The Current Status of Spinal Posttraumatic Deformity: A Systematic Review

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Abstract

Study Design: Systematic Review.

Objective: To systematically analyze the definitions and descriptions in literature of “Spinal Posttraumatic Deformity” (SPTD) in order to support the development of a uniform and comprehensive definition of clinically relevant SPTD.

Methods: A literature search in 11 international databases was performed using “deformity” AND “posttraumatic” and its synonyms. When an original definition or a description of SPTD (Patient factors, Radiological outcomes, Patient Reported Outcome Measurements and Surgical indication) was present the article was included. The retrieved articles were assessed for methodological quality and the presented data was extracted.

Results: 46 articles met the inclusion criteria. “Symptomatic SPTD” was mentioned multiple times as an entity, however any description of “symptomatic SPTD” was not found. Pain was mentioned as a key factor in SPTD. Other patient related parameters were (progression of) neurological deficit, bone quality, age, comorbidities and functional disability. Various ways were used to determine the amount of deformity on radiographs. The amount of deformity ranged from not deviant for normal to >30°. Sagittal balance and spinopelvic parameters such as the Pelvic Incidence, Pelvic Tilt and Sacral Slope were taken into account and were used as surgical indicators and preoperative planning. The Visual Analog Scale for pain and the Oswestry Disability Index were used mostly to evaluate surgical intervention.

Conclusion: A clear-cut definition or consensus is not available in the literature about clinically relevant SPTD. Our research acts as the basis for international efforts for the development of a definition of SPTD.

Keywords

spinal posttraumatic deformity, posttraumatic kyphosis, systematic review, spine trauma

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Introduction

A trauma to the spine was registered in 17% (144,909/861,888 incidents) of total traumatic incidents of the population in the USA in 2015.1 Some degree of deformity is common after spine trauma, regardless of the treatment.2-13 According to White et al and Whitesides, even a small degree of kyphosis, by increasing the moment arm, can lead to a progressive deformity over the years14,15; however, at which point a posttraumatic deformity of the spine becomes clinically “relevant” or symptomatic is still up for debate. This “Spinal Posttraumatic Deformity” (SPTD) can require extensive surgery with high risk of complications and is more aggressive than treatment of the primary injury itself.16-18 Indications for such surgical interventions for patients suffering from SPTD differ in literature.

The etiology of SPTD is multifactorial and the key factors are still unknown. Some examples of the factors involved are wrong or delayed fracture diagnosis, failure of treatment (either non-surgical or surgical), intervertebral disc (IVD)-injury and diseases influencing the bone quality.12,16-22 SPTD has been described in various ways using clinical symptoms, kyphotic angles and other spine-related measurements on radiographs and Patient Reported Outcomes Measures (PROMs).

A decade ago, Schoenfeld et al published a survey to reach consensus about SPTD. A definition on which consensus between experts was reached was “a painful kyphotic deformity,” but no further specifics related to define SPTD reached a consensus.23 This basic definition results in no practical conclusion to be used in clinical practice. Moreover, this definition does not consider the different spine regions. The absence of a clear definition of “clinically relevant” SPTD limits the possibilities to compare different treatments and prognostic factors involved. The aim of this study is to systematically review and evaluate the current definitions and descriptions of SPTD and which patient factors, radiological assessments and surgical indications are part of SPTD in literature. This will be the first step in gathering broad information to support the development of a uniform and comprehensive definition of SPTD in follow-up research.

Methods

Protocol and Registration

This review was structured using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement (PRISMA-statement).24 The protocol was registered in PROSPERO (registration number: CRD42019122293).

Eligibility Criteria, Information Sources and Search Strategy

A literature search in Pubmed, Embase, Scopus and 8 other international databases was performed using the search terms deformity and posttraumatic and its synonyms (Table 1), from 1950 until the present (date of search: 23-12-2019). The search was limited to title and abstract using the correct field description. No language was excluded.

Study Selection

All articles were screened on title and abstract by 2 independent observers (EDG, TV) after removal of duplicates using Rayyan QRCI (web application, Qatar Computing Research Institute (Data Analytics), Doha, Qatar). Articles were included if they concerned adults (≥18 years) and if: a definition of SPTD was given; the indication for treatment was SPTD; SPTD was mentioned as a diagnosis; or when recurrent kyphosis was evident after acute fracture. Any discrepancies between the 2 observers were resolved by discussion and if necessary, by consulting a senior independent author (SPJM). The full texts were screened on the in- and exclusion criteria and included on consensus by the 2 observers. The first author was contacted when a full text was not available. Exclusion criteria were: absent full text, review articles, patients <18 years, no mention of SPTD and congress abstracts. A cross-reference check was performed.

Data Collection Process and Data Items

The characteristics of the articles were assessed by extracting year of publication, type of study, spine level of interest and number of patients included. All the data was extracted by 2 independent observers. Discrepancies were resolved by discussion. The descriptions of SPTD were extracted and placed in 4 categories: Patient factors(e.g. pain, neurology), Radiological Outcomes (e.g. amount of deformity, radiographic diagnosis entity), PROMs and Surgical indication.

Risk of Bias per Study

Methodological quality was reviewed using the PRISMA-statement.24 Because of the nature of the research questions the articles were critically appraised by our own system which was
applied by 2 observers independently. The quality assessment was based on the presence of an original description or definition of SPTD. If no original description or definition; just mentioning of SPTD without a description or recurrent kyphosis without additional information was given; the study was excluded based upon poor quality for the aim of this study. All types of study design were considered.

Summary and Synthesis

The terms/descriptions per category of SPTD were extracted from the included articles and placed in a table by both observers. As the data is qualitative data, a narrative synthesis was drafted, when certain terms were stated by multiple articles cumulative results were given.

Results

Search, Study Selection

In total, 1,675 articles were found in the searched databases of which 332 articles were included in full text analysis. Figure 1 displays the full search strategy. The cross-reference check showed 1 article which only mentioned SPTD and was excluded for the analysis. The included articles were placed in 2 categories: “Definition of SPTD” (9 articles) and “SPTD Surgical Indication” (37 articles). The study designs were: Expert opinion, Survey, Case reports, Case-series and Cohort studies. A chronological overview of the included articles and the extracted data can be found in Tables 2, 3A, and 3B.

General

Used synonyms of SPTD were: late kyphotic deformity, chronic vertebral instability, (severe) posttraumatic kyphosis and symptomatic posttraumatic deformity. Asymptomatic SPTD exists according to Schoenfeld et al. The presentation of patients with SPTD was between 3 months and 36 years after the primary spine injury. Only 4 articles addressed the cervical spine.

Patient Factors

Multiple patient factors were described as an element of SPTD in the included articles. The most common factor was pain which
was mentioned in 38 of the 46 articles. Pain may be originating from different regions: the injured vertebra itself due to mechanical instability/pseudoarthrosis, other regions of the spine due to degeneration of the compensatory segments, IVD-lesions, or due to the fatigue of the tendinomuscular apparatus as a compensatory mechanism. Another patient factor mentioned in 29 of the 48 articles was the presence of a (pre-existing or increasing) neurological deficit. Clinical neurology was classified and evaluated using the American Spinal Injury Association Impairment Scale (ASIA)\textsuperscript{52,57,62} or Frankel grade.\textsuperscript{53,41,64}

Table 2. Overview of the Study Characteristics of the 46 Articles Included in the Quantitative Analysis.

| Reference | SPTD Definition | Year | Study type | Spine region of interest | Number of patients with SPTD |
|-----------|----------------|------|------------|--------------------------|-----------------------------|
| White et al\textsuperscript{14} | 1977 Expert Opinion | C, Th, L | NA |
| Malcolm\textsuperscript{25} | 1979 Expert Opinion | Whole spine | NA |
| Rusu et al\textsuperscript{26} | 2007 Expert Opinion | ThL | NA |
| Kandziora et al\textsuperscript{27} | 2009 Expert Opinion | ThL | NA |
| Munting\textsuperscript{28} | 2010 Expert Opinion | Th, L | NA |
| Schoenfeld et al\textsuperscript{23} | 2010 Survey, Expert Opinion | CTh, Th, L | NA |
| Suchomel and Choutka\textsuperscript{29} | 2010 Expert Opinion | Upper C | NA |
| Cecchinato et al\textsuperscript{30} | 2014 Expert Opinion | ThL | NA |
| Boehm et al\textsuperscript{31} | 2017 Expert Opinion | Th, L | NA |

SPTD Surgical indication

SPTD = Spinal Posttraumatic Deformity;
C = cervical spine, Th = thoracic spine; L = lumbar spine; S = sacral spine; NA = not available

The first 9 articles gave a specific definition of SPTD, the other 37 articles presented an original description of SPTD.
### Tables 3. Overview of the Definitions and Descriptions of SPTD Divided in Patient Factors, Radiology, Spinopelvic Parameters, PROMs and Surgical Indications Given.

| Reference          | Patient factors                                                                                                                                                                                                 | Radiology                                                                 | Cutoff values                                                                 | Spinopelvic                                                                 | Cutoff values                                                                 | Patient Reported Outcome Measurements                                                                 | Surgical indication                                                                                   |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| White et al 14     | -                                                                                                                                                    | -                           | -                                                                             | -                                                                           | -                                                                             | -                                                                                                                                                                                                                                                                         | -                                                                |
| Malcolm 25         | Body habitus, pain (partly discs), spinal crepitus, impaired sitting/standing, ulceration, respiratory insufficiency, increased neurological deficit, chronic cases depending on severity of presenting signs and symptoms | X Standing/sitting FS AP+Lat | -                                                                             | C7plumbline, ThK (T2-T12); LL (T12-L1); ThL (T10-L2)                        | Deviation from normal: ThK: -35° (20°-50°) LL: -55° (-45°-65°) ThL: -50° (-40°-60°) | Chronic cases depending on severity of presenting signs and symptoms                                                                                                                                  | Clinical symptoms most important: pain, neurological deficit                                      |
| Rusu et al 26       | Pain, inability to work, deformities in clinical exam, neurological deficit (spasticity)                                                                                                                   | X Th/L AP+ Lat              | -                                                                             | -                                                                           | -                                                                             | -                                                                                                                                                                                                                                                                         | -                                                                |
| Kandziora et al 27  | Osteoporosis, refusal of therapy, Cardiac, pulmonic and abdominal dysfunction                                                                                                                                | X Standing F5 AP+Lat        | -                                                                             | C7plumbline, ThK (T2-T12); LL (T12-L1); ThL (T10-L2)                        | Deviation from normal: ThK: -35° (20°-50°) LL: -55° (-45°-65°) ThL: -50° (-40°-60°) | Pain unresponsive to therapy and physiotherapy; Neurological deficit (radiculopathy, myelopathy with claudication); Posttraumatic syrinx; Instability because of non-union                                                                 | Cosmetic appearance                                                                                 |
| Munting 28         | Nociceptive sensitivity, age, pain, deformity, function, forward gaze, psychosocial problems, neurological deficit, cosmetic altered function                                                             | X Standing FS: SI           | >20°                                                                          | Hyperlordosis, hypo-/ or hyperkyphosisTh                                     | Altered function                                                             | Proposed definition: Painful kyphotic deformity in posttraumatic spine                                                                                                                                     |                                                                                                             |
| Schoenfeld et al 23 | Pain, progressive deformity and deteriorating neurology (rare), A3/B1/B2 fractures Asymptomatic SPTD does exist                                                                                               | X regional flex/ext         | S-30°                                                                         | C7 plumbline                                                                | Imbalance relative to sacral endplate                                              |                                                                                                                                  | Proposed definition: Painful kyphotic deformity in posttraumatic spine                                                                                                                                     |
| Suchomel and Choutka 29 | Pain dependent on neck rotation, occipital pain, reduced neck mobility, myelopathy, vascular compromise; No specific clinical presentation                                                                 | X C AP+ Lat, Flex/ext       | -                                                                             | -                                                                           | -                                                                             |                                                                                                                                  | Cons: mild and stable deformity without neurological symptoms. Elderly and multiple comorbidities. Surg: neurological compromise, intractable pain as result of malalignment                                                                 |                                                                                                             |
| Cecchinato et al 30 | -                                                                                                                                                    | X FS AP+ Lat                | -                                                                             | C7 plumbline, C7/VA, PT, ThK, LL                                          | PT > 20° compared to expected PT                                              | VAS <70/100 or ODI <20/100 less likely to benefit from surgery; VAS high or ODI >40 more benefit from surgery                                                                                           | No response conservative treatment Spr: Sagittal index >20° PT > 20° or high compared to expected PT Lumbar hyper-/ OR hyperlordosis                                                                 |                                                                                                             |

(continued)
### Tables 3. (Continued)

| Reference | Patient factors                                                                 | Radiology                                      | Cutoff values | Spino pelvic Cutoff values | Patient Reported Outcome Measurements | Surgical indication                                                                 |
|-----------|--------------------------------------------------------------------------------|-----------------------------------------------|---------------|---------------------------|---------------------------------------|--------------------------------------------------------------------------------------|
| Boehm et al<sup>31</sup> | Load dependent pain, compensatory mechanisms, deviations of physiological curves during standing and walking, neurological deficit | X standing FS AP+Lat                          | Deviation from | C7-plumbline             | -                                     | Cons: Pain free deformity  
Surg: deformity, instability, stenosis >20° at former fracture site, pain at index level or other locations, neurological deficit.  
>15-20° should be corrected. | |
| Malcolm et al<sup>32</sup> | Pain: apical constant aching, reduced by recumbency, ThL deformity had radiation to buttocks, progression of kyphosis, spinal crepitus; neurological deficit | X Standing/sitting FS AP+Lat                   | -             | -                         | pain                                  | Symptomatic PTK                                                                     |
| McBride and Bradford<sup>33</sup> | Back pain at the apex of kyphosis, radicular pain or hypesthesia, urinary incontinence/urgency, rectal tenesmus or spasm, focal motor weakness (Frankel) | X Cobb X flex/ext X lateral bending in scoliosis |                |                           | -                                     | 1. persistent or increasing neurological deficit or radicular pain, with anterior bony impingement, compromising at least 25% of spinal canal; 2. failed posterior instrumentation and fusion attempts with unstable, painful pseudosclerotic and kyphosis | |
| Boni et al<sup>34</sup> | Neurological deficit                                                          | X C AP-Lat                                    | -             | -                         | -                                     | Stenosis of 3 or more intersomatic spaces with myelopathy                            |
| Kostuik<sup>35</sup> | Pain, progressive deformity, with/without neurological involvement             | X regional AP+Lat                             | -             | -                         | Pain                                  | Painful and/or progressive kyphotic deformities with or without neurologic involvement |
| Roberson and Whitesides<sup>36</sup> | Pain, deformity, neural embarrassment, incomplete rehabilitation               | X regional                                    | -             | -                         | Pain relieve poor, fair or good        | Increasing kyphotic deformity, pain, or increasing neurologic deficit                |
| Dick<sup>37</sup> | Severe pain                                                                    | X regional                                    | -             | -                         | -                                     | Severe pain with failure of previous treatment                                       |
| Kostuik and Matsusuke<sup>38</sup> | Pain at apex and/or levels below, neurological deficit, limited walking        | X regional                                    | -             | -                         | Pain                                  | Kyphosis angle >30°  
Symptomatic PTK                                                                    |

(continued)
**Tables 3. (Continued)**

| Reference | Patient factors                                      | Radiology                      | Cutoff values | Spino pelvic | Cutoff values | Patient Reported Outcome Measurements | Surgical indication                                                                 |
|-----------|------------------------------------------------------|-------------------------------|--------------|-------------|--------------|----------------------------------------|--------------------------------------------------------------------------------------|
| Gertzbein and Harris39 | With or without neurology, with or without mechanical back pain, facet pain | X regional AP+Lat "Cobb" (lower endplate cranial vertebra and lower endplate of fractured vertebra) | -            | -           | -            | Symptomatic PTK with Cobb > 30°, for the described procedure; but Cobb < 30° is not excluding factor for other surgical treatment |  |
| Chang40 | Neurological deficit (Eismont muscle strength evaluation), progressive back pain, fatigue | X Standing AP+Lat Cobb | X flex/ext: rigidity | CT or Tomography: neurological topography | -            | Progression of deformity and low back pain, constant fatigue with rigid kyphosis on flex/ext radiographs |  |
| Wu et al41 | Pain, neurologic compromise (Frankel), disabled, pressure sores, fatigue, progressive deformity | X reg AP/Lat Cobb | X flex/ext | Th > 30° L > 20° | -            | - coated PTK for PTD and pain | Rigid PTK                                                                 |
| Atici et al42 | Back pain at apex, neurological deficit, cosmetic | X-ray: Cobb | Scoliotic angle (Cobb method) | CT: spinal canal | -            | - back pain scoring; Greenough and Fraser, VAS pain, same surgery again |  |
| Been et al43 | Pain (apex or compensatory), neurological damage or progression, skin problems | X regional Standing AP+Lat Cobb | Scoliotic angle (Cobb method) | Th > 30° L > 20° | -            | - VAS pain, ODI Symptomatic PTK, pain not responding to conservative treatment |  |
| Robertson et al44 | - | X regional AP+Lat Cobb | Coronal plane deformity | -            | -            | Late reconstruction for PTD and pain |  |
| Stoltze et al45 | Vertebral (deformity, iatrogenic instability, stenosis, compensation/tendinosis) vs neurological (radiculopathy, tethered cord, atrophy/ myelopathy, syrinx) | X Standing FS | Arthritis hips, total balance | X regional function: segmental mobility | -            | Compensation: increased PT and flexion hips | Vertebral pain syndrome because of deformity or instability or neurological deficit |  |
| Chou et al46 | Pain (non-healed fracture or kyphosis) | X Standing FS AP+Lat CT: healed fracture | Positive balance or compensatory hyperlordosis | VAS pain | -            | VAS pain, ODI Symptomatic PTK, ERD > 60° still worsening with/without neurological defect, no osteoporosis/metabolic disease | Refractory to conservative treatment, debilitating pain. Kyphosis = 40°; no osteoporosis |
| Zhang et al47 | Back pain, Neurology, progressive deformity | X Standing AP+Lat, flex/ext, - Cobb= ERD = Cobb-physiologic cobb for level (Stagnara et al) | Severe PTK ERD > 60° | -            | -            | VAS pain, ODI Symptomatic PTK, ERD > 60° still worsening with/without neurological defect, no osteoporosis/endocrine or metabolic disease |  |
| El-Sharkawi et al48 | Persistent low back pain, cosmetic | X Standing FS AP+Lat - wedge angle | Compensatory hyperlordosis | VAS pain, ODI, patient satisfaction | -            | VAS pain, ODI, patient satisfaction | Symptomatic PTK                                                                 |
| Wang et al49 | Painful kyphotic angulation, back pain, neurological function | X lat: - Cobb - Ant. and post. vertebral body height | CT MRI: Disc injury | JOA Back pain scores | -            | JOA Back pain scores | Rigid PTK with: progression of kyphosis >5°, kyphosis >30° with significant low back pain and deterioration of neurological function |  |

(continued)
| Reference | Patient factors | Radiology | Cutoff values | Spinopelvic Cutoff values | Patient Reported Outcome Measurements | Surgical indication |
|-----------|-----------------|-----------|---------------|---------------------------|--------------------------------------|---------------------|
| Noor et al<sup>50</sup> | Severe back pain, sagittal imbalance, compression myelum or nerve roots, pseudarthrosis | - | - | - | - | Severe complaints with kyphosis $>15^\circ$-$30^\circ$ |
| Omidi-Kashani et al<sup>51</sup> | Fatigue and pain | X standing FS AP+Lat: - Cobb - MRI | - | - | - | VAS pain, ODI, patient satisfaction |
| Xi et al<sup>52</sup> | Local muscle fatigue or pain, focal deformity, neurological deficit (ASIA) | X AP+Lat - Cobb - ThK - LL - CT: 3D planning | - | SVA (cm) | - | VAS pain |
| He and Xu<sup>53</sup> | Severe back pain, kyphosis | X standing FS AP+Lat | - | C7 plumbline ThK LL | - | VAS pain, ODI |
| Obeid et al<sup>54</sup> | Neck or high Th deformity, impaired horizontal gaze, chronic pain | X Standing FS AP+Lat - Kyphosis Angle (-), Scoliosis, Coronal head shift | - | - | - | - | Absolute indication: progression of deformity |
| Soultanis et al<sup>55</sup> | Residual kyphosis, can be asymptomatic, back pain, osteoporosis | X regional AP+Lat - Wedge angle - loss of Vertebral body height | - | - | - | VAS pain, ODI | 10 patients with progressive deformity and back pain |
| Shigematsu et al<sup>56</sup> | Back pain, cosmetic deformity, late neurological deficit | Plain AP+Lat radiographs: - Fracture healing - Cobb (upper endplate of vertebra above and lower endplate fractured vertebra): MRI: neurological involvement | - | Sagittal balance: SVA | - | - | All patients had low energy trauma |
| Yagi et al<sup>57</sup> | ASIA A-D | X Standing FS AP: - Scoliosis Cobb angle | $>10^\circ$ lateral curve coronal plane | - | - | - | Difficulty with daily activities caused by severe sagittal imbalance, back pain or neurological disturbance |
### Tables 3. (Continued)

| Reference | Patient factors | Radiology | Cutoff values | Spinepelvic Cutoff values | Patient Reported Outcome Measurements | Surgical indication |
|-----------|----------------|-----------|---------------|---------------------------|--------------------------------------|---------------------|
| Gao et al58 | Intractable pain, stooping, rapid fatigue, progressive neurologic deficits | X regional: - Cobb CT: 3D reconstruction MRI: neurological involvement | >30° | - | VAS pain, ODI | Symptomatic PTK, focal ThL kyphosis >30° |
| Bourghli et al59 | Painful, rigid, flexion of the knees | X Standing FS AP+Lat - ThL kyphosis (T10-L2) - Upper local kyphosis (lower endplate vertebra below, upper endplate of fractured vertebra) X Dynamic: stiffness CT: anatomy (shape and osteophytes) | - | Frontal C7 Sagittal C7 ThK LL PT, SS, PI | - | Non-flexible ThL deformity with local kyphosis >30° on dynamic views and degenerated discs around fracture level |
| Liu et al60 | Overall loss of sagittal balance, back pain, cosmetic, could interfere with personal hygiene and daily physical life | X Regional AP+Lat: - Cobb CT: 3D reconstruction MRI: spinal cord compression | 45° | - | - | Progressive back pain with kyphosis |
| Hu et al61 | Pain, neurological impairment | X Standing FS - Cobb X Pelvis | >30° | SVA PT, SS, PI | VAS pain, ODI | Cobb >30° of SI; Significant pain refractory to conservative treatment; Increasing neurologic deficit |
| Chen et al62 | Neurological impairment (ASIA), some with obvious back pain | X Regional AP+Lat - Cobb CT | - | - | VAS pain, ODI | Chronic pain in segment, some with progressive kyphosis |
| Wang et al63 | Related to kyphosis: intractable pain, stooping, rapid fatigue, progressive neurological deficit, refractory after 3 months conservative therapy; no osteoporosis | X Regional AP+Lat - Cobb | >30° | - | VAS pain, ODI | Symptomatic late PTK, no osteoporosis |
| Li et al64 | Back pain, neurological deficit (Frankel) Functional disability | X standing ThL AP+Lat: - Cobb - LL | - | - | - | VAS pain |
| Rerikh et al65 | Painful deformity | X FS AP+Lat - Cobb Deviation from SRS-criteria Thk(T1-T12) LL(L1-S1) Thk(T10-L2) PT, SS, PI Roussouly Vrougas | Deviation from SRS-criteria | VAS pain, ODI | Cons: Cobb <20°, without obvious pain or neurological deficit Surg: Cobb >20° with pain, progressive nerve damage |
| El Naggar et al66 | Back pain, local deformity with neurology | X Standing FS AP+Lat - Cobb Occasional: CT: evaluate deformity MRI: neurological involvement | Severe Cobb >50 | Thk (TS-T12) LL (-) | VAS pain, ODI | Inclusion of Severe PTK: Back pain affecting QoL (ODI >40, VAS >5), neurological symptoms, Cobb >50°, SVA>25mm |

(continued)
| Reference       | Patient factors | Radiology                                      | Cutoff values | Spinopelvic Cutoff values | Patient Reported Outcome Measurements | Surgical indication                               |
|-----------------|-----------------|-----------------------------------------------|---------------|---------------------------|----------------------------------------|------------------------------------------------|
| Matsumoto et al<sup>67</sup> | Back pain       | X Standing FS AP+Lat                        | -             | SVA LL (fracture-S)       | -                                      | Surg: refractory back pain, deteriorating neurology and SI>20<sup>°</sup> Rigid kyphotic deformity + symptoms including non-flexible deformity and very mild vertebral instability with local kyphosis and severe low back pain |
| Avila et al<sup>68</sup>   | -               | X Standing FS AP+Lat                        | -             | C7 plumbline              | ODI                                    | Loss of spinal balance with PTK                  |

X: radiograph; AP+Lat: anteroposterior and lateral views; C: Cervical spine; T: Thoracic spine; L: Lumbar spine; S: Sacral spine
CT: Computer Tomography; MR: magnetic resonance imaging; FS: full spine
Cobb: upper endplate of vertebra cranial and lower endplate of vertebra caudal
SRS-criteria: Scoliosis Research Society criteria
ERD: Effective Regional Deformity, SI: Sagittal index
VAS pain: visual analog scale of pain, ODI: Oswestry Disability Index
Cons: Conservative treatment, Surg: surgical treatment; PTK: posttraumatic kyphosis; QoL: quality of life
Other factors mentioned were, in order of frequency; noticeable progression of deformity, functional disability, cosmetic appearance, diseases affecting bone quality, skin ulceration, inability to maintain a forward gaze, respiratory insufficiency, spinal crepitus, impaired sitting or standing, body habitus, inability to work and problems with hygiene.\textsuperscript{25-28,32,41-43,47,48,54-56,60,64}

Radiology

Diagnostic tests, amount of deformity and surgical planning.

The radiological workup to diagnose SPTD or for surgical planning was not clearly differentiated; therefore the results were combined. Regional and full standing lateral and antero-posterior radiographs of the spine were used by all but one article. Five different ways to measure the amount of deformity were described and 16 articles did not mention the way of measurement. The majority of the deformity angles were measured as proposed by Cobb (25 articles), between the upper endplate of the vertebra cranial of the affected vertebra and the lower endplate of the vertebra caudal to the affected vertebra. Other measurements were: between the upper and lower endplate of the affected vertebra (sometimes called “wedge angle”), between the lower or the upper endplate of the vertebra and the base of the skull. The C7-plumbline was described in 7 articles. Imbalance was present when the plumbline fell outside the sacrum. A SVA >50 mm was scored as an imbalance in 6 articles. Compensation was suspected in 3 articles if deviation of the normal spinal alignment, as stated by the Scoliosis Research Society, was present.\textsuperscript{31,65,67} Other signs of compensation mechanisms were: a PT >20 or a PT higher than expected; and an increased PT with flexion of the hips.\textsuperscript{30,45} Kandziora et al and Boehm et al stated that the spinopelvic parameters could discern between 2 types of SPTD: 1. the compensated and/or sagittal balanced; 2. the sagittal imbalanced.\textsuperscript{27,31}

Patient Reported Outcomes Measurements

Different PROMs were performed to evaluate a treatment in 23 articles. The PROMs used were: Visual Analog Scale (VAS) for pain, Oswestry Disability Index (ODI), patient satisfaction, Japanese Orthopedic Association (JOA) score of back pain and back pain scoring by Greenough and Fraser. Cechinato et al stated that a patient with VAS pain scale of <70/100 and an ODI of <20/100 would less likely benefit from surgical intervention. A patient with VAS pain scale >70/100 or an ODI >40/100 would benefit from surgical intervention.\textsuperscript{30} El Nagger et al only included patients in his study with severe SPTD and back pain affecting quality of life defined as a VAS >5 and an ODI >40.\textsuperscript{66}

Surgical Indication

Surgical indications of patients with SPTD were described in 42 articles. Description of the indication ranged from “symptomatic” or “rigid” SPTD\textsuperscript{32,41,48} to explicit requirements on patient factors, radiological parameters and PROMs. Refractory pain or increasing pain after conservative therapy was described in 9 articles.\textsuperscript{27,29,30,43,52,53,61,63,66} Nineteen articles considered a progressive neurological deficit an absolute indication for surgical intervention. Progression can result from tension on the spinal cord, stenosis or a syrinx. Stoltze et al recommended differentiating between vertebral pain and neurological pain, to avoid disappointing results after surgical treatment.\textsuperscript{45} Boni et al indicated surgical treatment when a cervical myelopathy due to stenosis, without specific kyphosis, was present in a patient.\textsuperscript{34}

Discussion

In this systematic review, we gave an overview of the descriptions of “Spinal Posttraumatic Deformity.” We explored 4 different domains that were used to describe SPTD. A clear-cut definition was absent in the literature.

We displayed the heterogeneity in the reported factors: the amount of deformity and method of measurement, the use of
spinopelvic parameters and the use of PROMs. This great heterogeneity can be attributed to different study formats and the fact that no specific description of SPTD was sought, in all but 2 articles.14,23

There is a relative lack of articles describing cervical SPTD. This can be explained by the fact that most fractures occur in the thoracic and lumbar spine.69 Another potential reason may be that cervical fractures are more prone for surgical treatment and are not influenced by the body weight, which is suggested as a factor of progressive deformity.25,70

The existence of asymptomatic SPTD is plausible as “symptomatic” SPTD is mentioned often. Schoenfeld et al concluded that asymptomatic SPTD does exist with agreement from all respondents.23 However patients with SPTD almost exclusively suffer back pain in literature.

The amount of deformity in SPTD is measured in many different ways and the amount of deformity varies greatly, this is in agreement with a survey performed by Sadiqi et al.71 The methods used most in our review (Cobb and wedge angle) have been shown to have a high intra- and interrater reliability.72

A major concern is the reporting of a mean or median kyphotic angle combining different spine regions within the same study. The regions of the spine have a different alignment, which means that an angle 30° in the high thoracic spine or the lumbar spine has different consequences. Some articles addressed this by using the Sagittal Index, the SRS-criteria or the Effective Regional Deformity.28,30,31,47,61,65-67

Spinopelvic parameters are of great importance to assess the spine and are extensively studied in the context of degenerative spine diseases as opposed to the context of a traumatic spine. Already, the use of various spinopelvic parameters in Adult Spinal Deformity is encouraged for surgical planning.73,74 Matsumoto et al suggested that if patients with SPTD compensated by increasing lumbar lordosis and thus maintained a SVA <50 mm, achieved good global spinal balance after surgical intervention combined with a decrease in lumbar lordosis.67 Koller et al looked for correlations between spinal alignment and regional kyphosis in 146 patients treated conservatively after a thoracolumbar burst fracture. They found that lumbo-sacral lordosis had a significant correlation with regional kyphosis and segmental kyphosis at follow-up (average 9.5 years).75 Rousseau et al looked at sagittal rebalancing after pedicle subtraction osteotomy in the lumbar spine for a multitude of etiologies, including SPTD. They found that patients with SPTD responded differently with a local lumbar lordosis gain, but no real reorientation of the pelvis was seen.76 Spinopelvic parameters show promising correlation with SPTD, the question remains if certain values increase the risk of development of SPTD.

Contradictory correlations between SPTD and different factors were found. For example, a correlation between SPTD, pain and kyphosis >30 degree was found,39 however others disagree.77 Malcolm et al stated that body habitus and IVD injury play a role in the development of SPTD.25 Jerkh et al found an inverse correlation of hyperlordosis/hyperkyphosis with the amount of thoracic kyphosis and lumbar lordosis. Also, a correlation was found between the deviation of SVA and the OD1 and VAS of pain.65 All these correlations were studied with different definitions of SPTD and are therefore difficult to interpret, compare and repeat.

Surgical indication of patients with SPTD was based on factors such as pain, progression of neurology, amount of deformity or “symptomatic” patients. Buchowski et al concluded in their review that pain was not an absolute indication for a surgical intervention contrary to some articles in our review.17 Of note, pain without radiological deformity after a spine trauma would be out of the context of SPTD. Due to the great variance in the surgical indications and definitions of SPTD, comparing effectiveness of interventions is not possible.

This review reflects the evolving concepts of SPTD over the last decades. For example, more recently PROMs are used increasingly in evaluation of patients with SPTD. Another striking point was the radiological assessments used to diagnose or describe SPTD. Some imaging techniques were not widely available and specific in the second half of the 20th century and were therefore not part of the description of SPTD. The way we see spinal trauma and treat it evolved throughout the last decades, this also influences the meaning of a deformity of the posttraumatic spine. The evolving vision on SPTD could partly explain the differences in descriptions throughout the years.

International efforts resulted in translation of all foreign languages by natives or capable readers. Two possible limitations of this study are both related to the nature of our research question. First, we searched for a description of SPTD which can be an opinion of an author. A risk-assessment as proposed by the PRISMA-statement was not applicable in our research. Normally Expert Opinion and Case Reports are rated as a high risk of bias, but in our study, it was occasionally the “best available evidence.” The quality of the articles that only mentioned SPTD without a description were considered low because they did not add value to the understanding of SPTD. The (re)current kyphosis after fracture” articles could provide some insights on the possible risk factors in SPTD. They were also considered as low quality because a clear description to the recurrent kyphosis was not given other than that it was significantly different than before primary treatment. A second limitation of this study was the narrative character of the review. It is however not possible to find a definition or description by meta-analysis in this case. A last limitation is the number of articles excluded for inability to retrieve the full texts.

Kyphosis (or synonym) is used multiple times as a part of the definition of SPTD in current literature. A deformity after trauma, however, can be of a different shape. We propose, for future clinicians and researchers, that the more neutral Spinal Posttraumatic Deformity will be used to avoid inaccuracy.

Future research should focus on reaching a consensus on the definition of SPTD. Armed with a new definition, factors can be identified which lead to SPTD in an, ideally prospective, observational cohort of patients with vertebral fractures. In the ideal situation SPTD can be prevented if the contributing factors are addressed accordingly and timely.
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References
1. American College of Surgeons. NTDB Annual Report. Table 26. Incidents by AIS Body Region, Committee on Trauma. American College of Surgeons; 2016.
2. Verlaan JJ, Diekerhof CH, Buskens E, et al. Surgical treatment of traumatic fractures of the thoracic and lumbar spine: a systematic review of the literature on techniques, complications, and outcome. Spine (Phila Pa 1976). 2004;29(7):803-814. doi:10.1097/01.BRS.000016990.31984.A9
3. Öztürk I, Ertüreker E, Sönmez MM, Sari S, Şeker A, Seçkin MF. Early mobilization with customized TLSO brace in thoracolumbar burst fractures. Acta Orthop Traumatol Turc. 2012;46(5):373-378. doi:10.3944/AOTT.2012.2830
4. Zheng GQ, Wang Y, Tang PF, et al. Early posterior spinal canal decompression and circumferential reconstruction of rotationally unstable thoracolumbar burst fractures with neurological deficit. Chin Med J (Engl). 2013;126(12):2343-2347. doi:10.3760/cma.j.issn.0366-6999.20130034
5. Cankaya D, Yılmaz S, Deveci A, et al. Clinical and radiological outcomes of conservative treatment after stable post-traumatic thoracolumbar fractures in elderly: is it really best option for all elderly patients? Ann Med Surg. 2015;4(4):346-350. doi:10.1016/j.amsu.2015.08.009
6. Anghel S, Petrisor M, Buiuc CF, Marton D, Bătauş T. Predictive factors for postoperative deformity in thoracolumbar burst fractures: a statistical approach. Acta Orthop Traumatol Turc. 2015;49(2):133-138. doi:10.3944/AOTT.2015.14.0274
7. Loibl M, Korsun M, Reiss J, et al. Spinal fracture reduction with a minimal-invasive transpedicular Schanz Screw system: clinical and radiological one-year follow-up. Injury. 2015;46 Suppl 4:S75-82. doi:10.1016/S0020-1383(15)30022-X
8. Sadatsune DA, Costa PP da, Caffaro MFS, Umeta RS, Meves R, Avanzí O. Thoracolumbar burst fracture: correlation between kyphosis and function after surgical treatment. Rev Bras Ortop. 2012;47(4):474-478. doi:10.1016/S2255-4971(15)30131-2
9. Alany A, Yazıcı M, Acaroglu E, Turhan E, Cila A, Surat A. Course of nonsurgical management of burst fractures with intact posterior ligamentous complex: an MRI study. Spine (Phila Pa 1976). 2004;29(21):2425-2431. doi:10.1097/01.brs.0000143169.80182.ac
10. Bagga RS, Gogeaenkar AB, Dahapute AA, Muni SR, Gokhalé S, Manghwani J. Functional and radiological outcomes of thoracolumbar traumatic spine fractures managed conservatively according to Thoracolumbar Injury Severity Score. J Craniovertebr Junction Spine. 2017;8(4):369-373. doi:10.4103/jcvjs.JCVJS_93_17
11. Bertram R, Bessem H, Wagner U, Diedrich O, Schmitt O. Comparison of dorso-lateral and dorso-ventral stabilization procedures in the treatment of vertebral fractures [in German]. Z Orthop Ihre Grenzgeb. 2003;141(5):573-577. doi:10.1055/s-2003-42841
12. Steib JP, Aouli M, Mitulescu A, et al. Thoracolumbar fractures surgically treated by “in situ contouring.” Eur Spine J. 2006;15(12):1823-1832. doi:10.1007/s00586-006-0161-5
13. Pellisé F, Barasteegui D, Hernandez-Fernandez A, et al. Viability and long-term survival of short-segment posterior fixation in thoracolumbar burst fractures. Spine J. 2015;15(8):1796-1803. doi:10.1016/j.spinee.2014.03.012
14. White AA, Panjabi MM, Thomas CL. The clinical biomechanics of kyphotic deformities. Clin Orthop Relat Res. 1977;(128):8-17.
15. Whitesides TE. Traumatic kyphosis of the thoracolumbar spine. Clin Orthop Relat Res. 1977;(128):78-92. doi:10.1007/978-0-387-97710-0_0011
16. Polly DWJ, Klemme WR, Shawen S. Management options for the treatment of posttraumatic thoracolumbar kyphosis. Semin Spine Surg. 2000;12(3):110-116.
17. Buchowski JM, Kuhns CA, Bridwell KH, Lenke LG. Surgical management of posttraumatic thoracolumbar kyphosis. Spine J. 2008;8(4):666-677. doi:10.1016/j.spinee.2007.03.006
18. Vaccaro AR, Silber JS. Post-traumatic Spinal Deformity. Spine (Phila Pa 1976). 2001;26(24 suppl):S111-S118. doi:10.1097/00007632-200112151-00019
19. Satin AM, Chen YH, Silber J, Essig D. Sagittal plane deformity: evaluation and management. Semin Spine Surg. 2017;29(4):208-214. doi:10.1053/j.smss.2017.08.006
20. Jacob M, Buchowski KH, Bridwell LGL. Management of post-traumatic kyphosis after thoracolumbar injuries. Semin Spine Surg. 2010;22(2):92-102. doi:10.1053/j.smss.2009.12.001
21. Eysel P, Hopf C, Förderer S. Kyphotic deformities in fractures of the thoracic and lumbar spine: a systematic review of the literature on techniques, complications, and outcomes of conservative treatment after stable post-traumatic thoracolumbar kyphosis. Spine (Phila Pa 1976). 1999;8(3):194-198. doi:10.1097/00003086-197710000-00019
22. Vaccaro AR, Silber JS. Post-traumatic Spinal Deformity. Spine (Phila Pa 1976). 2001;26(24 suppl):S111-S118. doi:10.1097/00007632-200112151-00019
23. Schoenfeld AJ, Wood KB, Fisher CF, et al. Posttraumatic kyphosis: current state of diagnosis and treatment: results of a
multinational survey of spine trauma surgeons. J Spinal Disord Tech. 2010;23(7):e1-8. doi:10.1097/BSD.0b013e3181e351f7
24. Moher D, Shamseer L, Clarke M, et al; PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4(1):1. doi:10.1186/2046-4053-4-1
25. Malcolm BW. Spinal deformity secondary to spinal injury. Orthop Clin North Am. 1979;10(4):943-952.
26. Rusu C, Herold L, Voigt C, Lill H. Thorakolumbaler Übergang der Wirbsäule. Trauma und Berufskrankheit. 2007;9(2):S249-S256. doi:10.1016/s1003-006-1149-4
27. Kandziaova F, Schnake KJ, Pingel A, Hoffmann R. Postrumatische thorakolumbale Kyphose. Trauma und Berufskrankheit. 2009;11(2):80-86. doi:10.1016/s1003-009-1487-0
28. Munting E. Surgical treatment of post-traumatic kyphosis in the thoracolumbar spine: indications and technical aspects. Eur Spine J. 2010;19(suppl 1):69-73. doi:10.1007/s00586-009-1117-3
29. Suchomel P, Choutka O. Reconstruction of Upper Cervical Spine and Craniovertebral Junction. Posttraumatic Deformity. 2010: 219-226.
30. Cecchinato R, Berjano P, Damilano M, Lamartina C. Spinal osteotomies to treat post-traumatic thoracolumbar deformity. Eur J Orthop Surg Traumatol. 2014;24(suppl 1):S31-37. doi:10.1007/s00590-014-1464-6
31. Boehm H, Shousha M, Bahrami R. Korrekturosteotome für posttraumatische Fehlstellungen. Trauma und Berufskrankheit. 2017; 19(2):86-96. doi:10.1016/s1003-017-0263-9
32. Malcolm BW, Bradford DS, Winter RB, Chou SN. Post-traumatic kyphosis. A review of forty-eight surgically treated patients. J Bone Joint Surg Am. 1981;63(6):891-899.
33. McBride GG, Bradford DS. Vertebral body replacement with femoral neck allograft and vascularized rib strut graft: a technique for treating post-traumatic kyphosis with neurologic deficit. Spine (Phila Pa 1976). 1983;8(4):406-415. doi:10.1097/00007632-19830500-00011
34. Boni M, Cherubino P, Denaro V, Benazzo F. Multiple subtotal somatectomy: technique and evaluation of a series of 39 cases. Spine (Phila Pa 1976). 1984;9(4):358-362. doi:10.1097/00007632-19840500-00005
35. Kostuik JP. Anterior fixation for fractures of the thoracic and lumbar spine with or without neurologic involvement. Clin Orthop Relat Res. 1984;(189):103-115.
36. Roberson JR, Whitesides TE Jr. Surgical reconstruction of late post-traumatic thoracolumbar kyphosis. Spine (Phila Pa 1976). 1985;10(4):307-312. doi:10.1097/00007632-19850500-00003
37. Dick W. The “Fixateur Interne” as a versatile implant for spine surgery. Spine (Phila Pa 1976). 1987;12(9):882-900. doi:10.1097/00007632-19871100-00009
38. Kostuik JP, Matsuoka HE. Anterior stabilization, instrumentation, and decompression for post-traumatic kyphosis. Spine (Phila Pa 1976). 1989;14(4):379-386. doi:10.1097/00007632-19890400-00006
39. Gertzbein SD, Harris MB. Wedge osteotomy for the correction of post-traumatic kyphosis: a new technique and a report of three cases. Spine (Phila Pa 1976). 1992;17(3):374-375. doi:10.1097/00007632-19920300-00025
40. Chang KW. Oligosegmental correction of posttraumatic thoracolumbar angular kyphosis. Spine (Phila Pa 1976). 1993;18(13):1909-1915. doi:10.1097/00007632-199310000-00032
41. Wu SS, Hwa SY, Lin LC, Pai WM, Chen PQ, Au MK. Management of rigid post-traumatic kyphosis. Spine (Phila Pa 1976). 1996;21(19):2260-2266. doi:10.1097/00007632-199610100-00016
42. Atici T, Aydinli U, Akesen B, Serifoglu R. Results of surgical treatment for kyphotic deformity of the spine secondary to trauma or Scheuermann’s disease. Acta Orthop Belg. 2004;70(4): 344-348.
43. Been HD, Poolman RW, Ubags LH. Clinical outcome and radiographic results after surgical treatment of post-traumatic thoracolumbar kyphosis following simple type A fractures. Eur Spine J. 2004;13(2):101-107. doi:10.1007/s00586-003-0576-1
44. Robertson PA, Rawlinson HJ, Hadlow AT. Radiologic stability of titanium mesh cages for anterior spinal reconstruction following thoracolumbar corpectomy. J Spinal Disord Tech. 2004;17(1):44-52. doi:10.1097/00024270-200402000-00010
45. Stoltze D, Harms J, Boyaci B. Correction of post-traumatic and congenital kyphosis: indications, techniques, results [in German]. Orthopade. 2008;37(4):321-338. doi:10.1007/s00132-008-1228-2
46. Chou D, Wang VY, Storm PB. Pedicle subtraction osteotomies for the correction of post-traumatic thoracolumbar kyphosis. J Clin Neurosci. 2010;17(1):113-117. doi:10.1016/j.jocn.2009.03.038
47. Zhang XS, Zhang YG, Wang Z, Chen C, Wang Y. Correction of severe post-traumatic kyphosis by posterior vertebra column resection. Chin Med J (Engl). 2010;123(6):680-685. doi:10.3760/cma.j.issn.0366-6999.2010.06.008
48. El-Sharkawi MM, Koptan WM, El-Miligui YH, Said GZ. Comparison between pedicle subtraction osteotomy and anterior corpectomy and plating for correcting post-traumatic kyphosis: a multicenter study. Eur Spine J. 2011;20(9):1434-1440. doi:10.1007/s00586-011-1720-y
49. Wang Q, Xiu P, Zhong D, Wang G, Wang S. Simultaneous posterior and anterior approaches with posterior vertebral wall preserved for rigid post-traumatic kyphosis in thoracolumbar spine. Spine (Phila Pa 1976). 2012;37(17):E1085-E1091. doi:10.1097/ brs.0b013e318255e353
50. Noor A, Bloemers FW, Bakker FC. Surgical correction of post-traumatic kyphosis: a thoracoscopic approach [in Dutch]. Ned Tijdschr Geneeskd. 2013;157(10):A5427.
51. Omidi-Kashani F, Hasankhani EG, Ebrahimzadeh MH, Kachooei AR, Heidari H. Posterior surgery alone in the treatment of post-traumatic thoracolumbar kyphosis using pedicle subtraction osteotomy. Eur J Orthop Surg Traumatol. 2013;23 suppl 1:S59-S66. doi: 10.1007/s00590-013-1168-3
52. He Q, Xu J. Transpedicular closing wedge osteotomy in the treatment of thoracic and lumbar kyphotic deformity with different
etiology. *Eur J Orthop Surg Traumatol.* 2013;23(8):863-871. doi:10.1007/s00590-012-1089-6
54. Obeid I, Laouissat F, Vital JM. Asymmetric T5 Pedicle Subtraction Osteotomy (PSO) for complex posttraumatic deformity. *Eur Spine J.* 2013;22(9):2130-2135. doi:10.1007/s00586-013-2942-y
55. Soutlantis KC, Mavrogenis AF, Starantzis KA, et al. When and how to operate on thoracic and lumbar spine fractures? *Eur J Orthop Surg Traumatol.* 2014;24(4):443-451. doi:10.1007/s00590-013-1341-8
56. Shigematsu H, Koizumi M, Iida J, Iwata E, Tanaka Y. Floating spine after pedicle subtraction osteotomy for post-traumatic kyphosis. *Eur Spine J.* 2014;23 suppl 2:278-284. doi:10.1007/s00586-014-3298-7
57. Yagi M, Hasegawa A, Takemitsu M, Yato Y, Machida M, Asazuma T. Incidence and the risk factors of spinal deformity in adult patient after spinal cord injury: a single center cohort study. *Eur Spine J.* 2015;24(1):203-208. doi:10.1007/s00586-014-3534-1
58. Gao R, Wu J, Yuan W, Yang C, Pan F, Zhou X. Modified partial pedicle subtraction osteotomy for the correction of post-traumatic thoracolumbar kyphosis. *Spine J.* 2015;15(9):2009-2015. doi:10.1016/j.spinee.2015.04.047
59. Bourghli A, Boissière L, Vital JM, et al. Modified closing-opening wedge osteotomy for the treatment of sagittal malalignment in thoracolumbar fractures malunion. *Spine J.* 2015;15(12):2574-2582. doi:10.1016/j.spinee.2015.08.062
60. Liu Y, Li X, Sun H, Yang H, Jiang W. Transpedicular wedge osteotomy for treatment of kyphosis after L1 fracture using intraoperative, full rotation, three-dimensional image (O-arm)-based navigation: a case report. *Int J Clin Exp Med.* 2015;8(10):18889-18893.
61. Hu W, Wang B, Run H, Zhang X, Wang Y. Pedicle subtraction osteotomy and disc resection with cage placement in posttraumatic thoracolumbar kyphosis, a retrospective study. *J Orthop Surg Res.* 2016;11(1):112. doi:10.1186/s13018-016-0447-1
62. Chen F, Kang Y, Zhou B, Dai Z. Correction of posttraumatic thoracolumbar kyphosis with modified pedicle subtraction osteotomy [in Chinese]. *Zhong Nan Da Xue Xue Bao Yi Xue Ban.* 2016;41(11):1208-1214. doi:10.11817/j.issn.1672-7347.2016.11.016
63. Wang H, Ma L, Wang Y, et al. Comparison of posterior vertebral column resection and anterior corpectomy and instrumentation for correcting late post-traumatic thoracolumbar kyphosis. *Int J Clin Exp Med.* 2016;9(9):17435-17441.
64. Li S, Li Z, Hua W, et al. Clinical outcome and surgical strategies for late post-traumatic kyphosis after failed thoracolumbar fracture operation: case report and literature review. *Medicine (Baltimore).* 2017;96(49):e8770. doi:10.1097/MD.0000000000008770
65. Rerikh VV, Borzykh KO, Samokhin AG. Correlations of functional capacity and parameters of sagittal balance in patients with posttraumatic deformities of the spine. *Modern problems of science and education* 2017;6: 4-4.