Systematic Review

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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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Table 1. Full Search Strategy for the PubMed-Database.

Database	
PubMed	(((scolio*[Title/Abstract]) OR kypho*[Title/Abstract]) OR spinal deform*[Title/Abstract]) AND ((post[Title/Abstract] AND trauma*[Title/Abstract]) OR posttrauma*[Title/Abstract] OR postrauma*[Title/Abstract])
All databases	Pubmed, Embase, Scopus, Global Clinical Trial Data, Cochrane library, SUDOC, Red de Revistas Científicas de América Latina y el Caribe, España y Portugal, eLibrary.ru, J-Stage and CNKI.net

The search string was adjusted accordingly to fit each different database. The search was performed on 23-12-2019.

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 years[14,15]; 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 ($\geq$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

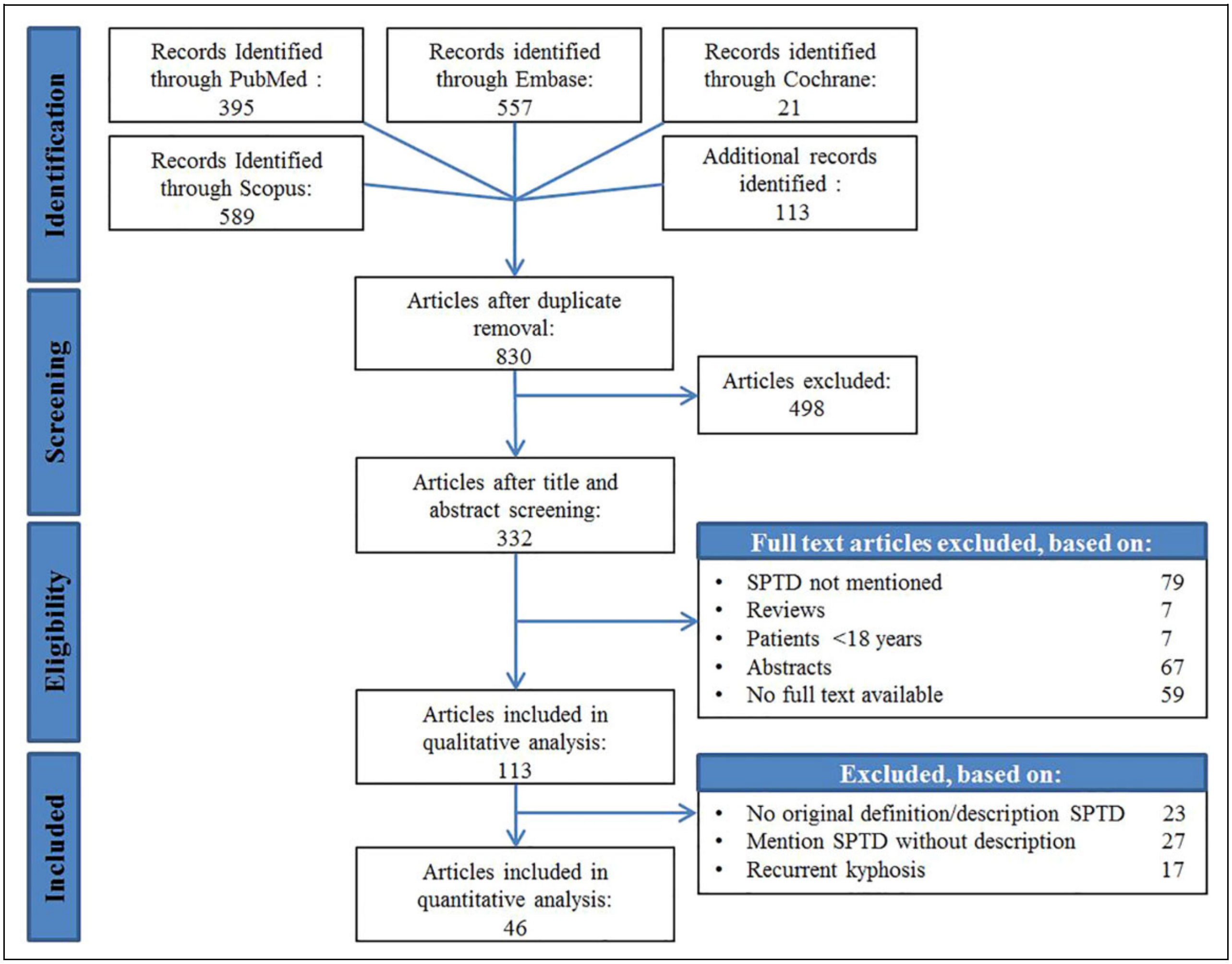

Figure 1. Flow chart of the conducted search for the definition or description of SPTD following the PRISMA-statement.

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.[23] 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

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[14]	1977	Expert Opinion	C, Th, L	NA
Malcolm[25]	1979	Expert Opinion	Whole spine	NA
Rusu et al[26]	2007	Expert Opinion	ThL	NA
Kandziora et al[27]	2009	Expert Opinion	ThL	NA
Munting[28]	2010	Expert Opinion	Th, L	NA
Schoenfeld et al[23]	2010	Survey, Expert Opinion	CTh, Th, L	NA
Suchomel and Choutka[29]	2010	Expert Opinion	Upper C	NA
Cecchinato et al[30]	2014	Expert Opinion	ThL	NA
Boehm et al[31]	2017	Expert Opinion	Th, L	NA
SPTD Surgical indication				
Malcolm et al[32]	1981	Retrospective Cohort	Th, L	48
McBride and Bradford[33]	1983	Case Series	ThL	6
Boni et al[34]	1984	Retrospective Cohort	C	10
Kostuik[35]	1984	Retrospective Cohort	Th, L	20
Roberson and Whitesides[36]	1985	Cohort	Th, L	34
Dick[37]	1987	Cohort	-	20
Kostuik and Matsusaki[38]	1989	Retrospective Cohort	Th, L	37
Gertzbein and Harris[39]	1992	Case Series, Expert Opinion	Th	3
Chang[40]	1993	Case Series	ThL, L	17
Wu et al[41]	1996	Case Series	ThL, L	13
Atici et al[42]	2004	Retrospective Cohort	Th, L	10
Been et al[43]	2004	Retrospective Cohort	Th, L	25
Robertson et al[44]	2004	Case Series	-	10
Stoltze et al[45]	2008	Retrospective Cohort, Expert opinion	Th, L	268
Chou et al[46]	2009	Case Report	ThL	2
Zhang et al[47]	2010	Case Series	ThL	5
El-Sharkawi et al[48]	2011	Prospective cohort with retrospective control	ThL, L	80
Wang et al[49]	2012	Retrospective Cohort	ThL	21
Noor et al[50]	2013	Expert opinion	Th, ThL	NA
Omidi-Kashani et al[51]	2013	Retrospective Cohort	ThL	26
Xi et al[52]	2013	Retrospective Cohort	ThL	19
He and Xu[53]	2013	Retrospective Cohort	ThL	10
Obeid et al[54]	2013	Case Report	High Th	1
Soultanis et al[55]	2014	Retrospective Cohort	Th, L, S	32
Shigematsu et al[56]	2014	Case Report	Th12	1
Yagi et al[57]	2015	Retrospective Cohort	NA	158
Gao et al[58]	2015	Retrospective Cohort	Th11-L2	89
Bourghli et al[59]	2015	Retrospective Cohort	ThL	10
Liu et al[60]	2015	Case Report	L1	1
Hu et al[61]	2016	Retrospective Cohort	ThL	46
Chen et al[62]	2016	Prospective Cohort	Th-L	58
Wang et al[63]	2016	Randomized Controlled Trial	ThL	43
Li et al[64]	2017	Retrospective Cohort	ThL	12
Rerikh et al[65]	2017	Retrospective Cohort	Th-L	45
El Nagger et al[66]	2018	Prospective Cohort	ThL	12
Matsumoto et al[67]	2018	Retrospective Cohort	ThL	20
Avila et al[68]	2019	Prospective multiple cohort	Th9-L3	30

The first 9 articles gave a specific definition of SPTD, the other 37 articles presented an original description of SPTD.
SPTD = Spinal Posttraumatic Deformity;
C = cervical spine, Th = thoracic spine; L = lumbar spine; S = sacral spine; NA = not available

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)[52,57,62] or Frankel grade.[33,41,64]

Tables 3. Overview of the Definitions and Descriptions of SPTD Divided in Patient Factors, Radiology, Spinopelvic Parameters, PROMs and Surgical Indications Given.

A Reference	Patient factors	Radiology	Cutoff values	Spinopelvic	Cutoff values	Patient Reported Outcome Measurements	Surgical indication
White et al[14]	-	- - Cobb	Th >30° C/L > 5° or any posterior curvature	-	-	-	-
Malcolm[25]	Body habitus, pain (partly discs), spinal crepitus, impaired sitting/standing, ulceration, respiratory insufficiency, increased neurological deficit,	X Standing/sitting FS AP+Lat X flex/ext, lat bending Tomography Myelography (decompression) CAT-scan	-	-	-	-	Chronic cases depending on severity of presenting signs and symptoms
Rusu et al [26]	Pain, inability to work, deformities in clinical exam, neurological deficit (spasticity)	X Th/L AP+Lat - Cobb - Wedge angle - Segmental angle CT: planning surgery MRI: soft tissue, neurologic involvement	-	-	-	-	Clinical symptoms most important: pain, neurological deficit Cobb >20 °
Kandziora et al[27]	Osteoporosis, refusal of therapy. Cardiac, pulmonic and abdominal dysfunction	X Standing FS AP+Lat X flex/ext: MRI exclude syrinx CT surgical planning and excl non union	-	C7plumbline, ThK (T2-T12); LL (T12-S1)/(L2-S1); ThL (T10-L2)	Deviation from normal ThK: +35° (20°-50°) LL -55°(-45°-65°) LL -50° (-40°-60°) ThL 0°	-	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	X Standing FS: - SI	>20 °		Hyperlordosis L, hypo-/ or hyperkyphosisTh	Altered function	
Schoenfeld et al[23]	Pain, progressive deformity and deteriorating neurology (rare), A3/B1/B2 fractures Asymptomatic SPTD does exist	X regional flex/ext - Cobb - Wedge angle MRI: Posterior Ligament Complex, spinal cord, Intervertebral discs CT: bony anatomy, non-union, facet joints Discography	5-30 °	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 CT: anatomy MRI: capacity spinal canal, neural compression	-	-	-	-	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	SI <15° compensation possible; SI >20° symptoms and in need of management	C7 plumbline, C7/SVA, PI, PT, ThK, LL	PT > 20° or high 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 Sagittal index >20° PT > 20° or high compared to expected PT Lumbar hyper-/ OR hypolordosis

(continued)

Tables 3. (*Continued*)

A Reference	Patient factors	Radiology	Cutoff values	Spinopelvic	Cutoff values	Patient Reported Outcome Measurements	Surgical indication
Boehm et al[31]	Load dependent pain, compensatory mechanisms, deviations of physiological curves during standing and walking, neurological deficit	X standing FS AP+Lat X functional (rigid, instability, correction potential) MR: ligaments, neurological structures, canal compromise CT: nonunion, anatomy	Deviation from SRS: T1–5: $\geq 20°$ T5–12: $\geq 50°$ T10–L2: $\geq 20°$ T12–S1: $\geq 40°$	C7-plumbline ThK ThL LL PI, PT, SS	-	-	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.

B **Reference**	Patient factors	Radiology	**Cutoff values**	**Spinopelvic**	**Cutoff values**	Patient Reported Outcome Measurements	Surgical indication
Malcolm et al[32]	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 Cobb X flex/ext X lateral bending in scoliosis Tomography Myelography: neurology	-	-	-	pain	Symptomatic PTK
McBride and Bradford[33]	Back pain at the apex of kyphosis, radicular pain or hypesthesia, urinary incontinence/urgency, rectal tenesmus or spasm, focal motor weakness (Frankel)	X Standing FS AP+Lat, flex/ext CAT, lateral planograms: spinal canal encroachment Myelography: neurological involvement	-	-	-	-	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 pseudarthrosis and kyphosis
Boni et al[34]	Neurological deficit	X C AP-Lat X C dynamic: residual mobility	-	-	-	-	Stenosis of 3 or more intersomatic spaces with myelopathy
Kostuik[35]	Pain, progressive deformity, with/without neurological involvement	X regional AP+Lat CAT	-	-	-	Pain	Painful and/or progressive kyphotic deformities with or without neurologic involvement
Roberson and Whitesides[36]	Pain, deformity, neural embarrassment, incomplete rehabilitation	X regional Tomography Occasionally CT	-	-	-	Pain relieve poor, fair or good	Increasing kyphotic deformity, pain, or increasing neurologic deficit
Dick[37]	Severe pain	X Reg: kyphosis angle: upper endplate of vertebra above and lower endplate of fractured vertebra	-	-	-	-	Severe pain with failure of previous treatment
Kostuik and Matsusaki[38]	Pain at apex and/or levels below, neurological deficit, limited walking	X regional AP+Lat Kyphosis angle: measured between cranial and caudal instrumented levels CAT Myelography Discography	-	-	-	Pain	Kyphosis angle $>30°$ Symptomatic PTK

(continued)

Tables 3. (*Continued*)

B **Reference**	Patient factors	Radiology	**Cutoff values**	**Spinopelvic**	**Cutoff values**	Patient Reported Outcome Measurements	Surgical indication
Gertzbein and Harris[39]	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
Chang[40]	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 al[41]	Pain, neurologic compromise (Frankel), disabled, pressure sores, fatigue, progressive deformity	X reg AP/Lat Cobb X Flex/ext	-	-	-	-	Rigid PTK
Atici et al[42]	Back pain at apex, neurological deficit, cosmetic	X-ray: Cobb	Th >30 ° L > 20 °	-	-	-	Th > 30°, L >20° or neurological deficit
Been et al[43]	Pain (apex or compensatory), neurological damage or progression, skin problems	X regional Standing AP+Lat Cobb Scoliotic angle (Cobb method) CT: spinal canal	-	-	-	back pain scoring: Greenough and Fraser. VAS pain, same surgery again?	Symptomatic ThL PTK, pain not responding to conservative treatment.
Robertson et al[44]	-	X regional AP+Lat Cobb Coronal plane deformity	-	-	-	-	Late reconstruction for PTD and pain
Stoltze et al[45]	Vertebral (deformity, iatrogenic instability, stenosis, compensation/tendinosis) vs neurological (radiculopathy, tethered cord, atrophy/myelopathy, syrinx)	X Standing FS: Arthrosis hips, total balance X regional function: segmental mobility CT: bony anatomy MR: neurological involvement	-	-	Compensation: increased PT and flexion hips	-	Vertebral pain syndrome because of deformity or instability or neurological deficit
Chou et al[46]	Pain (non-healed fracture or kyphosis)	X Standing FS AP+Lat CT: healed fracture			Positive balance or compensatory hyperlordosis	VAS pain	Refractory to conservative treatment, debilitating pain. Kyphosis = 40°; no osteoporosis
Zhang et al[47]	Back pain, Neurology, progressive deformity	X Standing AP+Lat, flex/ext, - Cobb–> ERD = Cobb-physiological cobb for level (Stagnara et al) CT: 3D reconstruction; MRI: spinal canal influence	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 al[48]	Persistent low back pain, cosmetic	X Standing FS AP+lat - wedge angle	-	-	-	VAS pain, ODI, patient satisfaction	Symptomatic PTK
Wang et al[49]	Painful kyphotic angulation, back pain, neurological function	X lat: - Cobb - Ant. and post. vertebral body height CT MRI: Disc injury	-	-	-	JOA Back pain scores	Rigid PTK with: progression of kyphosis >5°, kyphosis >30° with significant low back pain and deterioration of neurological function

(continued)

Tables 3. (*Continued*)

B **Reference**	Patient factors	Radiology	**Cutoff values**	**Spinopelvic**	**Cutoff values**	Patient Reported Outcome Measurements	Surgical indication
Noor et al[50]	Severe back pain, sagittal imbalance, compression myelum or nerve roots, pseudarthrosis	-	-	-	-	-	Severe complaints with kyphosis >15°-30°
Omidi-Kashani et al[51]	Fatigue and pain	X standing FS AP+Lat: - Cobb - MRI	-	-	-	VAS pain, ODI, patient satisfaction	Cons: mild cases Symptomatic PTK, no neurological deficit, no osteoporosis, Excl: Cobb>50° relative to normal, neurological deficit requiring ant. Decompression, age >60
Xi et al[52]	Local muscle fatigue or pain, focal deformity, neurological deficit (ASIA)	X AP+Lat - Cobb - ThK - LL CT: 3D planning	-	SVA (cm)	-	VAS pain	progressive increase in Cobb, pitched trunk clinically OR follow-up revealed intractable back pain and increase neurological deficit consider: 1. Cobb>30° with persisting pain after cons treatment 2. nerve compression or progressive aggravation of symptoms 3. progressive kyphosis deformity 4. urgent cosmetic requirement
He and Xu[53]	Severe back pain, kyphosis	X standing FS AP+Lat	-	C7 plumbline ThK LL	-	VAS pain, ODI	Severe backpain, kyphosis, conservative failed to alleviate symptoms Absolute indication: progression of deformity
Obeid et al[54]	Neck or high Th deformity, impaired horizontal gaze, chronic pain	X Standing FS AP+Lat - Kyphosis Angle (-), - Scoliosis, Coronal head shift CT	-	-	-	-	Unbearable neck and high thoracic deformity with horizontal visual impairment; kyphosis 80°
Soultanis et al[55]	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 22 patients: mild residual kyphosis, asymptomatic. Treated conservatively All patients had low energy trauma
Shigematsu et al[56]	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	-	-	Difficulty with daily activities caused by severe sagittal imbalance, back pain or neurological disturbance
Yagi et al[57]	ASIA A-D	X Standing FS AP: - Scoliosis Cobb angle	>10° lateral curve coronal plane	-	-	-	-

(continued)

Tables 3. (*Continued*)

B **Reference**	Patient factors	Radiology	**Cutoff values**	**Spinopelvic**	**Cutoff values**	Patient Reported Outcome Measurements	Surgical indication
Gao et al[58]	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 al[59]	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 al[60]	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 al[61]	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 al[62]	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 al[63]	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 al[64]	Back pain, neurological deficit (Frankel) Functional disability	X standing ThL AP+Lat: - Cobb - LL	-	-	-	VAS pain	Cons: Cobb $<20°$, without obvious pain or neurological deficit Surg: Cobb $>20°$ with pain, progressive nerve damage
Rerikh et al[65]	Painful deformity	X FS AP+Lat - Cobb	Deviation from SRS-criteria	ThK(T1-T12) LL(L1-S1) ThL(T10-L2) PT, SS, PI Roussouly	Deviation from SRS-criteria	VAS pain, ODI	
El Nagger et al[66]	Back pain, local deformity with neurology	X Standing FS AP+Lat: - Cobb Occasional: CT: evaluate deformity MRI: neurological involvement	Severe: Cobb>50	SVA ThK (T5-T12) LL (-)	>25 mm	VAS pain, ODI	Inclusion of Severe PTK: Back pain affecting QoL (ODI>40, VAS >5), neurological symptoms, Cobb $>50°$, SVA>25 mm

(continued)

Tables 3. (*Continued*)

B Reference	Patient factors	Radiology	Cutoff values	Spinopelvic	Cutoff values	Patient Reported Outcome Measurements	Surgical indication
							Surg: refractory back pain, deteriorating neurology and SI>20°
Matsumoto et al[67]	Back pain	X Standing FS AP+Lat - Local kyphosis (lower endplate cranial, upper endplate caudal vertebra)	-	SVA LL (fracture-S) ThK (T5-fracture) Segmental LL (L3-S/L4-S) PT, SS, PI	SRS-criteria	-	Rigid kyphotic deformity + symptoms including non-flexible deformity and very mild vertebral instability with local kyphosis and severe low back pain
Avila et al[68]	-	X Standing FS AP+Lat - Cobb	-	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
ThK: thoracic kyphosis, LL: lumbar lordosis; SVA: Sagittal Vertical Axis; PT: Pelvic tilt, SS: Sacral Slope, PI: Pelvic Incidence;
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.[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 cranial and the lower endplate of the affected vertebra.

The amount of deformity to diagnose or treat SPTD was very diverse and depended on the way of measurement. The cut-off deformity angles for SPTD ranged from "different from the normal anatomy of the spine" to $>30°$. The majority of the articles included patients with deformities on different levels of the spine (i.e. T3-L2) but used the same cut-off value for each individual patient regardless of level of deformity. Some articles only gave a median or average of the angular deformities at different levels. Three articles used the SRS-criteria for adult spinal deformity to see if the deformity exceeded the normal anatomy of the spine.[31,65,67] All these different amounts of deformity were defined as SPTD.

Other methods to diagnose SPTD or plan a surgery were: flexion-extension radiographs (11 articles), myelography (3 articles), Computerized Tomography (CT) scan (19 articles) and Magnetic Resonance Imaging (MR) scan (13 articles). Flexion-extension radiographs were used to assess mechanical instability and the rigidity of the deformity. Myelography was used to depict the neurological anatomy.[25,32,38] CT scan was used to assess the presence of pseudoarthrosis (i.e. non-union or non-healed fracture), pre-operative bony anatomy, the facet joints and the spinal canal encroachment and to use 3D images for planning. MR scan was used to evaluate the neurological involvement, the posterior ligamentous complex (PLC) injury and to exclude a syrinx.

Spinopelvic parameters in SPTD.
In recent papers, spinopelvic parameters were included in the definition, diagnosis and treatment of SPTD. The spinopelvic parameters were: the C7-plumbline or the Sagittal Vertical Alignment (SVA) for sagittal balance; and the pelvic parameters such as the Pelvic Tilt (PT), Sacral Slope (SS) and Pelvic Incidence (PI) to assess compensation in the pelvis.[30,31,59,61] All parameters were measured on standing full spine lateral radiographs, including the hip joints and preferably 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.[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.[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.[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. Cecchinato 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.[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.[66]

Surgical Indication

Surgical indications of patients with SPTD were described in 42 articles. Description of the indication ranged from "symptomatic" or "rigid" SPTD[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.[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.[45] Boni et al indicated surgical treatment when a cervical myelopathy due to stenosis, without specific kyphosis, was present in a patient.[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 lumbosacral 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] Rerikh 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 ODI 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 therefor 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 "recurrent 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 is 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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