undue difficulties regarding the anterior approach (eg. previous retroperitoneal surgery, severe arterial calcifications); and severe weakening of the gluteus maximus
Pflugmacher JOT 2009 prospective case series June 2002 - Aug 2005	short posterior fixation and kyphoplasty	12 m 25 pts, 25 levels	21	"The diagnosis was established by patient history and radiographic evaluation. In most patients, DEXA measurement was performed postoperatively [...]"	osteoporosis and traumatic, painful A3-type fractures, according to the AO classification
Gu JOSR 2015 nd, Nov 2010-Aug 2011	screws & VP	MIPS group: 27.2m SD 2.5 31 pts (MIPS group)	31 (MIPS group) <i>[also PVP (percutaneous vertebroplasty) group w/ 37 pts. but not considered here]</i>	T-score: -3.5 ± 0.9	osteoporotic vertebral compression (AO: A-1) w/ o neuro deficit

Yamana ESJ 2010 case series, no info whether pro- or retrospective, not clear if patient consent refers to procedure or study participation 2000 - 2008	posterior fusion with PMMA augmented pedicle rod and nail system.	37m 34 pts	34 pts additional "augmentation" w/ HA sticks: 16 pts	"osteoporotic compression fractures "	paraplegia and/or persistent pain from osteoporotic compression fractures
Nakashima H JMS 2014 retrospective nd	PLF w/ALIF	3.8y (0.6-11.3) 35 pts	35	no info	neurological deficit after osteoporotic vertebral fracture
Nakashima H Spine 2015 retrospective comparative 1997-2010	AP group: pedicle screws and interbody fusion VP group: pedicle screws w/ VP	AP group: 45.3m SD 21.2 VP group: 39.8m SD 12.7 total: 45 pts AP group: 24 pts VP group: 21 pts	total: 45 AP group: 24 VP group: 21	"Osteoporotic Delayed Vertebral Fracture "	Included: Patients with Osteoporotic Delayed Vertebral Fracture in the thoracolumbar region (T10-L2) and progressive neurological deficits and/or continuous severe lower back pain caused by vertebral collapse with a minimum FU of 24 months Excluded: Patients with metastatic spinal tumors, degenerative spinal stenosis, and/or a previous spinal surgical history

<p>Nakajima JNS 2016 retrospective 1993-2013</p>	<p><u>w/ cleft (14 pts):</u> VP: 2 decompression & VP & PSF & PLF: 12 <u>w/o cleft (n = 16):</u> decompression, PSF, and PLF: 10 posterior lumbar interbody fusion (PLIF): 4 correction osteotomy (Ponte osteotomy, PSO, and vertebral column resection [VCR]): 2</p>	<p>2.4y (1-4.5) 30 pts (28 pts w/ pedicle screws assuming VCR involves pedicle screws)</p>	<p>30 Pts w/ cleft: 14 (all w/VP), 14% (2) w/o pedicle screws Pts w/o cleft: 16 (none w/ VP)</p>	<p>lumbar spine BMD (g/cm²) pts w/ comps: 0.60 ± 0.08 pts w/o comps: 0.68 ± 0.05</p>	<p>low lumbar osteoporotic vertebral collapse (OVC)</p>
<p>Kashii ESJ 2013 retrospective cohort study 2000 - 2009</p>	<p>various, always screw and rod system involved anterior neural decompression and reconstruction (AR): 27 pts posterior spinal shortening osteotomy with direct neural decompression (PS): 36 pts posterior indirect neural decompression and short segment spinal fusion combined with VP using CP: 25 pts</p>	<p>35.5m (24-123) 88 pts</p>	<p>88 pts (total) anterior neural decompression and reconstruction (AR): 27 pts posterior spinal shortening osteotomy with direct neural decompression (PS): 36 pts posterior indirect neural decompression and short segment spinal fusion combined with VP using CP: 25 pts</p>	<p>no details; only indication "osteoporotic vertebral collapse"</p>	<p>OVC w/ neuro deficit</p>

Uchida JNS 2010 retrospective cohort nd	pedicle screws (SSF) w/ or w/o VP by means of HA blocks or CPC filling	total: 4.4 y Group A, 3.9 y Group B, 4.7 y Group C, 4.5 y <i>not considered</i> 83 pts (total), 53 pts considered here	83 pts (total), 53 pts considered here A: SSF + vertebroplasty + HA blocks or CPC filling: 28 pts B: Short Segment Fixation (SSF): 25 pts C: <i>anterior procedure</i> (<i>not considered here</i>): 30 pts	According to the radiographic classification of bone atrophy, 37 the severity of osteoporosis was greater than Saville Grade II (vertical striation is more obvious; endplates are thinner) in all patients	osteoporotic vertebral collapse at a single level of the thoracolumbar junction associated with neurological deficits
Sudo ESJ 2010 retrospective case series nd	posterior fusion w/ or w/o vertebroplasty	42m 21 pts (NA)	21 pts	pts treated for "osteoporotic vertebral collapse"	Surgical indication for this study was vertebral collapse in the thoracic or lumbar spine with neurological problems and difficulty in walking due to paralysis of the lower extremities, which decreased the patients' quality of daily life.
Sawakami JSDT 2012 retrospective cohort 1999-2006	38 pts total (2 had died) w/ PMMA augmented pedicle screws: 17 pts w/ non- augmented pedicle screws: 21 pts	31 m 40 pts	38 pts total (2 had died) w/ PMMA augmented pedicle screws: 17 pts w/ non-augmented pedicle screws: 21 pts	> grade 1 acc.to the Jikei University Classification, significantly higher grade in augmented group	osteoporotic vertebral fracture with neurological symptoms and pseudarthrosis after conservative treatment

ALIF: anterior lumbar interbody fusion, AO: Arbeitsgruppe Osteosynthese, ASD: adjacent segment degeneration, BMD: bone mineral density, CPC: calcium phosphate cement, D(E)XA: dual energy x-ray absorptiometry, FU: follow-up, HA: Hydroxyapatite, OVCF: osteoporotic vertebral compression fracture, PEEK: Polyetheretherketone, PLIF: posterior lumbar interbody fusion, PMMA: Polymethylmethacrylate, PSF: Pedicle screw fixation, PSO: pedicle subtraction osteotomy, QCT: quantitative computed tomography, SD: standard deviation, SSF: short segment fixation, TLIF: transforaminal lumbar interbody fusion, TPD: trans pedicular decompression, WHO: World Health Organization, VCF: vertebral compression fracture, w/: with, w/o: without, m: months, pt: patient, pts: patients y: year(s)