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# Restoration of Sagittal Alignment and Pulmonary Function With Percutaneous Vertebral Body Augmentation for Painful Osteoporotic Vertebral Compression Fractures: A Systematic Review

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## Abstract

Sagittal spinal malalignment is associated with functional disability. Therefore, a key question in treating patients with painful osteoporotic vertebral compression fractures (OVCFs) is whether vertebral augmentation improves sagittal alignment and its associated outcomes. In a systematic literature review based on interventional and observational studies, we evaluated the effect of percutaneous vertebral body augmentation on sagittal alignment and pulmonary function in patients with painful OVCFs. In November 2022 and December 2023, we searched for relevant studies in Medline, Embase, SCOPUS, Web of Science, the Cochrane Central Registry of Controlled Trials, and five trial registries. In total, 15 cohort studies and two non-randomized clinical trials met our inclusion criteria. Participants in these studies had painful OVCFs treated with vertebral body augmentation. Sagittal alignment outcomes from nine articles represented 456 participants with mean ages from 69.3 to 80.8 years, and pulmonary function outcomes from eight articles represented 343 participants with mean ages from 69.1 to 75.7 years. The quality assessment tool for quantitative studies by the Effective Public Health Practice Project assessed the risk of bias (RoB). Mean pre- and postoperative outcome values were calculated for all included studies and those without a high RoB. None of the sagittal alignment parameters improved after vertebral augmentation, and no additional deformity was detected. Vertebral augmentation positively affected pulmonary function, as measured by the percentage of predicted values, and reduced perceived pain levels and functional disability. Data in the included studies were incomplete due to variability in chosen outcomes and follow-up time points. The incomplete data curtailed our data analysis and only allowed cautious conclusions. Variations in study populations and protocols highlight the need for standardized reporting and follow-up in future research.

**Categories:** Orthopedics, Neurosurgery
**Keywords:** osteoporotic fracture, postural balance, pulmonary function, sagittal alignment, vertebral augmentation, vertebral compression fracture

## Introduction And Background

Appropriate management of painful osteoporotic vertebral compression fractures (OVCFs) remains an ongoing topic of debate. Worldwide, the estimated number of individuals with a 10-year probability of a major osteoporotic fracture is expected to increase from 158 million in 2010 to 371 million in 2040 [1], with vertebral fractures accounting for 16% of fragility fractures in Europe [2].

Effective pain management is a crucial step toward restoring normal activities of daily living in patients with painful OVCFs. Consequently, randomized controlled trials (RCTs) [3-5] and a Cochrane review [6] focused on pain reduction and safety of vertebral body augmentation for the treatment of OVCFs.

Spinal malalignment due to OVCFs is associated with functional disability [7,8] as the spine becomes malaligned due to a combination of aging [9], osteoporosis, and OVCFs [10,11]. OVCFs, in turn, are associated with decreased quality of life [12,13], smaller chest volume, and decreased pulmonary function [14-16].

Sagittal spine alignment is strongly associated with clinical outcomes [17]. Radiographic parameters were measured in only three of the nine most cited RCTs on vertebral body augmentation, and none of the studies included outcomes on sagittal alignment [18]. In addition, a recent systematic review on the impact of vertebral augmentation on pulmonary function is not available. We, therefore, conducted a systematic literature review on radiographic outcomes from both interventional and observational studies to determine if percutaneous vertebral body augmentation (1) protects or restores sagittal alignment and (2) improves pulmonary function in patients with painful OVCFs.

## Review

### Methodology

*Study Design and Research Question*

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The protocol for this systematic review was registered on September 9, 2022, on the International Prospective Register of Systematic Reviews (PROSPERO) and https://www.crd.york.ac.uk/PROSPERO/view/CRD42022349164 is the location it can be accessed at. Prior to registration, a search on PROSPERO was performed to confirm that no identical literature reviews were in progress. The critical appraisal tool, a Measurement Tool to Assess Systematic Reviews (AMSTAR 2) [19], was used as a guide to conduct the review, and it is presented according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline [20].

The review was designed to estimate any effect of vertebral body augmentation on sagittal alignment and pulmonary function using the PICO model: (P) populations of individuals with painful OVCFs; (I) interventions in which bone cement is injected into the vertebrae percutaneously; (C) comparison to individuals receiving non-surgical treatment (alternatively, two vertebral augmentation procedures are compared, or a longitudinal cohort study includes only before and after intervention comparison); and (O) outcome measures associated with spinal sagittal alignment and pulmonary function.

*Information Sources and Searches*

We searched five bibliographic databases for published and accepted articles: Medline, Embase, SCOPUS, Web of Science, and the Cochrane Central Registry of Controlled Trials. In addition, we searched five trial registries for relevant ongoing studies and clinical study reports: ClinicalTrials.gov, the WHO International Clinical Trials Registry Platform, the EU Clinical Trials Register, the International Standard Randomised Controlled Trial Number registry, and the Medical Research Council Clinical Trials Unit.

T.F.F., an experienced information specialist, reviewed the multi-stranded search strategy before H.J. completed all searches from the inception of each bibliographic database until November 1 and December 31, 2022. H.J. first searched the trial registries on November 2, 2022. Updates to searches in all bibliographic databases and trial registers were conducted on December 6, 2023. The tables in Appendix 1 outline the details of search histories for the bibliographic databases.

In a supplementary search, H.J. scrutinized the cited literature in all systematic reviews and meta-analyses from the list of retrieved articles, studies included in our review, and a Cochrane review by Buchbinder et al. [6] to identify further relevant articles to be entered into the screening and reviewing process.

*Eligibility Criteria*

This systematic review includes full-text publications reporting results from RCTs and observational studies (cohort and case/control studies). We excluded technical notes, review papers, meta-analyses, case reports, expert opinions, economic analyses, and publications with incomplete database information. When studies reported results unsuitable for analyses, the authors were contacted to ask for results in a format that would enable inclusion.

We included studies only on percutaneous procedures (not open procedures). Studies were included if the intervention included combined bone cement and a vertebral expander, such as Osseofix®, Spine Jack, SKy Bone Expander, intravertebral expandable pillar, vertebral body stenting, or similar products.

We excluded studies on vertebral body augmentation in combination with spinal fusion or instrumentation (such as pedicle screws or intervertebral cages), as well as augmentation using fillers other than bone cement. Studies on cadaveric spines, model organisms, prophylactic vertebral augmentation, and sacroplasty were excluded.

Eligible study populations consisted of persons with osteoporosis who had vertebral compression fractures (VCFs) and experienced pain from their fractures. Therefore, patients included in each study should meet these inclusion criteria: a vertebral fracture is present (no specific compression ratio), and pain from a fractured vertebra is present (no specific time period).

Publications or treatment groups were excluded from the review if they reported on vertebral augmentation in patients with the following conditions: spinal infection, spinal deformity not secondary to osteoporosis, primary tumors or metastases in the spine, or spinal re-fractures after previous augmentation.

As pain from the fractured vertebra(e) is the primary indication for treatment with vertebral body augmentation, we also included studies that did not specifically mention pain from the fracture(s). Likewise, we assumed that vertebral augmentation was not offered to patients with spinal deformities unrelated to osteoporosis unless specifically noted. Studies that did not specifically mention how patients were diagnosed with osteoporosis were accepted, as low-energy vertebral fractures are an indication of osteoporosis.

If a study included eligible and ineligible patients in the same cohort, we asked the authors if they would share their raw, de-identified data so that we could extract data for eligible patients only. If a study reported results for cohorts of all eligible patients, we included data for patients in these cohorts in our data synthesis.

Articles and trial reports in English, German, Norwegian, Swedish, and Danish were included, allowing the reviewers to conduct full-text appraisals of eligible articles.

*Screening and Study Selection Process*

All articles retrieved from searches in the five databases were exported to EndNote (Clarivate, Philadelphia, PA, USA), merged, and duplicates removed. The resulting publications were exported to Covidence (Melbourne, Australia), where additional duplicates were removed.

H.J. screened all titles and abstracts. L.C., L.W., and B.K. shared the role of independent second reviewer of titles and abstracts, and M.A. resolved any conflicts. L.C. and M.A. independently assessed full texts for potential inclusion and solved consensus-based disputes. Study characteristics were registered in two templates; one contains information reported in Tables *1-2*, and the other contains additional details reported in Appendix 2. Reasons for excluding full-text articles were (1) the intervention was not relevant, (2) the outcomes were not relevant or the data format did not allow extraction and analysis, or (3) the study population was not relevant (Appendix 3).

| Authors | Year | Study design | Inclusion period | Intervention | Edema on MRI | Symptom duration | n | Male-to-female ratio | Mean age | Mean follow-up (months) |
|---|---|---|---|---|---|---|---|---|---|---|
| Cao et al. [21] | 2020 | Longitudinal observational cohort study | 2013-2018 | KP | Yes | NA | Overall: 90<br>MT: 9<br>TL: 71<br>LU: 10 | Overall: 20:70<br>MT: 3:6<br>TL: 14:57<br>LU: 3:7 | 69.3 | 0.1 |
| Erkan et al. [22] | 2009 | Longitudinal comparative cohort study, prospective | 2006-2007 | KP | Yes | Acute: <2 months<br>Chronic: NA | Overall: 28<br>Acute: 15<br>Chronic: 13 | Overall: 8:20<br>Acute: 4:11<br>Chronic: 4:9 | Acute: 70<br>Chronic: 74 | 18 |
| Kanayama et al. [23] | 2015 | Longitudinal observational cohort study | NA | KP | No | 3.4 months | Overall: 56 | 7:49 | 75.3 | 32 |
| Kim et al. [24] | 2022 | Longitudinal observational cohort study | 2010-2017 | PVP | NA | NA | No recollapse: 106 | 23:83 | 77.5 | 24 |
| Oishi et al. [25] | 2020 | Longitudinal observational cohort study | 2012-2015 | KP | NA | 4.2 months | No AVF: 23 | 4:19 | 80.8 | 24 |
| Pumberger et al. [26] | 2020 | Longitudinal observational cohort study | 2014-2018 | KP | NA | 4.7 weeks | Overall: 73 | 26:47 | 70 | 0.1 |
| Su et al. [27] | 2022 | Longitudinal observational cohort study | 2020 | PVP | NA | NA | Overall: 42 | 8:34 | 80.74 | 3 |
| Sutipornpalangkul et al. [28] | 2016 | Longitudinal observational cohort study | 2007-2014 | KP | Yes | NA | KP: 17 | 6:11 | 78.29 | 0.25 |
| Yokoyama et al. [29] | 2015 | Longitudinal observational cohort study | 2013-2014 | KP | Yes | NA | Overall: 21 | NA | 77.1 | 1 |

**TABLE 1: Study characteristics for included articles reporting on the effect of vertebral body augmentation on sagittal alignment outcomes**

PVP: percutaneous vertebroplasty, KP: kyphoplasty, MT: main thoracic (T1 to T9), TL: thoracolumbar (T10 to L2), LU: lumbar (L3 to L5), MRI: magnetic resonance imaging, NA: not available, AVF: adjacent vertebral fracture

| Authors | Year | Study design | Inclusion period | Intervention | Edema on MRI | Symptom duration | n | Male-to-female ratio | Mean age | Mean follow-up (months) |
|---|---|---|---|---|---|---|---|---|---|---|
| Dong et al. [30] | 2009 | Non-randomized clinical trial | 2006-2008 | | NA | NA | Overall: 38 | Overall: 0:38 | | 3 |
| | | | | PVP | | | PVP: 18 | | PVP: 70.2 | |
| | | | | KP | | | KP: 20 | | KP: 69.5 | |
| Greven et al. [31] | 2017 | Longitudinal observational cohort study | NA | KP | NA | NA | Overall: 25 | Overall: 11:14 | 70.4 | 1 |
| | | | | | | | TH: 4 | | | |
| | | | | | | | TL: 16 | | | |
| | | | | | | | LU: 5 | | | |
| Lee et al. [32] | 2011 | Longitudinal observational cohort study | 2005-2006 | PVP | NA | Acute | Overall: 72 | 10:62 | 75.7 | 3 |
| Masala et al. [33] | 2014 | Longitudinal observational cohort study | NA | PVP | Yes | <3 months | Overall: 45 | 49:16 | 71.4 | 12 |
| Sheng et al. [34] | 2015 | Longitudinal observational cohort study | NA | KP | NA | NA | Overall: 31 | NA | 71.2 | 3 |
| Tanigawa et al. [35] | 2008 | Longitudinal observational cohort study | 2005 | PVP | NA | NA | Overall: 41 | 2:39 | 72.0 | 1 |
| Wu et al. [36] | 2018 | Non-randomised clinical trial | 2013-2015 | | Yes | NA | Overall: 69 | Overall: 10:51 | 71.5 | 12 |
| | | | | KP | | | KP: 31 | KP: 6:25 | | |
| | | | | PVP | | | PVP: 30 | PVP: 4:26 | | |
| Yang et al. [37] | 2007 | Longitudinal observational cohort study | NA | KP | NA | NA | Overall: 30 | 0:30 | 69.1 | 1 |

**TABLE 2: Study characteristics for included articles reporting on the effect of vertebral body augmentation on pulmonary function outcomes**

PVP: percutaneous vertebroplasty, KP: kyphoplasty, TH: thoracic (T8 to T11), TL: thoracolumbar (T12 to L2), LU: lumbar (L3 to L4), MRI: magnetic resonance imaging, NA: not available

*Outcomes and Data Extraction*

L.C. manually extracted and entered the data into Microsoft Excel (Microsoft Corp., Redmond, WA, USA). H.J. verified the extracted data. Initially, we extracted data for all sagittal alignment and pulmonary function outcomes to get an overview of available data (Tables *3*-*4*). The key measure of spinal sagittal alignment is the sagittal vertical axis (SVA [38]), and the postoperative change in SVA is the primary outcome in this study. We also included other radiographic spinopelvic measures that allowed comparisons of patients' sagittal alignment before and after vertebral body augmentation (Figure *1*): pelvic incidence (PI) [39], sacral slope (SS) [40], pelvic tilt (PT) [40], thoracic kyphosis (TK) [38], lumbar lordosis (LL) [38], spino-sacral angle (SSA) [41], T1 pelvic angle (TPA) [42], and PI-LL [43].

| Author | Cao et al. [21] | Cao et al. [21] | Cao et al. [21] | Cao et al. [21] | Erkan et al. [22] | Erkan et al. [22] | Kanayama et al. [23] | Kim et al. [24] | Oishi et al. [25] | Pumberger et al. [26] | Su et al. [27] | Sutipornpalangkul et al. [28] | Yokoyama et al. [29] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2020 | 2020 | 2020 | 2020 | 2009 | 2009 | 2015 | 2022 | 2020 | 2022 | 2022 | 2016 | 2015 |
| Inclusion period | 2013-2018 | 2013-2018 | 2013-2018 | 2013-2018 | 2006-2007 | 2006-2007 | - | 2010-2017 | 2012-2015 | 2014-2018 | 2020 | 2007-2014 | 2013-2014 |
| Intervention group | KP_ MT | KP_ TL | KP_ LU | KP_ All | KP_ Acute | KP_ Chronic | KP | PVP_ NoRe collapse | KP_AVF | KP | PVP | KP | KP |
| N | 9 | 71 | 10 | 90 | 15 | 13 | 56 | 106 | 23 | 73 | 42 | 17 | 21 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean age | 69.6 | 68.8 | 72.1 | 69.3 | 70 | 74 | 75.3 | 77.5 | 80.8 | 70 | 80.7 | 78.3 | 77.1 |
| Mean follow-up (months) | 0.1 | 0.1 | 0.1 | 0.1 | 18 | 18 | 32 | 24 | 24 | 0.1 | 3 | 0.25 | 1 |
| Pre_ODI | - | - | - | - | 86.0 | 86.0 | - | - | - | - | 83.1 | - | - |
| AnyPost_ODI | - | - | - | - | 54.0 | 44.0 | - | - | - | - | 21.2 | - | - |
| PreOVCF_BI | - | - | - | - | - | - | - | - | - | - | 79.5 | - | - |
| Pre_BI | - | - | - | - | - | - | - | - | - | - | 57.4 | - | - |
| AnyPost_BI | - | - | - | - | - | - | - | - | - | - | 96.5 | - | - |
| Pre_VAS | - | - | - | - | - | - | 55.0 | - | - | 37.0 | - | - | 79.8 |
| AnyPost_VAS | - | - | - | - | - | - | 20.0 | - | - | 17.0 | - | - | 23.8 |
| Post6wk_VAS_%diff | - | - | - | - | 59.0 | 48.0 | - | - | - | - | - | - | - |
| Post3mo_VAS_%diff | - | - | - | - | 50.0 | 46.0 | - | - | - | - | - | - | - |
| Post6mo_VAS_%diff | - | - | - | - | 47.0 | 43.0 | - | - | - | - | - | - | - |
| Post12mo_VAS_%diff | - | - | - | - | 44.0 | 41.0 | - | - | - | - | - | - | - |
| Post18mo_VAS_%diff | - | - | - | - | 42.0 | 37.0 | - | | - | - | - | - | - |
| Pre_SVA (mm) | - | - | - | 14.5 | 83.0 | 97.0 | 31.0 | 21.0 | 76.8 | 50.8 | 49.0 | - | 70 |
| AnyPostSVA | - | - | - | 5.8 | 74.0 | 86.0 | 59.0 | 22.0 | 73.7 | 40.5 | 37.8 | - | 50.2 |
| Post12mo_SVA | - | - | - | - | 74.0 | 86.0 | - | 22.0 | 84.7 | - | - | - | - |
| Pre_SSA | - | - | - | 119.2 | - | - | - | - | - | - | 114.1 | - | 106.2 |
| AnyPost_SSA | - | - | - | 121.7 | - | - | - | - | - | - | 114.9 | - | 111.5 |
| Pre_TPA | - | - | - | 18.7 | - | - | - | - | - | - | 23.0 | - | - |
| AnyPost_TPA | - | - | - | 16.7 | - | - | - | - | - | - | 20.7 | | - |
| Pre_PI | - | - | - | 52.2 | - | - | - | - | - | 56.1 | - | - | 54.6 |
| AnyPost_PI | - | - | - | - | - | - | | - | - | 55.6 | - | - | 54.9 |
| Pre_PI-LL | - | - | - | 9.3 | - | - | - | - | - | - | - | - | - |
| AnyPost_PI-LL | - | - | - | 3.7 | - | - | - | - | - | - | - | - | - |
| Pre_SS | - | - | - | 30.0 | - | - | - | - | - | 35.9 | - | - | 28.8 |
| AnyPost_SS | - | - | - | 31.7 | - | - | - | - | - | 35.9 | - | - | 27.2 |
| Pre_PT | - | - | - | 24.0 | - | - | - | - | - | 20.7 | - | - | 25.3 |
| AnyPost_PT | - | - | - | 22.1 | - | - | - | - | - | 20.9 | - | - | 26.0 |
| Pre_LL | - | - | - | 48.4 | - | - | - | - | - | 33.2 | 36.0 | - | 41.8 |
| AnyPost_LL | - | - | - | 50.2 | - | - | - | - | - | 34.7 | 37.9 | - | 44.7 |
| Pre_TK | - | - | - | 37.8 | - | - | - | 21.7 | - | 46.8 | 25.8 | - | - |
| AnyPost_TK | - | - | - | 36.7 | - | - | - | 23.1 | - | 46.1 | 14.9 | - | - |

## TABLE 3: Input data for sagittal alignment outcomes in all relevant cohorts

Due to variation in follow-up time points, results from one day postoperatively to the last follow-up were combined into AnyPost. SVA was the most commonly selected effect measure in the included studies.

PVP: percutaneous vertebroplasty, KP: kyphoplasty, BI: Barthel index, SVA: sagittal vertical axis, ODI: Oswestry Disability Index, OVCF: osteoporotic vertebral compression fracture, VAS: Visual Analogue Scale, %diff: percentage difference, SSA: spino-sacral angle, TPA: T1 pelvic angle, PI: pelvic incidence, PI-LL: pelvic incidence minus lumbar lordosis, SS: sacral slope, PT: pelvic tilt, LL: lumbar lordosis, TK: thoracic kyphosis, KP: kyphoplasty, MT: main thoracic, TL: thoracolumbar, LU: lumbar, AVF: adjacent vertebral fracture, Pre: preoperatively, AnyPost: any time postoperatively, Post6wk: six weeks postoperatively, Post3mo: three months postoperatively, Post6mo: six months postoperatively, Post12mo: 12 months postoperatively, Post18mo: 18 months postoperatively

| Authors | Dong et al. [30] | Greven et al. [31] | Greven et al. [31] | Greven et al. [31] | Greven et al. [31] | Lee et al. [32] | Masala et al. [33] | Sheng et al. [34] | Tanigawa et al. [35] | Wu et al. [36] | Wu et al. [36] | Yang et al. [37] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2009 | 2017 | 2017 | 2017 | 2017 | 2011 | 2014 | 2015 | 2008 | 2018 | 2018 | 2007 |
| Inclusion period | 2006-2008 | - | - | - | - | 2005-2006 | 2011-2013 | - | 2005 | 2013-2015 | 2013-2015 | - |
| Intervention | PVP | KP_Th8-11 | KP_Th12-L2 | KP_L3-4 | KP_All | PVP | PVP | KP | PVP | PVP | KP | KP |
| N | 18 | 4 | 16 | 5 | 25 | 72 | 45 | 31 | 41 | 30 | 31 | 30 |
| Mean age | 70.2 | - | - | - | 70.4 | 75.7 | 71.4 | 71.2 | 72.0 | 73.6 | 71.5 | 69.1 |
| Mean follow-up (mo) | 3 | 1 | 1 | 1 | 1 | 3 | 12 | 3 | 1 | 12 | 12 | 1 |
| Pre_VAS | 83.0 | 77.4 | 78.5 | 62.4 | 75.1 | 79.0 | 77.0 | 80.0 | 70.0 | - | - | - |
| AnyPost_VAS | 29.0 | 15.6 | 0.0 | 15.8 | 5.7 | 17.0 | 22.0 | 23.0 | 19.0 | - | - | - |
| Post12mo_VAS | - | - | - | - | - | - | 2.1 | - | - | - | - | - |
| Pre_ODI | - | 73.4 | 66.5 | 53.3 | 65.0 | - | - | - | - | - | - | - |
| Post1mo_ODI | - | 18.5 | 2.5 | 18.2 | 8.2 | - | - | - | - | - | - | - |
| Pre_VC | 2.4 | - | - | - | - | - | - | - | - | 2.3 | 2.2 | 2.4 |
| AnyPost_VC | 2.4 | - | - | - | - | - | - | - | - | 2.5 | 2.5 | 2.5 |
| Pre_VC | - | - | - | - | - | - | - | - | - | 2.3 | 2.2 | - |
| Post12mo_VC | - | - | - | - | - | - | - | - | - | 2.5 | 2.5 | |
| Pre_TLC | 4.1 | - | - | - | - | - | - | - | | - | - | 4.0 |
| AnyPost_TLC | 4.1 | - | - | - | - | - | - | - | - | - | - | 4.0 |
| Pre_FVC | 2.2 | - | - | - | - | - | - | - | - | 2.2 | 2.1 | 2.2 |
| AnyPost_FVC | 2.4 | - | - | - | - | - | - | - | - | 2.3 | 2.3 | 2.3 |
| Pre_FVC | - | - | - | - | - | - | - | - | - | 2.2 | 2.1 | - |
| Post12mo_FVC | - | - | - | - | - | - | - | - | - | 2.3 | 2.3 | |
| Pre_MVV | 57.7 | - | - | - | - | - | - | - | - | 54.4 | 54.2 | 57.6 |
| AnyPost_MVV | 60.7 | - | - | - | - | - | - | - | - | 63.2 | 62.7 | 60.7 |
| Post12mo_MVV | - | - | - | - | - | - | - | - | - | 63.2 | 62.7 | - |
| Pre_VC% | - | - | - | - | - | - | 81.5 | - | - | - | - | - |
| Post12mo_VC% | - | - | - | - | - | - | 98.6 | - | - | - | - | - |
| Pre_FEV1% | - | 73.0 | 71.0 | 72.0 | 71.5 | 58.3 | 97.4 | 60.2 | 77.0 | 62.2 | 61.0 | - |
| AnyPost_FEV1% | - | 91.0 | 86.0 | 86.0 | 86.8 | 68.0 | 97.4 | 60.8 | 77.6 | 63.5 | 61.6 | - |
| Pre_FEV1% | - | - | - | - | - | - | 97.4 | - | 77.0 | 62.2 | 61.0 | - |
| Post12mo_FEV1% | - | - | - | - | - | - | 97.4 | - | 77.6 | 63.5 | 61.6 | - |
| Pre_FVC% | - | - | - | - | - | 58.0 | 77.8 | 74.3 | 85.2 | - | - | - |
| AnyPost_FVC% | - | - | - | - | - | 76.0 | 98.2 | 84.9 | 91.5 | - | - | - |
| Pre_FVC% | - | - | - | - | - | - | 77.8 | - | 85.2 | - | - | - |
| Post12mo_FVC% | - | - | - | - | - | - | 98.2 | - | 91.5 | - | - | - |

### TABLE 4: Input data for pulmonary function outcomes in all relevant cohorts

Due to variation in follow-up time points, results from day 1 postoperatively to the last follow-up were combined into a single category, AnyPost. When available, separate results for 12 months postoperatively were included. FEV1% was the most commonly selected effect measure in the included studies.

PVP: percutaneous vertebroplasty, KP: kyphoplasty, FEV1%: percentage of predicted forced expiratory volume in one second, VAS: Visual Analogue Scale, ODI: Oswestry Disability Index, VC: vital capacity, TLC: total lung capacity, FVC: forced vital capacity, MVV: maximum voluntary ventilation, VC%: percentage of predicted vital capacity, FVC%: percentage of predicted forced capacity, Pre: preoperatively, AnyPost: any time postoperatively, Post12mo: 12 months postoperatively, Post1mo: one month postoperatively

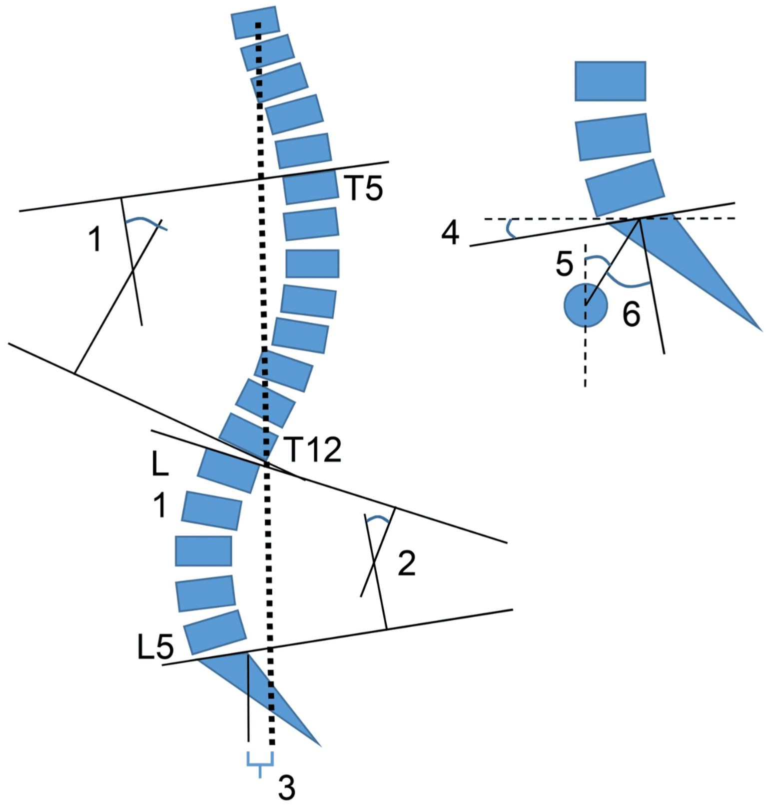



**FIGURE 1: Sagittal alignment outcomes in included articles**

Outcomes were measured on standing radiographs. Results from each study are presented in Table 3.

TK: thoracic kyphosis, LL: lumbar lordosis, SVA: sagittal vertical axis: distance between reference and C7 plumb line, SS: sacral slope, PT: pelvic tilt, PI: pelvic incidence

We identified six studies that reported on sagittal alignment outcomes for participants with osteoporosis but no VCFs [11,44-48]. By comparing results from the included study populations to those for elderly osteoporosis patients without VCFs, we could gauge the severity of malalignment in the included study populations.

For the pulmonary outcomes, the following data points were collected: vital capacity (VC) [49], total lung capacity (TLC) [49], forced vital capacity (FVC) [49], maximum voluntary ventilation (MVV) [50], percentage of predicted vital capacity (VC%), percentage of predicted forced expiratory volume in 1 second (FEV1%), and percentage of predicted forced capacity (FVC%) (predictions according to the American Thoracic Society [51]).

Patient-reported outcomes, including the Oswestry Disability Index (ODI) [52] and pain scores (Visual Analogue Scale (VAS)) [53], were collected when available.

*Risk-of-Bias Assessment*

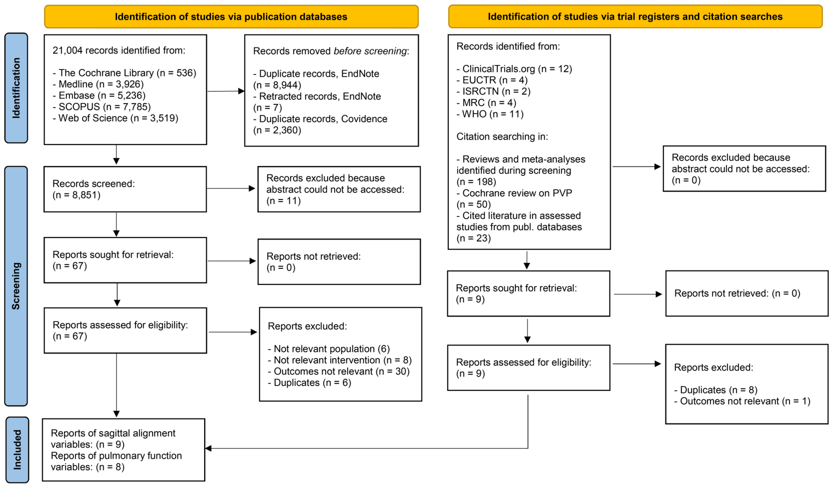
M.A. and H.J. independently assessed the risk of bias (RoB) for each study using the quality assessment tool for quantitative studies by the Effective Public Health Practice Project (EPHPP) [54]. The EPHPP tool can be applied to randomized and observational studies, assessing potential bias due to six study characteristics: selection of study population, study design, confounders, incomplete blinding of assessors and participants, data collection methods, and withdrawals and dropouts. M.A. and H.J. agreed to assess each category of potential bias and discuss any discrepancies. Results from the RoB assessment are reported using the online RobVis visualization tool (McGuinness LA and Higgin JP, Bristol, UK).

*Data Synthesis*

A weighted average was calculated for each of the outcomes of interest. A sub-analysis excluding cases with a high RoB was also performed. We did not perform a meta-analysis due to the considerable heterogeneity among the included studies. The differences in study designs, populations, interventions, and outcomes prevented meaningful data aggregation.

## Results

A total of 21,004 records were identified from bibliographic databases. After removing duplicates, 8,851 records were screened, and 67 were included in the full-text analysis. In addition, 33 records from trial registries and 271 cited references were screened. Data from nine articles reporting on sagittal alignment for 12 eligible cohorts [21-29] were included in the analysis. Also included were data from eight articles reporting on pulmonary function outcomes for 12 eligible cohorts [30-37]. An overview of the selection process is presented in a PRISMA flow diagram (Figure 2) [20].



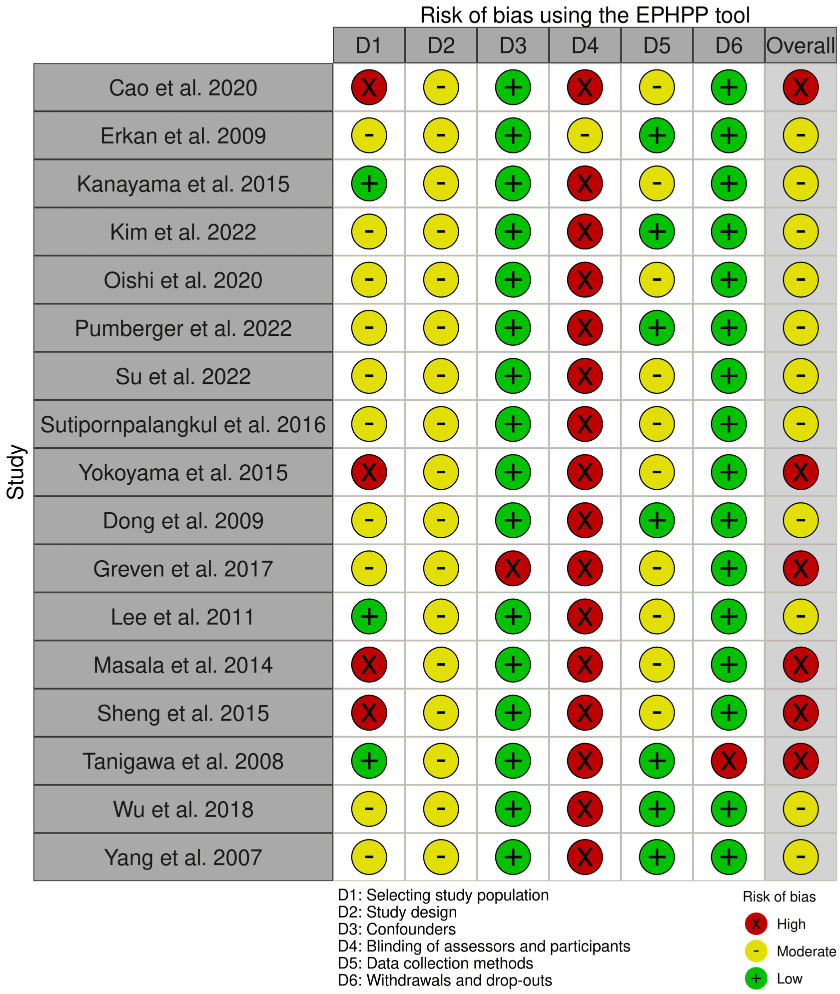

### FIGURE 2: PRISMA diagram presenting the identification and screening process

On the left are publication databases, and on the right are records from trial registries and citation searches. We applied a multi-stranded search strategy, and the diagram shows the overall number of records.

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses, EUCTR: EU Clinical Trials Register, ISRCTN: International Standard Randomised Controlled Trial Number, MRC: Medical Research Council, WHO: World Health Organization

Tables 1-2 present study characteristics for all included articles (additional details in Appendix 2). The included articles comprise reports on two non-randomized clinical studies, a prospective longitudinal comparative cohort study, and 14 longitudinal observational cohort studies. Studies excluded during full-text review and reasons for exclusion are presented in Appendix 3.

Strong, moderate, and weak study quality ratings were converted into low, moderate, or high RoB assessments, as shown in Figure 3. We did not include any RCTs, which is reflected in the moderate RoB, mainly due to the study design and the high RoB due to a lack of blinding. Overall, the RoB due to confounders and dropouts was low.




## FIGURE 3: Results of the RoB assessment

For the assessment, we used the quality assessment tool for quantitative studies by the EPHPP [54].

EPHPP: Effective Public Health Practice Project, RoB: risk of bias

Data on sagittal alignment measures were extracted for 456 individuals (male-to-female ratio 102:333, excluding Yokoyama et al. [29], who did not report sex ratio) with mean reported ages ranging from 69.3 to 80.8 years (Table 3). Data on pulmonary function measures were extracted for 343 individuals (male-to-female ratio 68:275) with mean reported ages ranging from 69.1 to 75.7 years (Table 4). Follow-up time points varied widely between studies. To handle this, we combined time points from one day to the last postoperative follow-up for data analysis. This resulted in data for three time points: preoperatively, any time postoperatively (Tables 5-6), and 12 months postoperatively for VC% (Table 6).

| | Medium to high RoB | | Medium RoB | | Literature, patients with osteoporosis but no VCF | |
|---|---|---|---|---|---|---|
| | Number of cohorts | Weighted mean (SD) | Number of cohorts | Weighted mean (SD) | Number of cohorts (references) | Range of means |
| Number of studies | | 9 | | 7 | - | - |
| Number of cohorts | | 12 | | 8 | - | - |
| N | | 456 | | 345 | - | - |
| Males, % | 11 | 35% | 8 | 24% | - | - |
| Age, years | 12 | 75.53 (4.39) | 8 | 75.75 (4.30) | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| ODI | 1 | | 1 | | | |
| Preoperative* | | 84.26 (NR) | | 84.26 (NR) | - | - |
| Any postoperative[a] | | 32.46 (NR) | | 32.46 (NR) | - | - |
| VAS (1-10) | 7 | | 3 | | | |
| Preoperative | | 5.80 (1.55) | | 5.36 (2.09) | - | - |
| Any postoperative | | 2.12 (0.31) | | 1.09 (0.22) | - | - |
| SVA (mm) | 12 | | 8 | | | |
| Preoperative | | 39.94 (28.56) | | 43.42 (25.99) | 6 (11,44-48) | -15.5–63.6 |
| Any postoperative | | 34.05 (26.73) | | 38.76 (23.38) | - | - |
| SSA ($^{o}$) | 4 | | 2 | | | |
| Preoperative | | 116.30 (6.73) | | 115.36 (3.12) | 2 (11,47) | 114.9–124.8 |
| Any postoperative | | 118.73 (6.64) | | 116.31 (3.37) | - | - |
| TPA ($^{o}$) | 3 | | 1 | | | |
| Preoperative | | 20.10 (5.07) | | 22.98 (8.38) | - | - |
| Any postoperative | | 18.07 (3.96) | | 20.69 (7.37) | - | - |
| PI-LL ($^{o}$) | 3 | | 0 | | | |
| Preoperative[b] | | 6.33 (7.90) | | NA | 2 (44,48) | 11.6–4.7 |
| Any postoperative[b] | | 2.98 (5.70) | | NA | - | - |
| SS ($^{o}$) | 6 | | 2 | | | |
| Preoperative | | 32.27 (3.04) | | 35.31 (2.28) | 5 (11,45-48) | 25.1–35.7 |
| Any postoperative | | 32.64 (3.80) | | 34.89 (3.83) | - | - |
| PT ($^{o}$) | 6 | | 2 | | | |
| Preoperative | | 23.28 (4.12) | | 22.13 (5.51) | 6 (11,44-48) | 16.3–27.5 |
| Any postoperative | | 22.41 (4.01) | | 21.88 (3.85) | - | - |
| LL ($^{o}$) | 3 | | 0 | | | |
| Preoperative[b] | | 41.31 (9,78) | | NA | 5 (11,45-48) | 27.3–46.7 |
| Any postoperative[b] | | 43.25 (3.50) | | NA | - | - |
| TK ($^{o}$) | 7 | | 3 | | | |
| Preoperative | | 32.80 (9.80) | | 30.78 (13.46) | 5 (11,45-48) | 30.9–45.3 |
| Any postoperative | | 29.34 (11.26) | | 29.13 (16.16) | - | - |

**TABLE 5: Weighted mean effect of vertebral augmentation on sagittal alignment measures**

Results are presented for all studies with medium-to-high RoB and a sub-analysis excluding cases with a high RoB. For comparison, results are shown on the right for study populations with osteoporosis but no OVCF. Except for PI-LL, all mean outcome measures from study cohorts fall within the ranges reported for persons with no OVCF. Vertebral augmentation did not affect any of the outcomes.

[a] Data point available for only one article (Erkan et al. [22]), [b] Data point not available for medium RoB articles

ODI: Oswestry Disability Index, VAS: Visual Analogue Scale, SVA: sagittal vertical axis, SSA: spino-sacral angle, TPA: T1-pelvic angle, PI-LL: pelvic incidence minus lumbar lordosis, SS: sacral slope, PT: pelvic tilt, LL: lumbar lordosis, TK: thoracic kyphosis, RoB: risk of bias, SD: standard deviation, VCF: vertebral compression fracture, OVCF: osteoporotic vertebral compression fracture, NR: not reported, NA: not available

| | **Medium to high RoB** | | **Medium RoB** | |
|---|---|---|---|---|
| | Number of cohorts | Weighted mean (SD) | Number of cohorts | Weighted mean (SD) |
| Number of studies | | 8 | | 4 |
| Number of cohorts | | 12 | | 6 |
| N | | 343 | | 201 |
| Males | | 20% | | 10% |
| Age, years | | 71.9 (31.4) | | 73.0 (28.0) |
| ODI | 3 | | 0 | |
| Preoperative | | 65.0 (10.2) | | NA |
| Any postoperative | | 22.6 (3.8) | | NA |
| VAS (1-10) | 9 | | 3 | |
| Preoperative | | 7.8 (0.6) | | 8.2 (0.2) |
| Any postoperative | | 2.1 (0.6) | | 2.3 (0.7) |
| VC (L) | 5 | | 5 | |
| Preoperative[a] | | 2.4 (0.1) | | 2.4 (0.1) |
| Any postoperative[a] | | 2.5 (0.0) | | 2.5 (0.0) |
| TLC (L) | 3 | | 3 | |
| Preoperative[a] | | 4.1 (0.0) | | 4.1 (0.0) |
| Any postoperative[a] | | 4.1 (0.0) | | 4.1 (0.0) |
| FVC (L) | 5 | | 5 | |
| Preoperative[a] | | 2.2 (0.1) | | 2.2 (0.1) |
| Any postoperative[a] | | 2.3 (0.0) | | 2.3 (0.0) |
| MVV (L) | 5 | | 5 | |
| Preoperative[a] | | 56.5 (2.0) | | 56.5 (2.0) |
| Any postoperative[a] | | 62.3 (1.2) | | 62.3 (1.2) |
| VC% (% of predicted)[b] | 1 | | 1 | |
| Preoperative | | 81.5 (3.9) | | 81.5 (3.9) |
| 12-month postoperative | | 98.6 (1.2) | | 98.6 (1.2) |
| FEV1% (% of predicted) | 9 | | 3 | |
| Preoperative[a] | | 69.6 (12.2) | | 59.8 (2.0) |
| Any postoperative[a] | | 73.9 (13.9) | | 65.5 (3.3) |
| FVC% (% of predicted) | 4 | | 1 | |
| Preoperative | | 71.3 (11.5) | | 58.0 (23.8)[c] |
| Any postoperative | | 86.1 (9.1) | | 76.0 (22.1)[c] |

**TABLE 6: Weighted mean effect of vertebral augmentation on pulmonary function measures**

Results are presented for all studies with medium-to-high RoB and a sub-analysis excluding cases with a high RoB. A positive effect was seen in outcomes reported as a percentage of the expected value.

[a] values are from studies with medium RoB only, [b] Masala et al. [33], [c] Lee et al. [32]

ODI: Oswestry Disability Index, VAS: Visual Analogue Scale, VC: vital capacity, TLC: total lung capacity, FVC: forced vital capacity, MVV: maximum voluntary ventilation, VC%: percent vital capacity, FEV1%: percent forced expiratory volume in one second, FVC%: percent forced vital capacity, RoB: risk of bias, NA: not available

We analyzed data extracted for all sagittal alignment outcomes except the Barthel index, which was only reported by Su et al. (Table *3*) [27]. It was not possible to make comparisons of the pulmonary function outcomes, FEV1%/FVC% ratio, inspiratory capacity (IC), residual volume (RV), functional residual capacity (FRC), and peak respiratory flow (PEF). The FEV1%/FVC% ratio was included in two studies, but the values varied widely [32,34]. PEF [31] and IC, RV, and FRC [37] were included in only one study.

None of the sagittal alignment parameters in our analysis improved after vertebral augmentation (Table *5*). SVA, the primary outcome in our analysis, and PI-LL had very high standard deviations pre- and postoperatively. The weighted mean values for all preoperatively sagittal alignment parameters in the study populations were within the range reported in the literature for patients with osteoporosis but no VCFs.

Unadjusted pulmonary function measures (VC, TLC, FVC, MVV) did not improve after vertebral augmentation (Table *6*). When the percentage of predicted values was analyzed, vertebral augmentation positively affected pulmonary function (VC%, FVC%, FEV1%). Results for VC% were based on one cohort with a moderate RoB, and results for FVC% were based on four cohorts, of which one had a moderate RoB. FEV1% was the most widely used measure, and the most distinct improvement after vertebral augmentation was seen when comparing weighted means of the three studies with a moderate RoB.

Data on perceived level of disability (ODI) and pain (VAS) were collected in studies on both sagittal alignment (ODI: two cohorts, moderate RoB; VAS: seven cohorts, three with a moderate RoB) (Table *5*) and pulmonary function (ODI: three cohorts, high RoB; VAS: nine cohorts, three with a moderate RoB) (Table *6*). Overall, vertebral augmentation had a positive effect on both ODI and VAS.

## Discussion

The present study is the first to examine systematically collected literature on the effect of vertebral augmentation on global sagittal alignment and pulmonary function in patients with OVCFs. We found no significant impact of vertebral augmentation on spinal sagittal alignment parameters. However, it is equally noteworthy that there was no deterioration in the SVA or TK. Our analysis showed that vertebral augmentation does improve pulmonary function when measured as a percentage of expected values. Overall, vertebral augmentation also reduced experienced pain levels (VAS) and disability scores (ODI), as previously reported [55,56].

*Spinal Sagittal Alignment*

Vertebral augmentation of OVCFs did not significantly change global spinal alignment as measured by SVA, SSA, TPA, PI-LL, SS, PT, LL, and TK. This aligns with a meta-analysis by Najjar et al. [57] on four studies with no overall effect of kyphoplasty on sagittal alignment parameters in patients with OVCFs. The inability to identify changes in spinal sagittal alignment may partly be due to incomplete data, which, in turn, is due to variability in follow-up time points, inconsistency in measurements chosen by different authors (Tables *3*-*4*), and differences in participant positioning for radiographs. In addition, the heterogeneous study populations, mainly due to the inclusion of both lumbar and thoracic fractures, influence the results.

The primary outcome in this study, the SVA [38], showed a modest 4.66 mm change from preoperatively to last follow-up in studies with a moderate RoB. Given the variability in SVA, this modest change may not be clinically relevant. Preoperative SVA in our analysis varied significantly, from 14.5 mm [21], within the normal range, to 97 mm [22], denoting malalignment.

*Pulmonary Function*

Building on previous work linking sagittal alignment with pulmonary function, the authors of the included studies hypothesized that improved sagittal alignment after vertebral augmentation of OVCFs would enhance pulmonary function. Vertebral augmentation mostly improved VC% (results from only one study [33]) and FVC%. Our review did not represent all measures from the included articles because data were too scarce for analysis.

A 2007 systematic review by Harrison et al. [14] cautiously concluded that increased kyphosis due to OVCFs correlated with a modest decline in VC. Tanigawa et al. [35] showed that improved pulmonary function (FVC%) was only seen when treating thoracic OVCFs, with no difference based on the number of OVCFs. In contrast, Morseth et al. [58] found a significant correlation between the number of VCFs and FVC% and FEV1% in men but not women. FVC% and FEV1% did not differ significantly between fracture sites (T4-T12, L1-L4) in either men or women.

Horie et al. [59] reported a correlation between LL and reduced pulmonary function in healthy women with an average age of 76.8 years. Rahman et al. [60] found that FEV1% and FVC% were significantly negatively correlated with TK, but the percentage predicted maximum inspiratory and expiratory pressure was significantly negatively correlated with LL.

One explanation for improving pulmonary function is that back pain due to TK restricts normal breathing [61]. Our analysis's considerable mean pain reduction may improve pulmonary function after vertebral augmentation. An alternative explanation is that kyphosis may decrease the anterior-posterior diameter of the thoracic cavity, and changes in thoracic curvature will affect ribs and intercostal muscle function [60]. Likewise, it has been suggested that increased LL may decrease diaphragm constriction efficiency and thereby lower FVC [59,60]. Of the studies included in our analysis, only thoracic VCFs were treated in two studies, while both thoracic and lumbar VCFs were treated in six. Therefore, our results suggest that the improvement in pulmonary function may be due to a combination of underlying physiological changes.

*Limitations*

Our analysis is based on two non-randomized clinical studies, a prospective longitudinal comparative cohort study, and 14 longitudinal observational cohort studies. The results from these studies are considered level II and level III evidence.

Follow-up time points and length varied widely among the included studies, and data were merged into “preoperative” and “any time postoperative” for all outcomes. Merging data from the entire follow-up period, one risks reducing the level of detail and allowing data from different time points to cancel each other out.

The number of participants in studies on pulmonary function is often low. In the included articles, cohorts ranged from 72 participants [32] to four to five participants [31]. Reference values for pulmonary function measures depend on several factors, such as age, sex, standing height, and ethnicity [62]. However, the included articles did not report the specific reference values used to calculate percentage predicted outcomes. In addition, only one study reported which height measure they used to estimate predicted values of pulmonary function [32]; using different height measures is a source of considerable variability in predicted measures of pulmonary function [14,63].

No studies reported the effect on sagittal alignment and pulmonary function when combining bone cement and intravertebral instrumentation. Our study did not include spinal sagittal alignment as measured by local kyphosis at the level of OVCFs or treated vertebral body height, since it has been extensively studied elsewhere [64-66].

Literature was identified using a multi-stranded search strategy to ensure that we did not miss any relevant articles that failed to mention in the title, abstract, and keywords that their study population consisted of participants with osteoporosis. Despite a thorough search and screening process, we may have missed relevant studies, particularly those published in Chinese.

## Conclusions

Vertebral augmentation of OVCFs did not affect sagittal alignment parameters, possibly due to the heterogeneity in reported outcomes, follow-up time points, and study populations. Vertebral augmentation positively affected pulmonary function measured as VC%, FVC%, and FEV1%. However, results for VC% and FVC% are based on a very limited number of studies. In addition, vertebral augmentation had a positive effect on experienced pain level and disability.

The data in this systematic review were heterogeneous, considerably restricting the data analysis. In addition, we have pointed out critical factors that have not been thoroughly reported in previous articles. We want to encourage the scientific community to agree on optimal follow-up time points and core spinopelvic parameters, accurate reporting on treated fracture levels, positioning instructions for imaging, and calculation of predicted pulmonary function values. Each clinical study would then contribute to a valuable compilation of data on the effect of vertebral augmentation procedures on global spinal sagittal alignment and pulmonary function in patients with OVCFs.

## Appendices

### Appendix 1.1

Medline search history exemplifies bibliographic database searches. We applied a multi-stranded search strategy, and Table 7 represents searches for publications that mentioned osteoporosis in their title, abstract, or keywords. Database: Ovid MEDLINE(R) ALL.

| # | Search terms | Hits 1 Nov 2022 (including osteoporosis terms) |
|---|---|---|
| 1 | exp spine/ | 161,299 |
| 2 | (spine or spinal or vertebra$).mp. | 671,444 |
| 3 | exp fractures, bone/ | 203,585 |
| 4 | (fractur$ or compres$).mp. | 515,957 |
| 5 | exp Spinal Fractures/ | 17,075 |
| 6 | 1 or 2 | 682,507 |
| 7 | 3 or 4 | 518,239 |
| 8 | exp Osteoporosis/ | 61,381 |
| 9 | osteopor$.mp. | 102,968 |
| 10 | 8 or 9 | 102,968 |
| 11 | 6 and 7 and 10 | 17,215 |
| 12 | 5 and 10 | 6,573 |
| 13 | 11 or 12 | 17,215 |
| 14 | exp Bone Cements/ | 24,629 |
| 15 | (bone adj3 cement$).mp. | 16,794 |
| 16 | (bone adj3 glue$).mp. | 155 |
| 17 | (bone adj3 past$).mp. | 394 |
| 18 | exp Fracture Fixation, Internal/ | 49,852 |
| 19 | (facture adj3 fixat$).mp. | 4 |
| 20 | exp Cementoplasty/ | 3,385 |
| 21 | cementoplast$.mp. | 375 |
| 22 | vertebroplast$.mp. | 4,266 |
| 23 | kyphoplast$.mp. | 2,363 |
| 24 | KIVA.mp. | 80 |
| 25 | skyphoplast$.mp. | 4 |
| 26 | (vertebral adj3 augmentation).mp. | 825 |
| 27 | (vertebral adj3 body adj3 augmentation).mp. | 80 |
| 28 | or/14-27 | 81,205 |
| 29 | 13 and 28 | 3,210 |

**TABLE 7: Medline search history exemplifying the bibliographic database searches with search terms related to osteoporosis**

## Appendix 1.2

Medline search history exemplifies bibliographic database searches. Table 8 represents bibliographic database searches for publications that did not mention osteoporosis in their title, abstract, or keywords. We added different combinations of search terms related to posture to focus the search. Database: Ovid MEDLINE(R) ALL.

| # | Search terms | Hits 24 Oct 2023 (including posture terms) |
|---|---|---|
| 1 | exp spine/ | 166,157 |
| 2 | (spine or spinal or vertebra$).mp. | 711,327 |
| 3 | exp fractures, bone/ | 210,264 |
| 4 | (fractur$ or compres$).mp. | 560,934 |
| 5 | exp Spinal Fractures/ | 17,899 |
| 6 | 1 or 2 | 722,721 |
| 7 | 3 or 4 | 563,273 |
| 8 | 6 and 7 | 85,050 |
| 9 | 5 or 8 | 85,050 |
| 10 | exp Bone Cements/ | 25,304 |
| 11 | (bone adj3 cement$).mp. | 17,752 |
| 12 | (bone adj3 glue$).mp. | 165 |
| 13 | (bone adj3 past$).mp. | 418 |
| 14 | exp Fracture Fixation, Internal/ | 51,850 |
| 15 | (fracture adj3 fixat$).mp. | 72,821 |
| 16 | exp Cementoplasty/ | 3,567 |
| 17 | cementoplast$.mp. | 413 |
| 18 | vertebroplast$.mp. | 4,643 |
| 19 | kyphoplast$.mp. | 2,673 |
| 20 | KIVA.mp. | 86 |
| 21 | skyphoplast$.mp. | 4 |
| 22 | (vertebral adj3 augmentation).mp. | 922 |
| 23 | (vertebral adj3 body adj3 augmentation).mp. | 89 |
| 24 | or/10-23 | 105,500 |
| 25 | 9 and 24 | 10,655 |
| 26 | exp Postural Balance/ | 28,340 |
| 27 | ((sagittal or body or postur*) adj3 (balance or alignment or equlibrium)).mp | 38,193 |
| 28 | 26 or 27 | 38,221 |
| 29 | 25 and 28 | 153 |

**TABLE 8: Medline search history exemplifying the bibliographic database searches with search terms related to posture**

## Appendix 2

Additional study characteristics are included in the data analysis and overview.

| Publication | Title | Aim of study | Study setting | Study design | Study population | No. of participants | Treated compression fractures | Intervention | Inclusion criteria | Exclusion criteria | Follow-up time points | Relevant outcomes | Author conclu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | (1) The | (1) Lumbar disc herniation, spondylolisthesis, scoliosis, spinal osteoarthritis, ankylosing | | | PKP is |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cao et al. 2020 [21] | Percutaneous kyphoplasty for osteoporotic vertebral compression fractures improves spino-pelvic alignment and global sagittal balance maximally in the thoracolumbar region | To analyze the differences in sagittal balance parameters after a vertebral fracture at different sites and to analyze the differences in sagittal balance improvement after PKP at different fracture sites | Shandong Provincial Hospital, Jinan, China | Longitudinal observational study | Patients with OVCFs receiving treatment from 2013 to 2018. Age 67.9 ± 6.2 years. Subgroups according to site of fracture: MT group (T1 to T9), TL group (T10 to L2), and LU group (L3 to L5) | Overall: n=90 (70 W, 20 M). MT group: n=9 (6 W, 3 M), TL group: n=71 (57 W, 14 M), and LU group: N=10 (7 W, 3 M) | T1-T9, T10-L2, L3-L5, only single fracture: NA | KP | vertebral compression ratio of the injured vertebrae is <80%. (2) Osteoporosis confirmed via bone mineral density. (3) Fractured vertebrae showed a high signal intensity on STIR MRI images and a low signal intensity on T1-weighted MRI images. (4) Imaging data were complete | spondylitis, spinal tumors, and spinal tuberculosis. (2) History of spinal surgery. (3) Hip and knee joint limitations. (4) Spinal cord compression with clinical manifestations of spinal cord and cauda equina nerve injury. (5) Pathogenic fracture caused by a tumor or an incomplete posterior wall of the vertebral body. (6) Patients could not stand upright independently or did not have a standing X-ray | Preoperative + 2-3 days postoperative | VAS TK, LL, PI, PT, SS, PI-LL, SVA, SSA, and TPA | effectiv treatm thorac (T10-L PKP ca the low causec fracture correct posteri during compe balanc 2–3 da can sig improv angula parame SSA, a sagitta alignm |
| Erkan et al. 2009 [22] | Does timing matter in performing kyphoplasty? Acute versus chronic compression fractures | To compare the clinical outcomes, the radiographic outcomes, and the complication rates of symptomatic acute (<10 weeks) and chronic (>16 weeks) osteoporotic VCFs treated with KP | Celal Bayar University School of Medicine, Manisa, Türkiye | Longitudinal comparative cohort study, prospective | Patients with symptomatic osteoporotic VCFs receiving treatment in 2006-2007. Age 72 (62-79) years | Overall: n=28 (20 W, 8 M). Acute group: n=15 (11 W, 4 M) and chronic group: n=13 (9 W, 4 M) | T11-L4, only single fracture: no | KP | (1) Severely disabling back pain, which was reproduced by deep palpation over the spinous process at the involved level. (2) VCFs not responsive to bed rest, activity modification, bracing, and analgesics for at least two weeks | (1) Subacute fractures. (2) Fractures not showing oedema on MRI | Preoperative + 6 weeks postoperative + 3, 6, 12, 18 months postoperative | ODI, VAS, SVA, cement leakage, and subsequent fractures | KP imp clinical radiolo outcom patient acute ( weeks) (>16 w VCFs. outcom mostly the acu but not signific |
| Kanayama et al. 2015 [23] | Does balloon kyphoplasty improve the global spinal alignment in osteoporotic vertebral fracture? | To review radiographic and clinical outcomes of balloon KP for delayed union or non-union after osteoporotic vertebral fracture, and to evaluate its effect on the global spinal alignment | Hakodate Central General Hospital, Hokkaido, Japan | Longitudinal observational study | Patients with failed nonoperative treatment for OVCF. Treatment period not mentioned. Age 75.3 (49-71) years. SVA analysis in sub-groups: (1) sagittal imbalance (SVA <50 mm), (2) previous OVCF, and (3) no previous OVCF | Overall: n=56 (49 W, 7 M) | T6-L5, only single fracture: no | KP | NA | NA | Preoperative + immediately postoperative + final follow-up (8-91 months) | VAS, SVA, and subsequent fractures | KP cor immed relief, b improv global spinal a after O |
| Kim et al. 2022 [24] | Correlation of sagittal imbalance and recollapse after percutaneous vertebroplasty for thoracolumbar osteoporotic vertebral compression fracture: A multivariate study of risk | To evaluate the risk factors for recollapse following PVP in patients with thoracolumbar OVF and the association between recollapse and | Daejeon Eulji Medical Center, Daejeon, Korea | Longitudinal observational study | Patients who underwent single-level PVP 2010-2017. Age 77.5 ± 8.6 years | No recollapse group: n=106 (83 W, 23 M) | Thoracolumbar, only single fracture: yes | Vertebroplasty | (1) Ambulatory with senile or postmenopausal osteoporosis. (2) Recent OVF diagnosis. (3) BMD T-score below −2.5 (4) Follow-up ≥24 months. (5) | (1) Neurological deficit associated with vertebral fracture. (2) Osteoporosis caused by other pathologic conditions. (3) History of spine surgery. (4) | Preoperative + immediately postoperative + 12, 24 months postoperative | TK and SVA | Sagitta imbala signific predict further of a ce vertebr progres sagitta in patie recolla |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | factors | sagittal spinal parameters | | | | | | | Fracture at the thoracolumbar junction | History of high-energy trauma | | | vertebr followi thoraco OVF |
| Oishi et al. 2020 [25] | Presence or absence of adjacent vertebral fractures has no effect on long-term global alignment and quality of life in patients with osteoporotic vertebral fractures treated with balloon kyphoplasty | To investigate whether the presence or absence of AVF after PKP is correlated with the loss of global alignment and change in quality of life | Hamawaki Orthopaedic Hospital, Hiroshima, Japan | Longitudinal observational study | Medical records of consecutive OVF patients who underwent PKP 2012-2015. Age 80 (59-92) years | No AVF group: n=23 (19 W, 4 M) | T7-L3, only single fracture: no | KP | (1) Global sagittal alignment could be assessed preoperatively and throughout the follow-up. (2) Quality of life could be assessed preoperatively and throughout the follow-up | (1) Presence of tumour, infection, or any other disease that would induce pathological fractures. (2) History of lumbar fusion surgery. (3) Inability to maintain a standing position for whole-spine imaging. (4) Inability to attend follow-up due to comorbidities or institutionalization | Preoperative + 1 year postoperative + final follow-up (1-5 years) | SVA | The pr absenc did not long-te alignm patient life. Lo alignm PKP w due to the AV group, recolla BKP si AVF (- and bo showe global before at the f |
| Pumberger et al. 2020 [26] | Kyphoplasty restores the global sagittal balance of the spine independently from pain reduction | To gain more detailed knowledge about the effect of PKP on the sagittal profile of the spine for a differentiated evaluation of the long-term risk/benefit ratio and to allow for more precise treatment recommendations for VCFs | Charité – Universitätsmedizin Berlin, Berlin, Germany | Longitudinal observational study | Consecutive patients with a single VCF, 2014-2018. Age 70 ± 10.9 years | Overall: n=73 (47 W, 26 M) | Thoracic, lumbar, only single fracture: yes | KP | (1) Preoperative and postoperative upright whole spine radiographs <30 days before and after the operation. (2) Futile conservative treatment attempt | (1) Additional spinal operations. (2) New vertebral fractures between preoperative and postoperative radiographs. (3) Prior instrumented spinal fusion including L5/S1 | Preoperative + 2.8 ± 3.3 days postoperative | TK, LL, SVA, SS, and PT | Our res a signi improv the SV patient vertebr fracture KP. Th in SVA correla postop pain re While mainly recomm conside only af conser treatm attemp physici should in mind patient (espec with a imbala benefit restore irrespe pain re that thi only be for a sp after fr occurre |
| | The short-term changes of the sagittal spinal alignments after acute vertebral compression | To investigate the change of sagittal | Hualien Tzu Chi | Longitudinal | Patients diagnosed with OVCF and treated in 2020. Age 80.7 ± 8.3 years. Three groups: the thoracic group (T1–T9), thoracolumbar | | T1-T9, T10-L2, | | | (1) Previous spinal instrumentation surgery. (2) History of cancer. (3) Multiple | Preoperative + 2, 6 weeks | VAS TK, LL, SVA, | PVP fo elderly VCFs i subacu was ef functio restora spine a improv and it v |

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| Su et al. 2022 [27] | fracture receiving vertebroplasty and their relationship with the change of Bathel Index in the elderly | alignment using PVP and evaluate the outcomes with the BI | Hospital, Hualien, Taiwan | observational study | group (T10–L2), and lumbar group (L3–L5), according to the location of the fractured vertebra. Two subgroups: AVF (+), AVF (-), no AVF | Overall: n=42 (34 W, 8 M) | and L3-L5, only single fractures: yes | Vertebroplasty | NA | fractures. (4) Cardiopulmonary disorders. (5) Spinal infection. (6) Pathologic fracture. (7) Difficulty standing straight | postoperative + 3 months postoperative | SSA, TPA, PI, PT, and SS | for qua recove elderly with ac PVP im functio sagitta alignm 12 wee was a stage i future r |
| Sutipornpalangkul et al. 2016 [28] | Comparison of sagittal balance between radiofrequency targeted vertebral augmentation and balloon kyphoplasty in treatment of vertebral compression fracture: A retrospective study | To compare the effectiveness of high-viscosity cement, RF-TVA, and PKP on spinal sagittal balance | Faculty of Medicine Siriraj Hospital, Bangkok, Thailand | Longitudinal observational study | Medical records of patients with single painful OVCF treated from 2007 to 2014. PKP group: Age 78.3 ± 6.1 years | PKP group: 17 (11 W, 6 M) | Levels not reported, only single fracture: yes | RF-TVA, KP | (1) Osteoporosis as the cause of VCF confirmed by biopsy. (2) Compression fracture vertebrae showed a high signal intensity on short T1 inversion recovery MRI and a low signal intensity on T1-weighted MRI | (1) Biopsy showed a pathological fracture. (2) Incomplete lateral whole spine radiography for radiographic measurement of spinopelvic parameters* | Preoperative + 1 week postoperative | LL, PI, SS, PT, SSA, and SVA | Treatin with RF PKP di improv spine a |
| Yokoyama et al. 2015 [29] | Postoperative change in sagittal balance after Kyphoplasty for the treatment of osteoporotic vertebral compression fracture | To analyze the changes in total spinal alignment after PKP in VCF patients | Takeda General Hospital, Kyoto, Japan | Longitudinal observational study | Patients with osteoporotic VCFs were referred to a hospital because conservative treatment did not alleviate pain. Treatment period 2013-2014. Age 77.1 ± 5.8 years | Overall: n=21 (? W, ? M) | T11-L4, only single fracture: yes | KP | (1) VCF with 0–90% loss of vertebral body height on plain X-rays of the spine. (2) severe back pain associated with a single VCF refractory to analgesic medication administered for 2+ weeks. (3) VAS ≥5, interfering with the activities of daily living, or pain on tapping on the spinal process of the fractured vertebra. (4) Affected vertebral body showing a high signal intensity on STIR MRI and a low signal intensity on T1-weighted MRI | (1) Cannot maintain a standing position because of lumbar pain. (2) Impaired cardiopulmonary function. (3) Spinal metastatic cancer. (4) Evidence of radiculopathy. (5) History of spinal surgery | Preoperative + 1 month postoperative | LL, SVA, SSA, PI, PT, and SS | KP is h the ma of VCF not onl relievin caused also fo improv balanc the alle local ky |
| Dong et al. 2009 [30] | Improvement in respiratory function after vertebroplasty and kyphoplasty | To study the changes in the respiratory function of patients with OVCFs after PVP | First Affiliated Hospital of Suzhou University, Suzhou, China | Non-randomized clinical trial | Patients with thoracic OVCFs treated in 2006-2008. Vertebroplasty: age 70.2 ± 5.5 years. KP: age | Overall: n=38 (38 W, 0 M). Vertebroplasty: n=18. KP: n=20 | T9-L3, only single fracture: no | Vertebroplasty, KP | (1) OVCFs | (1) Pulmonary diseases. (2) Infection of the respiratory passages within the last three weeks. (3) Previous surgery or fracture of the spine. (4) Significant | Preoperative + 3 days postoperative + 3 months postoperative | VAS VC, TLC, FVC, MVV, and TK | PVP ar improv functio by OV( KP is b improv |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | and PKP | | | 69.5 ± 6.4 years | | | | | scoliosis. (5) Neurological disorder. (6) Cardiac pacemaker | | | thoraci |
| Greven et al. 2017 [31] | Influence of radiofrequency kyphoplasty on pulmonary function | To investigate how using radiofrequency PKP for treating VCFs influences pulmonary function, reduces back pain and functional impairment, and achieves height restoration of the vertebral body | Universitätsklinikum Bonn, Bonn, Germany | Longitudinal observational study | Patients with one VCF each. Treatment period not mentioned. Age 70.4 ± 9.4 years. Three groups based on the location of the fracture: group 1: Th8-11, group 2: Th12-L2, and group 3: L3-L4 | Overall: n=25 (14 W, 11 M). Group Th8-11: n=4 (? W, ? M), group Th12-L2: n=16 (? W, ? M), and group L3-4: n=5 (? W, ? M) | Thoracic, lumbar, only single fracture: yes | KP | NA | (1) High-energy trauma. (2) Known tumor involvement. (3) Osteonecrotic-, burst-, or pedicle fractures. (4) Previous surgical treatment for a VCF. (5) Rheumatic disorders or Paget's disease. (6) Acute or chronic infections. (7) BMI >35. (8) Uncontrolled diabetes HbA1c >7%. (9) Severe cardiopulmonary disease. (10) Myelopathy. (11) Long-term steroid therapy | Preoperative + 1 month postoperative | VAS, ODI %FEV1, %REF | Radiofr KP incr vertebr height, pain ar functio impairr also de noticea improv pulmor functio when t fracture located central region diaphra |
| Lee et al. 2011 [32] | The effect of vertebroplasty on pulmonary function in patients with osteoporotic compression fractures of the thoracic spine | To determine the effect of PVP on pulmonary function in patients with OVCFs of the thoracic spine | Dongshin General Hospital, Seoul, Korea | Longitudinal observational study | Patients with intractable pain owing to osteoporotic compression fractures in the thoracic spine. Treatment period 2005-2006. Age 75.7 ± 7.6 years | Overall: n=72 (62 W, 10 M) | Thoracic, only single fracture: no | Vertebroplasty | (1) 65+ yrs. (2) Osteoporosis. (3) Intractable back pain of >2 weeks duration. (4) 1 or 2 acute vertebral fractures in the thoracic spine confirmed by MRI | (1) Neoplasm in the fractured vertebral body. (2) Pulmonary disease. (3) Previous cardiothoracic surgery. (4) Previous spine surgery. (5) Neurologic disorders. (6) Muscular disorders. (7) Thoracic scoliosis | Preoperative + 2 days postoperative + 1, 3 months postoperative | VAS %FEV1, %FVC, FEV1/FVC ratio TK | PVP in pulmor functio immed the pro patient OVCFs thoraci and thi improv mainta thereaf Althoug kyphoti deform not cor PVP ef reduce pain ar improv pulmor functio was co with pa |
| Masala et al. 2014 [33] | Chronic obstructive pulmonary disease (COPD) patients with osteoporotic vertebral compression fractures (OVCFs): Improvement of pulmonary function after percutaneous vertebroplasty (VTP) | To investigate the changes in respiratory function in patients affected by COPD with single OVCFs treated with PVP | Fondazione Policlinico "Tor Vergata", Rome, Italy | Longitudinal observational study | Patients with COPD affected by OVCFs.Treatment period 2011-2013. Age 71.4 (65-77) years | Overall: n=45 (16 W, 49 M) | Thoracic, only single fracture: yes | Vertebroplasty | (1) Single dorsal vertebral involvement. (2) Bone marrow oedema on MRI. (3) No intracanal bone fragments. (4) Refractory pain despite conventional medical treatment for 3+ months | (1) Radicular pain and symptoms suggestive of neurological involvement | Preoperative + 1 week postoperative + 3, 12 months postoperative | VAS %VC, %FVC, %FEV1 | PVP in restrict ventilat impairr patient modera severe affecte thoraci We rec this tre the ma of thes |
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| Sheng et al. 2015 [34] | Improvement in pulmonary function of chronic obstructive pulmonary disease (COPD) patients with osteoporotic vertebral compression fractures (OVCFs) after kyphoplasty under local anesthesia | To investigate respiratory function changes, spinal deformity, and pain scores in COPD patients with OVCFs after PKP. To determine if the changes in pulmonary function are related to the spinal deformity correction and pain scores | Soochow University-affiliated Ninth Hospital of Wuxi City, Wuxi City, China | Longitudinal observational study | Older patients affected by COPD with OVCFs in the thoracolumbar segment. Treatment period not reported. Age 71.2 ± 6.3 years | Overall: n=31 (? W, ? M) | T9-L2, only single fracture: no | KP | (1) Severe pain from the fracture. (2) Pain resistant to conservative treatment | (1) Radicular pain. (2) Neurologic disorders | Preoperative + 3 days postoperative + 3 months postoperative | VAS %FEV1, %FVC, %MVV, FEV1/FVC ratio | most c of KP i alleviat this stu clarifie also im impaire functio directly the mo quality COPD There v signific correla betwee parame LKA, th scores LKA |
| Tanigawa et al. 2008 [35] | Improvement in respiratory function by percutaneous vertebroplasty | To retrospectively investigate changes in respiratory function after PVP | Kansai Medical University Hirakata Hospital, Osaka, Japan | Longitudinal observational study | Patients who had VCFs caused by osteoporosis. Treatment period 2005. Age 72.0 (59-86) years. Subgroups by fracture location: Th group, Th + L group, and L group. Subgroups by number of treated vertebrae: single group and multiple group | Overall: n=41 (39 W, 2 M) | T6-L5, only single fracture: no | Vertebroplasty | (1) Back pain caused by VCF. (2) Pain on percussion of the vertebral spinous process | (1) Back pain attributed to myelopathy. (2) Radiculopathy resulting from stenosis of the vertebral canal or narrowing of the intervertebral foramen | Preoperative (+ 1 day postoperative) + 10 moths postoperative | %FVC, %FEV1 | Althou most c of PVP alleviat the pre clarifie also im decrea functio improv could l inciden pulmor compli thus in the clin signific PVP |
| Wu et al. 2018 [36] | Is balloon kyphoplasty a better treatment than percutaneous vertebroplasty for chronic obstructive pulmonary disease (COPD) patients with osteoporotic vertebral compression fractures (OVCFs)? | To test whether PVP and PKP can provide similar short-term improvements in respiratory function for COPD patients with single-segment OVCFs | China-Japan Friendship Hospital, Beijing, China | Non-randomized clinical trial | COPD patients with one OVCF. Treatment period 2013-2015. Vertebroplasty: age 73.6 ± 6.2 years. KP: age 71.5 ± 5.6 years | Overall: n=69 (51 W, 10 M). KP: n=31 (25 W, 6 M) and vertebroplasty: n=30 (26 W, 4 M) | T8-L4, only single fracture: yes | Vertebroplasty, KP | (1) Severe back pain from a fracture that was resistant to 2-week non-surgical management | (1) Pathologic fractures, fractures caused by high-energy traumas, previous spinal surgery or fracture, multiple-segment vertebral fractures. (2) Fractures involving neurological deficits. (3) Significant spinal deformity. (4) Severely disabled. (5) Respiratory tract infection within the last 3 weeks. 6) FEV1 <30% Pred FEV1. (7) Back pain due to myelopathy or radiculopathy | Preoperative + 1 week postoperative + 3, 12 months postoperative | VAS, ODI VC, FVC, %FEV1, and MVV | PVP ar both al pain ar acceler mobility in turn, pulmor functio observ similar cemen in both and a s operati PVP. Radiog BKP is restorir height fracture vertebr correct kyphos advant BKP in radiogr not cor with im spirom parame |
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| Yang et al. 2007 [37] | Changes of pulmonary function for patients with osteoporotic vertebral compression fractures after kyphoplasty | To measure the pulmonary function, spinal deformity, and pain scores before and after treatment with PKP, and test for changes | The First Affiliated Hospital of Soochow University, Suzhou, China | Longitudinal observational study | Patients with OVCFs in the thoracolumbar segment. Treatment period not reported. Age 69.1 ± 5.2 years | Overall: n=30 (30 W, 0 M) | T9-L2, only single fracture: no | KP | (1) OVCF. (2) non-smoker | (1) Pulmonary diseases. (2) Previous surgery or fracture of the spine. (3) Significant scoliosis. (4) Neurologic disorder. (5) Cardiac pacemaker | Preoperative + 3 days postoperative, 1 month postoperative | VC, IC, RV, FRC, TLC, FVC, and MVV | parame IC, RV FRC) c immed improv KP pro and ult spine realign After K realign drastic quickly |

## TABLE 9: Characteristics of all included studies

OVCF: osteoporotic vertebral compression fracture, VCF: vertebral compression fracture, KP: kyphoplasty, PKP: percutaneous kyphoplasty, PVP: percutaneous vertebroplasty, RF-TVA: radiofrequency-targeted vertebral augmentation, MRI: magnetic resonance imaging, STIR: short tau inversion recovery, BI: Barthel index, SVA: sagittal vertical axis, SSA: spino-sacral angle, TPA: T1 pelvic angle, TK: thoracic kyphosis, LL: lumbar lordosis, PI: pelvic incidence, PT: pelvic tilt, SS: sacral slope, PI-LL: pelvic incidence minus lumbar lordosis, VAS: Visual Analogue Scale, ODI: Oswestry disability index, %FEV1: percent predicted forced expiratory volume in one second, %FVC: percent predicted forced vital capacity, FEV1/FVC: forced expiratory volume in one second to forced vital capacity, VC: vital capacity, TLC: total lung capacity, MVV: maximum voluntary ventilation, AVF: adjacent vertebral fracture

## Appendix 3

Articles excluded during full-text review and reasons for exclusion.

| Study ID | Reference citation | Eligible participants? | Eligible intervention? | Eligible data? |
|---|---|---|---|---|
| Behrbalk 2016 | Behrbalk E, Uri O, Folman Y, et al. Staged correction of severe thoracic kyphosis in patients with multilevel osteoporotic vertebral compression fractures. Glob Spine J. 2016;6:710-20. 10.1055/s-0035-1569460 | Yes | No | Yes |
| Bo 2023 | Bo J, Zhao X, Hua Z, et al.: Impact of sarcopenia and sagittal parameters on the residual back pain after percutaneous vertebroplasty in patients with osteoporotic vertebral compression fracture. Orthop Surg Res 2022;17:111. 10.1186/s13018-022-03009-4 | Yes | Yes | No |
| Cavanilles-Walker 2022 | Cavanilles-Walker JM, Rodriguez Montserrat D, Plano Jerez X, et al.: Sagittal imbalance influences outcome of vertebroplasty in patients with osteoporotic vertebral compression fracture. [Translated article] Rev Esp Cir Ortop Traumatol. 2022;66:T348-T354. 10.1016/j.recot.2021.04.002 | Yes | Yes | No |
| Chen 2022 | Chen Z, Yao Z, Wu C, et al.: Assessment of clinical, imaging, surgical risk factors for subsequent fracture following vertebral augmentation in osteoporotic patients. Skeletal Radiol. 2022;51:1623-30. 10.1007/s00256-022-04009-5 | Yes | Yes | No |
| Cheng 2021 | Cheng H, Wang GD, Li T, et al.: Radiographic and clinical outcomes of surgical treatment of Kümmell's disease with thoracolumbar kyphosis: a minimal two-year follow-up. BMC Musculoskelet Disord. 2021;22:761. 10.1186/s12891-021-04640-8 | Yes | No | Yes |
| Deen 2005 | Deen HG, Aranda-Michel J, Reimer R, et al.: Preliminary results of balloon kyphoplasty for vertebral compression fractures in organ transplant recipients. Neurosurg Focus. 2005;18:e6. 10.3171/foc.2005.18.3.7 | Yes | Yes | No |
| Griffoni 2020 | Griffoni C, Lukassen JNM, Babbi L, et al.: Percutaneous vertebroplasty and balloon kyphoplasty in the treatment of osteoporotic vertebral fractures: a prospective randomized comparison. Eur Spine J. 2020;29:1614-20. 10.1007/s00586-020-06434-3 | Yes | Yes | No |
| Iwata 2017 | Iwata A, Kanayama M, Oha F, et al.: Does spinopelvic alignment affect the union status in thoracolumbar osteoporotic vertebral compression fracture? Eur J Orthop Surg Traumatol. 2017;27:87-92. 10.1007/s00590-016-1844-1 | Yes | No | Yes |
| Kao 2019 | Kao FC, Huang YJ, Chiu PY, et al.: Factors predicting the surgical risk of steoporotic vertebral compression fractures. J Clin Med. 2019;8:501. 10.3390/jcm8040501 | Yes | Yes | No |
| Kim 2016 | Kim YC, Bok DH, Chang HG, et al.: Increased sagittal vertical axis is associated with less effective control of acute pain following vertebroplasty. | Yes | Yes | No |

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| | Bone Joint Res. 2016;5:544-51. 10.1302/2046-3758.511.BJR-2016-0135.R1 | | | |
| Korovessis 2007 | Korovessis P, Repantis T, George P: Treatment of acute thoracolumbar burst fractures with kyphoplasty and short pedicle screw fixation: Transpedicular intracorporeal grafting with calcium phosphate: A prospective study. Indian J Orthop. 2007;41:354-61. 10.4103/0019-5413.37000 | No | No | No |
| Korovessis 2008 | Korovessis P, Zacharatos S, Repantis T, et al.: Evolution of bone mineral density after percutaneous kyphoplasty in fresh osteoporotic vertebral body fractures and adjacent vertebrae along with sagittal spine alignment. J Spinal Disord Tech. 2008;21:293-98. 10.1097/BSD.0b013e31812e6295 | Yes | Yes | No |
| Kuo 2022 | Kuo YR, Cheng TA, Chou PH, et al.: Healing of vertebral compression fractures in the elderly after percutaneous vertebroplasty—An analysis of new bone formation and sagittal alignment in a 3-year follow-up. J Clin Med. 2022;11:708. 10.3390/jcm11030708 | Yes | Yes | No |
| Lee 2007a | Lee TO, Jo DJ, Kim SM: Outcome and efficacy of height gain and sagittal alignment after kyphoplasty of osteoporotic vertebral compression fractures. J Korean Neurosurg Soc. 2007;42:271-75. 10.3340/jkns.2007.42.4.271 | Yes | Yes | No |
| Lee 2007b | Lee SB, Cho KS, Huh PW, et al.: Clinical and radiographic results of unilateral transpedicular balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures. Acta Neurochir Suppl. 2008;101:157-60. 10.1007/978-3-211-78205-7_27 | Yes | Yes | No |
| Li 2014 | Li D, Huang Y, Yang H, et al.: Jack vertebral dilator kyphoplasty for treatment of osteoporotic vertebral compression fractures. Eur J Orthop Surg Traumatol. 2014;24:15-21. 10.1007/s00590-012-1131-8 | Yes | Yes | No |
| Liang 2020 | Liang XJ, Zhong WY, Luo XJ, et al.: Risk factors of adjacent segmental fractures when percutaneous vertebroplasty is performed for the treatment of osteoporotic thoracolumbar fractures. Sci Rep. 2020;10:399. 10.1038/s41598-019-57355-1 | Yes | Yes | No |
| Liu 2008 | Liu JB, Tang XM, Xu NW, et al.: Preliminary results for the treatment of a pain-causing osteoporotic vertebral compression fracture with a sky bone expander. Korean J Radiol. 2008;9:420-25. 10.3348/kjr.2008.9.5.420 | Yes | Yes | No |
| Liu 2022 | Liu H, Zhou Q, Shao X, et al.: Percutaneous kyphoplasty in patients with severe osteoporotic vertebral compression fracture with and without Intravertebral cleft: A retrospective comparative study. Int J Gen Med. 2022;15:6199-6209. 10.2147/IJGM.S369840 | Yes | Yes | No |
| Ma 2022 | Ma CH, Yang HL, Huang YT, et al.: Effects of percutaneous vertebroplasty on respiratory parameters in patients with osteoporotic vertebral compression fractures. Ann Med. 2022;54:1320-27. 10.1080/07853890.2022.2063373 | Yes | Yes | No |
| Matsumoto 2023 | Matsumoto K, Hoshino M, Omori K, et al.: The relationship between global sagittal balance and the incidence of early adjacent vertebral fractures following balloon kyphoplasty. World Neurosurg. 2023;175:e818-22. 10.1016/j.wneu.2023.04.027 | Yes | Yes | No |
| Papadopoulos 2008 | Papadopoulos EC, Edobor-Osula F, Gardner MJ, et al.: Unipedicular balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures: Early results. J Spinal Disord Tech. 2008;21:589-96. 10.1097/BSD.0b013e31815d6997 | No | Yes | No |
| Park 2017 | Park JW, Park JH, Jeon HJ, et al.: Kümmell's disease treated with percutaneous vertebroplasty: minimum 1 year follow-up. Korean J Neurotrauma. 2017;13:119-23. 10.13004/kjnt.2017.13.2.119 | Yes | Yes | No |
| Park 2021 | Park JS, Park YS: Survival analysis and risk factors of new vertebral fracture after vertebroplasty for osteoporotic vertebral compression fracture. Spine J. 2021;21:1355-61. 10.1016/j.spinee.2021.04.022 | Yes | Yes | No |
| Pflugmacher 2005 | Pflugmacher R, Kandziora F, Schroder R, et al.: [Vertebroplasty and kyphoplasty in osteoporotic fractures of vertebral bodies -- a prospective 1-year follow-up analysis]. Rofo. 2005;177:1670-76. 10.1055/s-2005-858631 | Yes | Yes | No |
| Pflugmacher 2006 | Pflugmacher R, Schroeder RJ, Klostermann CK: Incidence of adjacent vertebral fractures in patients treated with balloon kyphoplasty: Two years' prospective follow-up. Acta Radiol. 2006;47:830-40. 10.1080/02841850600854928 | Yes | Yes | No |
| Phillips 2003 | Phillips FM, Ho E, Campbell-Hupp M, et al.: Early radiographic and clinical results of balloon kyphoplasty for the treatment of osteoporotic vertebral | Yes | Yes | No |

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| | compression fractures. Spine. 2003;28:2260-65; discussion 2265-67. 10.1097/01.BRS.0000085092.84097.7B | | | |
| Plais 2023 | Plais N, Bustos JG, Mahillo-Fernández I, et al.: Osteoporotic vertebral fractures localized in the lumbar area significantly impact sagittal alignment. Osteoporos Int. 2024;35:277-84. 10.1007/s00198-023-06936-y Note: Available online in December 2023. | Yes | No | No |
| Pradhan 2006 | Pradhan BB, Bae HW, Kropf MA, et al.: Kyphoplasty reduction of osteoporotic vertebral compression fractures: Correction of local kyphosis Versus overall sagittal alignment. Spine. 2006;31:435-41. 10.1097/01.brs.0000200036.08679.1e | No | Yes | No |
| Röhrl 2006 | Rohrl B, Sadick M, Brocker K, et al.: MDCT after balloon kyphoplasty: Analysis of vertebral body architecture one year after treatment of osteoporotic fractures. [German]. RoFo. 2006;178:801-9. 10.1055/s-2006-926872 | No | Yes | No |
| Shibuya 2022 | Shibuya Y, Katsumi K, Ohashi M, et al.: Effect of adjuvant therapy with teriparatide in patients with thoracolumbar osteoporotic vertebral fractures who underwent vertebroplasty with posterior spinal fusion. Sci Rep. 2022;12:8854. 10.1038/s41598-022-12655-x | Yes | No | Yes |
| Singh 2010 | Singh K, Pflugmacher R: Directed cement flow kyphoplasty for treatment of osteoporotic vertebral compression fractures. In: Yue JJ, Guyer R, Johnson JP, et al. (eds). The Comprehensive Treatment of the Aging Spine: Minimally Invasive and Advanced Techniques. Philadelphia, PA: W. B. Saunders; 2010:243-47. | No | Yes | No |
| Spiegl 2019 | Spiegl UJ, Anemuller C, Jarvers JS, et al.: Hybrid stabilization of unstable osteoporotic thoracolumbar vertebral body fractures: clinical and radiological outcome after a mean of 4 years. Eur Spine J. 2019;28:1130-37. 10.1007/s00586-019-05957-8 | Yes | No | Yes |
| Sung 2023 | Sung HS, Kim SI, Park HY, et al.: Predictive factors for conversion from conservatively to surgically treatment osteoporotic thoracolumbar compression fractures based on sagittal parameters and magnetic resonance imaging features. Eur Spine J. 2023;32:3933-40. 10.1007/s00586-023-07864-5 | Yes | No | No |
| Takezawa 2012 | Takezawa M, Takahashi T, Hanakita J, et al.: Early clinical and radiological results of balloon kyphoplasty in the treatment of ostoporotic vertebral compression fractures. Japanese Journal of Neurosurgery. 2012;21:959-66. 10.7887/jcns.21.959 | Yes | Yes | No |
| Tanigawa 2012 | Tanigawa N, Kariya S, Komemushi A, et al.: Added value of percutaneous vertebroplasty: Effects on respiratory function. AJR Am J Roentgenol. 2012;198:W51-54. 10.2214/AJR.11.6730 | Yes | Yes | No |
| Topalidou 2015 | Topalidou A, Tzagarakis G, Balalis K, et al.: Sagittal and frontal plane evaluation of the whole spine and clinical outcomes after vertebral fracturesAdv Orthop. 2015;2015:787904. 10.1155/2015/787904 | No | No | No |
| Trieb 2020 | Trieb K, Nittinger M: Timing of kyphoplasty influences the outcome: a prospective study. Sportverletz Sportschaden. 2020;34:42-7. 10.1055/s-0043-124989 | Yes | Yes | No |
| Voggenreiter 2005 | Voggenreiter G: Balloon kyphoplasty is effective in deformity correction of osteoporotic vertebral compression fractures. Spine. 2005;30:2806-12. 10.1097/01.brs.0000190885.85675.a0 | Yes | Yes | No |
| Voggenreiter 2008 | Voggenreiter G, Brocker K, Rohrl B, et al.: Results of balloon kyphoplasty in the treatment of osteoporotic vertebral compression fractures. Unfallchirurg. 2008;111:403-12. 10.1007/s00113-008-1453-5 | Yes | Yes | No |
| Yang 2020 | Yang JJ, Koo KH, Kim K, et al.: Efficacy of postural reduction of vertebral compression fracture with extension lateral radiograph before vertebroplasty. World Neurosurg. 2020;143:e430-41. 10.1016/j.wneu.2020.07.188 | Yes | Yes | No |
| Yeh 2011 | Yeh JH, Yang SC, Kao YH, et al.: Clinical and radiographic evaluation of balloon kyphoplasty using VCFX for osteoporotic vertebral compression fracture. Formosan J Musculoskelet Disord. 2011;2:94-8. 10.1016/j.fjmd.2011.06.003 | Yes | Yes | No |
| Yi 2007 | Yi WJ, Lee JH, Lee HG, et al.: Efficacy and safety of balloon kyphoplasty in the treatment of osteoporotic vertebral body compression fractures: Compared with vertebroplasty. J Korean Neurosurg Soc. 2007;42:112-17. URL: https://jkns.or.kr/journal/view.php?number=1680 | Yes | Yes | No |
| | Zhang YL, Shi LT, Tang PF, et al.: Correlation analysis of osteoporotic | | | |

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|---|---|---|---|---|
| Zhang 2017 | vertebral compression fractures and spinal sagittal imbalance. Orthopade. 2017;46:249-55. 10.1007/s00132-016-3359-1 | Yes | No | Yes |
| Zhao 2022 | Zhao C, Liu X, Wang Y, et al.: The effects of biomechanical factors on adjacent vertebral compression fractures after percutaneous kyphoplasty: a propensity score matching analysis. Osteoporos Int. 2022;33:1795-1806. 10.1007/s00198-022-06428-5 | Yes | Yes | No |

**TABLE 10: Studies excluded during full-text review and reason for exclusion**

# Additional Information

## Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

**Acquisition, analysis, or interpretation of data:** Hanne H. Jørgensen, Mikkel Ø. Andersen, Line A. Wickstrøm, Benjamin Kostic, Leah Y. Carreon

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## Disclosures

**Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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