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RESEARCH

The fourth column in thoracic vertebral fractures: concomitant thoracic cage injuries and mortality in 27,814 inpatient cases from the german national DRG database

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Abstract

Purpose Population-level data on fourth column fractures and prognostic implications remain lacking. This study aimed to characterise the epidemiology of thoracic vertebral fractures in Germany, including the prevalence of fourth column injuries and geriatric patients, comorbidity burden and the in-hospital mortality across distinct fracture populations.

Methods A Nationwide cross-sectional administrative inpatient data analysis of all adult thoracic vertebral fracture cases (ICD-10-GM S22.0x/S22.1) from the 2024 German Diagnosis Related Groups database was conducted across three groups: thoracic spine group (n = 27,315), geriatric subgroup (≥ 75 years; n = 16,276), and fourth column group with concomitant sternal fracture (n = 499). Data were provided by the German Institute for the Hospital Remuneration System.

Results Among 27,814 cases 63.0% were female and 58.5% aged ≥ 75 years. Fourth column fractures (1.8%) defined a mechanistically distinct entity: male predominance (57.7%), younger age distribution (≥ 75 years: 30.3% vs. 59.0%), prolonged hospitalisation (14.7 vs. 10.1 days) and comorbidity burden (PCCL ≥ 3: 59.3% vs. 11.7%). Mortality in the thoracic spine group was 2.00%, rising to 2.89% in patients aged ≥ 75 years, accounting for 86.1% of all deaths. In geriatric subgroup, mortality was dominated by acute organ-failure: cardiac arrest (OR = 51.74), sepsis (OR = 42.96) and respiratory insufficiency (OR = 14.67). In thoracic spine group, concomitant thoracic cage injuries were associated with elevated mortality: haemothorax (OR = 5.73) and serial rib fractures (≥ 4 ribs, OR = 3.31).

Conclusions Fourth column fractures constitute a mechanistically distinct high-energy injury entity, while in the geriatric thoracic spine fracture population, mortality is governed by vulnerability rather than fracture severity, suggesting that frailty assessment may be of value and risk-stratified clinical pathways.

Keywords Thoracic vertebral fracture · Fourth column fracture · Sternum fracture · Concomitant injury · In-hospital mortality · DRG

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Introduction

Thoracic vertebral fractures represent a major and growing musculoskeletal burden, accounting for a substantial share of all vertebral fractures in Germany [1]. The thoracic spine occupies a unique biomechanical position, characterised by structural integration of thoracic vertebrae with the rib cage through costovertebral and costotransverse articulations and by anterior continuity of the thoracic cage through the sternum [2, 3]. This anatomical arrangement endows the thoracic spine with a degree of intrinsic stability unmatched by other regions of the vertebral column [3, 4]. Sternal fractures typically occur in the setting of substantial blunt chest trauma and are frequently accompanied by additional severe injuries, particularly in polytraumatized patients [5]. High-energy mechanisms may simultaneously affect the sternum and thoracic spine, resulting in complex injury patterns associated with considerable functional impairment [4, 6]. Such trauma often involves multiple components of the thoracic cage, reflecting the transfer of substantial forces across the thorax [7]. Within this biomechanical framework, the sternum was identified as an important stabilising element of the thoracic spine and sternal fractures repeatedly observed in conjunction with thoracic spinal injuries [8].

In 1993, Berg introduced the concept of the sternum and rib cage as a “fourth column” (4th column) of structural support for the thoracic spine, supplementing Denis’ classic three column model [9, 10]. Subsequent biomechanical studies substantiated this concept, demonstrating that preservation of rib-cage integrity increased thoracic spinal stability by approximately 30–40% during flexion–extension, lateral bending and axial rotation. Cadaveric and computational investigations further suggested that the rib–sternum complex accounted for up to 78% of overall thoracic spine stability [11–13].

Despite this biomechanical significance, clinical evidence on concomitant thoracic cage injuries was largely limited to smaller cohorts, historically focused on young high-energy polytrauma patients [14]. The recently proposed four-column classification of thoracic fractures has renewed interest in the fourth column as a determinant of stability and outcome [15]. However, population-level data are lacking so far.

Using nationwide inpatient data from the German Diagnosis Related Groups (DRG) database, this study pursued two primary objectives: first, to determine the population-level prevalence and clinical characteristics of 4th column injuries, thereby providing an epidemiological validation of Berg’s biomechanical construct and second, to quantify the mortality burden associated with age and comorbidity in the geriatric thoracic vertebral fracture population. As a secondary objective, we characterised the pattern of concomitant thoracic cage injuries and their association with in-hospital mortality across these distinct fracture populations.

Methods

Data source and study population

A retrospective cross-sectional analysis was conducted using data from the German DRG system, based on diagnostic coding according to the International Classification of Diseases, 10th Revision (ICD-10) [16]. Data were obtained from the German Institute for the Hospital Remuneration System (InEK, Germany) and comprised all inpatient cases treated in Germany in 2024. The database aggregates records of essentially all acute inpatient cases reimbursed under the German G-DRG system and provides counts of principal and secondary diagnoses (ICD-10-GM), procedures (OPS), DRG distribution, length of stay, patient clinical complexity level (PCCL) and in-hospital mortality. The PCCL is a patient-level composite score used in the German DRG system to quantify the cumulative burden of comorbidities and complications. It ranges from 0, indicating no relevant comorbidity or complication, to 4, indicating extreme severity, and directly influences DRG assignment and reimbursement. In the present study, PCCL was used as a proxy for overall comorbidity burden, with values of 3 or 4 defined as indicating severe or extreme comorbidity.

All adult inpatient cases with a principal or secondary diagnosis of thoracic vertebral fracture (ICD-10-GM S22.0x and S22.1) were included. For the purposes of this analysis, three analytically distinct study groups were defined. The first group comprised all thoracic vertebral fracture cases without a concomitant sternal fracture (thoracic spine group, $n = 27{,}315$). The second group was a pre-specified subgroup of the thoracic spine group consisting of patients aged $\geq$ 75 years (geriatric subgroup, $n = 16{,}276$), defined based on the well-established association between advanced age and fracture-related mortality in this population. The third group comprised cases with a concurrent sternal fracture coded as a secondary diagnosis (ICD-10-GM S22.20, S22.21, or S22.22), constituting the 4th column fracture group ($n = 499$). 4th column injuries were defined as the concurrent occurrence of a thoracic vertebral fracture (principal or secondary diagnosis S22.0x or S22.1) and a sternal fracture (secondary diagnosis S22.2x), operationalising Berg’s biomechanical 4th column concept at the population level. Concomitant thoracic injuries were further characterised through additional ICD-10 coding, including rib fractures (single, two-rib, and serial ≥4-rib patterns), graded thoracic soft-tissue injury (5th-digit S21.8x codes), haemothorax

(S27.1/S27.2), traumatic pneumothorax (S27.0), pulmonary contusion (S27.31) and cardiac contusion (S26.81).

Cases discharged through transfer pathways were excluded from the analysis, including interhospital transfers, transfers within cooperative care arrangements and internal transfers between DRG reimbursement categories. The InEK system was established during the COVID-19 pandemic to consolidate nationwide information on hospital workload across Germany [17]. It functions as a comprehensive, nationwide administrative inpatient dataset encompassing all German hospitals and thereby provides a complete overview of inpatient care activity and healthcare system performance. Data inclusion is restricted to cases from 1 January 2019 onwards, reflecting its system-wide implementation, and participation of all hospitals is mandatory. For the present analysis, data were extracted using the InEK data browser (accessed on 15 October 2025), with all records provided in anonymised form.

Statistical analysis

Secondary diagnoses, comorbidities and complications identified through ICD-10 coding were summarised as absolute frequencies and proportions within each study group. Comparative analyses were performed across the thoracic spine group, the geriatric subgroup, and the fourth-column group, with between-group differences in proportions assessed using Pearson's chi-square test. As the InEK DRG Data Browser provides aggregated case-level frequencies rather than individual patient records, analyses were performed at the population level. Associations between exposures of interest and in-hospital mortality were quantified using odds ratios (ORs), relative risks (RRs), risk differences and corresponding 95% confidence intervals (CIs), derived from 2 × 2 contingency tables. As the underlying data are available only as aggregated cell frequencies, multivariable adjustment for age, sex, PCCL or other potential confounders was not possible. All odds ratios reported herein are therefore unadjusted, bivariate estimates and are reported as descriptive associations rather than independent or causal predictors of mortality. Differences in proportions were assessed using Pearson's chi-square test, with Fisher's exact test applied where appropriate. Fracture-level comparisons used T11/T12 as the reference. To limit type-I error from multiple testing, fracture-level comparisons used a Bonferroni-adjusted α of 0.01 with five comparisons and comorbidity screening used the Holm–Bonferroni procedure.

Mortality analysis and OR estimation were performed separately for the thoracic spine group and the geriatric subgroup. Formal mortality quantification for the 4th column group was not feasible: the InEK data-protection framework suppresses any reporting cell containing fewer than ten cases and the number of deceased patients with a coded sternal fracture fell below this threshold. Accordingly, an exact mortality rate and comorbidity-specific OR could not be derived for this subgroup, only an upper bound of < 2.0% is reported. Given the aggregate structure of the dataset, all effect estimates reflect population-level associations. The study was conducted and reported in accordance with the STROBE and RECORD recommendations for observational studies using routinely collected health data [18, 19].

Table 1 Demographic and clinical characteristics of the cohort

Characteristic	Overall	≥75 years	Deceased
n	27,814	16,271 (58.5%)	545 (1.96%)
Female, %	63.0	72.3	47.1
Male, %	37.0	27.7	52.9
Age≥80 years, %	47.5	81.1	76.6
Mean length of stay, days	10.2	11.7	14.8
PCCL 0, %	65.7	61.8	14.5
PCCL≥3, %	12.6	13.5	61.0

PCCL = patient clinical complexity level.

Results

Cohort characteristics

A total of 27,814 inpatient cases with a thoracic vertebral fracture were identified for 2024, forming the overall cohort. For analysis, three groups were distinguished: the thoracic spine group (n = 27,315, 98.2%), with a geriatric subgroup (n = 16,276), comprising patients aged ≥ 75 years and the 4th column group (n=499, 1.8%), defined as thoracic vertebral fractures with a concomitant sternal fracture as secondary diagnosis. The overall cohort was predominantly female with 63.0% and elderly, with 58.5% aged ≥75 years and 47.5% aged ≥80 years. The mean length of stay was 10.2 days overall, rising to 11.7 days in patients aged ≥75 years. PCCL 0 was present in 66.7% of all cases and PCCL ≥3 in 12.6%. Demographic and clinical characteristics are summarised in Table 1.

Fracture distribution and level-specific mortality

Fracture distribution was strongly polarised toward the lower thoracic spine. The T11–T12 segment alone accounted for 57.9% with the adjacent T7–T8 and T9–T10 segments contributing a further 12.6% and 12.1%, respectively, bringing the cumulative burden of the lower thoracic spine to approximately 82% of the entire cohort. Fracture frequency declined systematically with ascending spinal level, reaching its nadir at T1–T2 representing 3.1%

Fig. 1 Thoracic vertebral fracture distribution by spinal level and corresponding in-hospital mortality

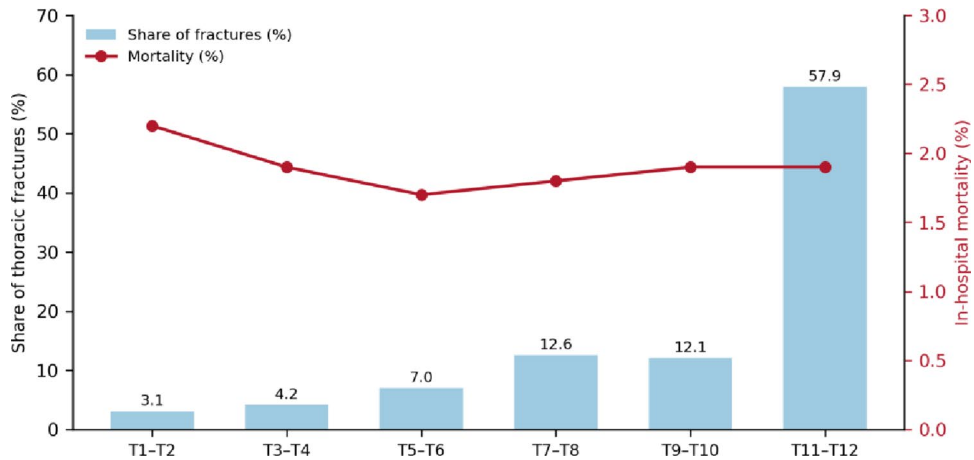

Table 2 Fracture level, case volume and in-hospital mortality by spinal segment

Level	Share (%)	Mortality (%)	OR vs. T11/T12 (95% CI)
T1–T2	3.1	2.2	1.17 (0.78–1.76)
T3–T4	4.2	1.9	1.01 (0.70–1.46)
T5–T6	7.0	1.7	0.90 (0.66–1.23)
T7–T8	12.6	1.8	0.95 (0.75–1.20)
T9–T10	12.1	1.9	1.00 (0.79–1.27)
T11–T12 (ref)	57.9	1.9	1.00 (ref)

OR = odds ratio; ref = reference category. Level shares are approximate where adjacent cells were aggregated; no level differed significantly from the reference after Bonferroni correction.

Table 3 Prevalence of concomitant injuries in thoracic spine fracture

Concomitant injury (ICD-10-GM)	Overall (%)	Deceased (%)
Thoracic soft-tissue injury, grade I	35.1	39.2
Second thoracic vertebral fracture, other level	16.6	18.9
Concomitant L1 fracture	8.9	9.2
Concomitant L2 fracture	4.6	5.5
Concomitant L3 fracture	3.4	4.2
Concomitant L4 fracture	2.3	2.0
Sacral fracture	2.0	2.7
Serial rib fractures (≥4 ribs)	2.4	7.1
Two-rib fracture	1.3	2.9
Concussion	4.1	4.2

of cases. In-hospital mortality remained low across all spinal levels, ranging from 1.7% at T5–T6 to 2.2% at T1–T2. Logistic regression with T11–T12 as the reference category yielded OR between 0.90 and 1.17, with confidence intervals crossing unity at all levels (Fig. 1; Table 2).

Fourth-column fractures

The 4th column group ($n = 499$) differed from the thoracic spine cohort. Men accounted for 57.7% of 4th column cases compared with 36.6% in the thoracic spine group ($p < 0.001$). Only 30.3% of 4th column patients were aged ≥ 75 and 22.8% were aged ≥ 80 years compared with 59.0% and 48.1% in the thoracic spine group ($p < 0.001$). The mean length of stay was in the 4th column group 14.7 days compared with 10.1 days in the thoracic spine group ($p < 0.001$). PCCL ≥3 was recorded in 59.3% of 4th column cases compared with 11.7% in the thoracic spine group ($p < 0.001$). The fracture level distribution was markedly different: T11/T12 accounted for 25.9% of 4th column fractures, while upper thoracic levels T1–T6 collectively represented 51.4%, compared with 16.5% in the thoracic spine group ($p < 0.001$). The concomitant injury profile of the 4th column group reflected the underlying high-energy mechanism: thoracic soft-tissue injury of grade I in 49.7%, serial rib fractures, defined as ≥4 ribs involved, in 23.4%, pulmonary contusion in 16.2%, traumatic pneumothorax in 11.2%, haemothorax in 10.8%, cardiac contusion in 4.2% and concussion in 13.0%. Polytrauma DRGs were documented in 9.6% compared with less than 1% in the thoracic spine group. For the thoracic spine group, the associated concomitant injury prevalences are summarised in Table 3. Comparative demographic, injury characteristics of the thoracic spine fracture group, the geriatric subgroup (≥75 years) and the 4th column cohort are presented in Table 4.

Overall, in-hospital mortality in the thoracic spine group was 2.0%, rising to 2.9% in patients aged ≥ 75 years. Of all 545 in-hospital deaths, 86.1% occurred in the geriatric subgroup. Thoracic cage injury diagnoses were associated with significantly elevated unadjusted mortality: traumatic haemothorax (OR = 5.73, 95% CI 3.50–9.40), serial rib fractures (OR = 3.31, 95% CI 2.36–4.62), thoracic soft-tissue injury grade II (OR = 2.10, 95% CI 1.33–3.30), a concomitant thoracic vertebral fracture at a non-index level (OR = 1.99, 95% CI 1.68–2.37), two-rib fractures (OR = 2.34, 95% CI 1.41–3.89), single rib fractures (OR = 2.11, 95% CI 1.37–3.26), and soft-tissue injury grade I (OR = 1.20, 95% CI 1.01–1.42) (Table 5).

Table 4 Comparative demographic, injury characteristics of the thoracic spine fracture group, the geriatric subgroup (≥75 years) and the 4th column cohort

Characteristic	Thoracic spine fracture (*n*=27,315)	Geriatric≥75 years (*n*=16,125)	4th column (*n*=499)	*p*
Male, %	36.6	27.7	57.7	<0.001
Age≥75 years, %	59.0	100.0	30.3	<0.001
Age≥80 years, %	48.1	81.1	22.8	<0.001
Mean LOS, days	10.1	11.7	14.7	-
PCCL 0, %	66.7	61.8	10.4	<0.001
PCCL≥3, %	11.7	13.5	59.3	<0.001
T11/T12, %	57.9	60.7	25.9	<0.001
Upper BWS T1–T6, %	16.5	12.7	51.4	<0.001
Polytrauma DRG, %	<1	<1	9.6	-
In-hospital mortality, %	2.00	2.92	<2.0	-

Table 5 Fourth-column injuries and unadjusted odds of in-hospital mortality

Fourth-column injury	OR	95% CI	*p* (Holm)
Concomitant thoracic vertebral fracture (other level)	1.99	1.68–2.37	<0.001
Soft-tissue injury grade II (S21.85)	3.27	2.24–4.78	<0.001
Soft-tissue injury grade I (S21.84)	1.20	1.02–1.41	0.026

OR=odds ratio; CI=confidence interval.

Table 6 Key comorbidity associations with in-hospital mortality

Comorbidity (ICD-10-GM)	Overall %	Deceased %	OR	95% CI
Cardiac arrest	<0.4	9.9	64.95	43.40–97.21
Sepsis	0.5	9.5	29.18	20.61–41.32
Heart failure	1.4	17.2	19.21	14.96–24.68
Respiratory insufficiency	4.7	39.7	15.69	13.08–18.82
Nosocomial pneumonia	2.7	26.2	15.43	12.55–18.98
Pleural effusion	3.5	24.4	10.21	8.30–12.56
Acute bleeding anaemia	5.1	26.2	7.16	5.87–8.73
Delirium	1.7	8.2	5.59	4.06–7.70
Volume depletion	5.7	20.1	4.43	3.57–5.50
Age≥75 years	58.5	86.3	4.55	3.57–5.82
Male sex	37.0	52.9	1.95	1.64–2.31

Table 7 Mortality and key comorbidity associations with in-hospital mortality: thoracic spine fracture group and geriatric subgroup (≥75 years)

Parameter	Thoracic spine fracture (*n*=27,315)	Geriatric (*n*=16,276)
Mortality		
In-hospital mortality, %	2.00	2.89
Age <75 years, %	0.68	—
Age ≥75 years, %	2.89	2.89
Deaths in ≥75 y, % of all	86.3	100
In-hospital deaths, n	546	471
Key comorbidity associations with in-hospital mortality - OR (95% CI)		
Palliative care (Z51.5)	25.18 (18.42–34.43)	90.53 (55.64–147.31)
Sepsis	29.18 (20.61–41.32)	42.96 (27.09–68.13)
Heart failure	19.21 (14.96–24.68)	13.73 (10.51–17.94)
Respiratory insufficiency	15.69 (13.08–18.82)	14.67 (12.00–17.93)
Nosocomial pneumonia	15.43 (12.55–18.98)	13.15 (10.50–16.48)
Pleural effusion	10.21 (8.30–12.56)	7.79 (6.24–9.74)
Acute bleeding anaemia	7.16 (5.87–8.73)	6.99 (5.59–8.72)
Delirium	5.59 (4.06–7.70)	4.43 (3.15–6.24)
Volume depletion	4.43 (3.57–5.50)	3.11 (2.47–3.91)
Age ≥75 years	4.55 (3.57–5.82)	2.55 (2.01–3.51)
Male sex	1.95 (1.64–2.31)	2.78 (2.32–3.35)

Comorbidity burden and mortality

The comorbidity profile differed markedly between survivors and deceased patients across the thoracic spine and geriatric subgroups. In the thoracic spine cohort, the PCCL distribution shifted from predominantly PCCL 0 (66.7%) in all cases to PCCL≥3 in 61.0% of deceased patients. Acute organ-failure states carried the strongest unadjusted mortality associations: cardiac arrest (OR=64.95, 95% CI 43.40–97.21), sepsis (OR=29.18, 95% CI 20.61–41.32), heart failure (OR=19.21, 95% CI 14.96–24.68), respiratory insufficiency (OR=15.69, 95% CI 13.08–18.82) and nosocomial pneumonia (OR=15.43, 95% CI 12.55–18.98). In the geriatric subgroup (≥75 years; *n*=16,276; mortality 2.89%), respiratory insufficiency (OR=14.67, 95% CI 12.00-17.93), heart failure (OR=13.73, 95% CI 10.51–17.94) and nosocomial pneumonia (OR=13.15, 95% CI 10.50-16.48) were present in more than 25% of deceased geriatric patients (Tables 6 and 7).

The injury severity and clinical profile across all three groups is summarised in Table 8. In the 4th column group, formal mortality quantification was precluded by InEK data-protection suppression (<10 deceased per sternum code; upper bound<2.0%), but the acute injury profile reflects the high-energy mechanism: PCCL≥3 in 59.3%, serial rib fractures in 23.4%, pulmonary contusion in 16.2%, and pneumothorax in 11.2% (Table 8).

Discussion

This nationwide analysis of 27,814 inpatient thoracic vertebral fracture cases provides, to our knowledge, the first population-level examination of Berg's 4th column concept in a contemporary, predominantly elderly fracture cohort.

Table 8 Injury severity and clinical profile across the three study groups: thoracic spine fracture group, geriatric subgroup and 4th column group

Injury / comorbidity parameter	Thoracic spine (*n*=27,315)	Geriatric (*n*=16,276)	4th column (*n*=499)
PCCL ≥3, %	11.7	13.5	59.3
Serial rib fractures, %	2.4	1.7	23.4
Pulmonary contusion, %	1.3	0.3	16.2
Traumatic pneumothorax, %	0.9	0.4	11.2
Haemothorax, %	0.6	0.4	10.8
Soft-tissue injury grade II, %	1.8	1.5	6.8
Cardiac contusion, %	< 0.1	< 0.1	4.2
Polytrauma DRG, %	< 1	0.4	9.6
Age ≥75 years, %	59.0	100	30.3
Mean LOS, days	10.1	11.7	14.7
In-hospital mortality, %	2.00	2.89	< 2.0

4th column fractures (*n*=499, 1.8%) constituted a mechanistically distinct injury entity differing fundamentally from the predominant thoracic spine fracture pattern in demographics, fracture topography and associated injury burden. In-hospital mortality in the thoracic spine cohort was overwhelmingly governed by age and pre-existing comorbidity rather than fracture severity, with the geriatric subgroup (≥75 years) accounting for 86.1% of all deaths. Therefore, these observations identified two mechanistically and prognostically distinct thoracic fracture populations, the high-energy 4th column injury demanding systematic thoracic cage evaluation and time-sensitive injury control and the comorbidity-driven geriatric fragility fracture requiring early frailty assessment and multidisciplinary decompensation management. Recognising this duality is a prerequisite for rational clinical decision-making in thoracic vertebral fracture care.

The 4th column: population-level validation of a biomechanical construct

Since Berg's original description in 1993, the biomechanical importance of the sternum–rib complex as a load-bearing structure contributing to thoracic spine stability was substantiated through cadaveric and finite-element studies [2, 9, 12, 13]. The 4th column classification proposed by Reinhold et al. formalised this concept by incorporating both direct sternal and indirect rib-cage mechanisms as the 4th column [20]. The present study confirms, at the national epidemiological level, that 4th column occurred in 1.8% of hospitalised patients. This prevalence is consistent with the mechanistic specificity of sternal-vertebral co-injury, requiring sufficient axial loading to simultaneously disrupt both the anterior column and the sternum, a force vector predominantly encountered in high-energy blunt thoracic trauma [12, 21]. The demographic and topographic profile of the 4th column group strongly corroborates the biomechanical rationale underlying the concept [22]. In marked contrast to the thoracic spine cohort as a whole, which is dominated by elderly women sustaining low-energy fragility fractures at the thoracolumbar junction, the 4th column group was predominantly male with 57.7%, substantially younger (age ≥ 75 years: 30.3% vs. 59.0%) and injury level concentrated in the upper and mid-thoracic spine (T1–T6: 51.4% vs. 16.5%). The concomitant injury profile with serial rib fractures in 23.4%, pulmonary contusion in 16.2%, traumatic pneumothorax in 11.2%, and cardiac contusion in 4.2%, is consistent with high-energy chest trauma, the typical mechanism of sternal fracture [11, 12]. The polytrauma DRG rate of 9.6%, compared with less than 1% in the thoracic spine group, further underscores the high-energy injury pattern [5, 7].

Two prognostically distinct populations within a single diagnostic code

Perhaps the most clinically consequential finding of this analysis is the coexistence, within the broad administrative category of "thoracic vertebral fracture," of two populations governed by entirely different mortality mechanisms. In the thoracic spine cohort, the 4.3-fold mortality gradient between patients aged 75 ≥ years and those < 75 years identifies age as the factor most strongly associated with death [23]. The dominance of acute organ-failure states in the geriatric subgroup including sepsis (OR = 42.96), respiratory insufficiency (OR = 14.67) and heart failure (OR = 13.73) in consistent with in-hospital death as medical decompensation in a severely comorbid host, precipitated by the physiological stress of fracture rather than the fracture itself [5, 24]. Reducing mortality in this population therefore depends less on fracture stabilisation than on the early recognition and active management of underlying medical frailty [25, 26]. In the 4th column group, although exact mortality could not be quantified owing to InEK data-protection suppression, the upper bound of less than 2.0% is numerically comparable to the overall thoracic spine rate despite a dramatically higher acute injury burden (PCCL ≥ 3: 59.3% vs. 11.7%). This apparent paradox resolves when the substantially younger age structure is considered: with only 30.3% of patients aged ≥ 75 years, compared with

59.0% in the thoracic spine cohort, the elevated PCCL ≥3 rate in the 4th column group therefore reflects acute, potentially reversible injury complexity rather than the chronic, cumulative multimorbidity predicting death in the elderly fragility-fracture population [23, 27]. Therefore, 4th column patients may benefit from systematic, time-sensitive injury control, whereas geriatric thoracic spine fracture patients may require early multidisciplinary decompensation management. Using a single clinical pathway for both phenotypes risks under-treating one and over-medicalising the other.

The geriatric thoracic spine fracture: a medical emergency within an orthopaedic diagnosis

The demographic profile of the thoracic spine cohort with 63.0% being female and 58.5% aged ≥ 75 years and 47.5% aged ≥ 80 years contrasts starkly with the polytrauma literature on which the 4th column concept was originally based. In contemporary practice, the numerically dominant thoracic vertebral fracture is the osteoporotic fragility fracture of the thoracolumbar junction in an octogenarian woman, a presentation fundamentally different in mechanism, stability and prognosis from the high-energy sternal-vertebral injury described by Berg [9]. The current analysis quantifies the mortality consequence of this demographic reality: with 86.1% of all 545 in-hospital deaths occurring in patients aged ≥ 75 years and a 4.3-fold age-specific mortality gradient, the geriatric thoracic spine fracture carries a prognostic severity being invisible in aggregate mortality statistics. The magnitude of the comorbidity in the geriatric subgroup is comparable to mortality effect sizes reported for sepsis in intensive care unit cohorts and reflects a population at the physiological margin where any intercurrent insult may precipitate irreversible decompensation [23, 28].

Thoracic cage injury as a severity signal in the thoracic spine group

Within the thoracic spine group, concomitant thoracic cage injuries were associated with substantially elevated mortality: haemothorax (OR = 5.73), serial rib fractures (OR = 3.31), and a second thoracic vertebral fracture at a non-index level (OR = 1.99). A graded relationship between rib fracture burden and mortality risk is consistent with the well-established dose-response between rib fracture number and pulmonary morbidity and mortality in blunt thoracic trauma literature [15]. These associations should be interpreted as markers of a higher-force injury mechanism within the predominantly low-energy elderly cohort rather than as independent causal drivers of death. Nevertheless, they identify a clinically recognisable injury pattern prompting monitoring and early intensive care treatment [21, 24].

Clinical implications and future directions

Three actionable implications follow from these findings. First, the identification of a sternal fracture on imaging in a patient with a thoracic vertebral fracture should trigger a systematic 4th column protocol: dedicated assessment for rib fractures, haemothorax, pneumothorax, pulmonary contusion and cardiac contusion, with cardiorespiratory monitoring. The 9.6% polytrauma DRG rate underscores that a substantial minority of 4th column patients arrive in the context of multi-system trauma and require trauma team activation [7]. Second, for elderly patients with thoracic vertebral fractures, the standard orthopaedic assessment should be complemented by structured frailty and decompensation screening. Comorbidity patterns associated with the highest mortality are identifiable on admission and amenable to early intervention. Third, the finding that male sex was associated with a substantially higher unadjusted mortality risk (OR = 1.95 overall, OR = 2.78 in the geriatric subgroup) challenges the prevalent clinical framing of thoracic vertebral fractures as predominantly a female fragility-fracture problem and argues for heightened vigilance in elderly men presenting with thoracic pain after minor trauma [27].

This sex disparity, although statistically in unadjusted analysis, was not further explored in the primary analysis and merits comment. Several non-mutually exclusive mechanisms may contribute. First, men in this age group carry a higher baseline burden of cardiovascular and pulmonary comorbidity than women, which may reduce physiological reserve to withstand the systemic stress imposed by an acute fracture. Second, because thoracic fragility fractures are clinically framed as a predominantly female disease, older men may present later or with more advanced decompensation and may be under-triaged for frailty assessment relative to their female counterparts. Third, given that the overall cohort was 63.0% female, the smaller absolute number of male cases may include a higher proportion of atypical or higher-energy fracture mechanisms not fully captured by the coding scheme, potentially inflating the observed mortality association. As the present aggregate-level data cannot adjudicate between these explanations, the sex-specific mortality gradient reported here should be regarded as hypothesis-generating and warrants dedicated investigation in patient-level cohorts capturing injury mechanism, comorbidity profile and frailty status stratified by sex.

Strengths and limitations

The InEK DRG database captures essentially all reimbursed inpatient cases nationwide, minimising selection bias and providing precise national counts. However, several limitations follow directly from the data source and must temper interpretation. Most fundamentally, the InEK dataset is an administrative reimbursement database rather than a dedicated clinical trauma registry: diagnosis and procedure coding is generated primarily to support DRG-based hospital remuneration rather than structured clinical research, and consequently injury mechanism, fracture morphology, imaging findings and other clinically granular variables that a purpose-built registry would capture are not available. We consider this distinction the most important limitation of the data source and have accordingly framed all findings as hypothesis-generating, population-level associations rather than clinically adjudicated injury characterisation. First, as with all registry-based studies, the data are not designed to establish causative relationships. Although the accuracy of diagnosis coding is assumed to be high due to DRG controls, the completeness and accuracy of the data depend on the documentation quality provided by healthcare professionals. Furthermore, the data are aggregated at the cell level and odds ratios are unadjusted. Patient-level confounders such as injury mechanism, frailty indices, and treatment timing could not be controlled, and adjusted or independent associations cannot be claimed. Second, the analysis is cross-sectional and limited to a single year, precluding trend or causal inference. Third, reliance on administrative ICD-10 coding introduces the usual risks of under-coding and coding artefacts. Admissions with atypical or undiagnosed presentations may have been missed and the data do not allow differentiation between acute and chronic cases. Additionally, the database provides only in-hospital mortality data, without mid- or long-term outcomes and post-discharge deaths are not captured. Fourth, although discharge reasons such as transfers to other hospitals, transfers as part of a cooperation, and internal transfers between DRG fee categories were excluded from the analysis, a residual risk of double counting cannot be entirely ruled out in some instances. Fifth, the analysis is limited to a bivariate assessment of risk factors and does not include a multivariable model to account for comorbidities and other confounders. A finer stratification of mortality risk by PCCL category, beyond the age-based stratification was considered but was not feasible, as several of the resulting strata fell below the InEK confidentiality threshold of ten cases per reporting cell. Sixth, the InEK data-protection threshold of fewer than ten cases per reporting cell prevented formal mortality quantification for the 4th column group. The exact number of deceased patients with a coded sternal fracture is suppressed and only an upper bound of < 2.0% could be derived. OR for individual comorbidities within this subgroup are therefore not estimable. This constraint specifically limits the comparability of mortality analyses across the three study groups and represents a structural limitation of nationwide administrative data for low-prevalence injury subgroups. Lastly, the study's focus on nationwide data from Germany may limit the generalisability of the findings to other healthcare systems or regions where access to surgical techniques and patient management practices may differ. These constraints mean that the associations reported are hypothesis-generating and should be confirmed in patient-level, preferably imaging-based, prospective cohorts allowing for adequate adjustment of relevant clinical variables.

Conclusions

In this nationwide cross-sectional analysis, 4th column fractures constituted a mechanistically distinct high-energy injury entity characterised by male predominance, younger age, upper thoracic fracture distribution and a multi-compartment concomitant injury profile. In the thoracic spine cohort, in-hospital mortality was overwhelmingly governed by age and comorbidity: 86.1% of all deaths occurred in patients aged ≥ 75 years, with acute organ-failure states carrying the highest unadjusted mortality risk in the geriatric subgroup. 4th column patients may benefit from systematic, time-sensitive thoracic injury-control protocols, whereas geriatric fragility-fracture patients may benefit from early frailty assessment, multidisciplinary decompensation management and goals-of-care discussions. Prospective validation of these risk-stratified pathways is warranted. These nationwide data provide the first population-level validation of Berg's 4th column concept in a contemporary predominantly elderly cohort, quantify the disproportionate mortality burden of the geriatric thoracic spine fracture and argue for risk-stratified clinical pathways distinguishing injury complexity from host vulnerability. Confirmation in patient-level studies with imaging adjudication and multivariable adjustment is warranted.

Author contributions The manuscript was created by JS and SL. JS and SL performed the statistical analysis and designed the study. JS, SL, JR, HA, MA, NW, DP, VA and AM conceived of the study, helped to draft the manuscript and participated in its design. All authors read and approved the final manuscript.

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Data availability The findings of this study are available from the Institute for the Hospital Remuneration System and data for this study is available upon request.

Declarations

Conflict of interest The authors declare no competing interests.

References

1. Lang S, Walter N, Freigang V et al (2023) Increased incidence of vertebral fractures in German adults from 2009 to 2019 and the analysis of secondary diagnoses, treatment, costs, and in-hospital mortality. Sci Rep 13:6984. https://doi.org/10.1038/s41598-023-31654-0
2. Watkins R, Watkins R, Williams L et al (2005) Stability provided by the sternum and rib cage in the thoracic spine. Spine 30:1283–1286. https://doi.org/10.1097/01.brs.0000164257.69354.bb
3. Oda I, Abumi K, Lü D et al (1996) Biomechanical role of the posterior elements, costovertebral joints, and rib cage in the stability of the thoracic spine. Spine 21:1423–1429. https://doi.org/10.1097/00007632-199606150-00005
4. Horton WC, Kraiwattanapong C, Akamaru T et al (2005) The role of the sternum, costosternal articulations, intervertebral disc, and facets in thoracic sagittal plane biomechanics: a comparison of three different sequences of surgical release. Spine 30:2014–2023. https://doi.org/10.1097/01.brs.0000180478.96494.88
5. Oyetunji TA, Jackson HT, Obirieze AC et al (2013) Associated injuries in traumatic sternal fractures: a review of the National Trauma Data Bank. Am Surg 79:702–705
6. Hanley EN, Eskay ML (1989) Thoracic spine fractures. Orthopedics 12:689–696. https://doi.org/10.3928/0147-7447-19890501-08
7. Morgenstern M, von Rüden C, Callsen H et al (2016) The unstable thoracic cage injury: The concomitant sternal fracture indicates a severe thoracic spine fracture. Injury 47:2465–2472. https://doi.org/10.1016/j.injury.2016.08.026
8. Huang Z, Chen F, Huang J et al (2015) Treatment of middle-super thoracic fractures associated with the sternum fracture. Int J Clin Exp Med 8:9751–9757
9. Berg EE (1993) The sternal-rib complex. A possible fourth column in thoracic spine fractures. Spine 18:1916–1919
10. Denis F (1983) The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine 8:817–831. https://doi.org/10.1097/00007632-198311000-00003
11. Rahm MD, Brooks DM, Harris JA et al (2019) Stabilizing effect of the rib cage on adjacent segment motion following thoracolumbar posterior fixation of the human thoracic cadaveric spine: A biomechanical study. Clin Biomech 70:217–222. https://doi.org/10.1016/j.clinbiomech.2019.10.008
12. Brasiliense LBC, Lazaro BCR, Reyes PM et al (2011) Biomechanical contribution of the rib cage to thoracic stability. Spine 36:E1686–1693. https://doi.org/10.1097/BRS.0b013e318219ce84
13. Bruno AG, Anderson DE, D'Agostino J, Bouxsein ML (2012) The effect of thoracic kyphosis and sagittal plane alignment on vertebral compressive loading. J Bone Min Res Off J Am Soc Bone Min Res 27:2144–2151. https://doi.org/10.1002/jbmr.1658
14. Odell DD, Peleg K, Givon A et al (2013) Sternal fracture: isolated lesion versus polytrauma from associated extrasternal injuries–analysis of 1,867 cases. J Trauma Acute Care Surg 75:448–452. https://doi.org/10.1097/TA.0b013e31829e227e
15. Aldakheel DA (2023) Classification of thoracic spine fractures: the four-column theory. Int Orthop 47:2907–2915. https://doi.org/10.1007/s00264-023-05778-x
16. International Classification of Diseases (ICD) https://www.who.int/standards/classifications/classification-of-diseases. Accessed 4 June 2026
17. DatenBrowser IEK InEK GmbH. https://www.g-drg.de/datenlieferung-gem.-21-khentgg/inek-datenbrowser. Accessed 4 June 2026
18. Benchimol EI, Smeeth L, Guttmann A et al (2015) The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement. PLoS Med 12:e1001885. https://doi.org/10.1371/journal.pmed.1001885
19. von Elm E, Altman DG, Egger M et al (2008) The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol 61:344–349. https://doi.org/10.1016/j.jclinepi.2007.11.008
20. Reinhold M, Knop C, Beisse R et al (2009) [Operative treatment of traumatic fractures of the thoracic and lumbar spinal column: Part III: Follow up data]. Unfallchirurg 112:294–316. https://doi.org/10.1007/s00113-008-1539-0
21. Şimşek S, Özmen CA, Onat S (2022) Morbidity and mortality associated with fracture of the sternum due to blunt trauma, by fracture type and location. Radiol Bras 55:167–172. https://doi.org/10.1590/0100-3984.2021.0074
22. Vioreanu MH, Quinlan JF, Robertson I, O'Byrne JM (2005) Vertebral fractures and concomitant fractures of the sternum. Int Orthop 29:339–342. https://doi.org/10.1007/s00264-005-0001-y
23. Hildebrand F, Pape H-C, Horst K et al (2016) Impact of age on the clinical outcomes of major trauma. Eur J Trauma Emerg Surg Off Publ Eur Trauma Soc 42:317–332. https://doi.org/10.1007/s00068-015-0557-1
24. Rupprecht H, Heppner HJ, Wohlfart K, Türkoglu A (2017) The geriatric polytrauma: Risk profile and prognostic factors. Ulus Travma Ve Acil Cerrahi Derg Turk. J Trauma Emerg Surg TJTES 23:156–162. https://doi.org/10.5505/tjtes.2016.77177
25. Giannoudis PV, Harwood PJ, Court-Brown C, Pape HC (2009) Severe and multiple trauma in older patients; incidence and mortality. Injury 40:362–367. https://doi.org/10.1016/j.injury.2008.10.016
26. Lopez AJ, Scheer JK, Smith ZA, Dahdaleh NS (2015) Management of flexion distraction injuries to the thoracolumbar spine. J Clin Neurosci Off J Neurosurg Soc Australas 22:1853–1856. https://doi.org/10.1016/j.jocn.2015.03.062
27. Breitenbach M, Phan A, Botros M et al (2022) The fourth column of the spine: Prevalence of sternal fractures and concurrent thoracic spinal fractures. Injury 53:1062–1067. https://doi.org/10.1016/j.injury.2021.12.040
28. Aldrian S, Nau T, Koenig F, Vécsei V (2005) Geriatric polytrauma. Wien Klin Wochenschr 117:145–149. https://doi.org/10.1007/s00508-004-0290-y