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ORIGINAL ARTICLE

Fracture patterns in patients with multiple fractures: the probability of multiple fractures and the most frequently associated regions

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Abstract

Introduction Multiple fractures are of high clinical relevance, as a significant increase in mortality rate has been described. The purpose of this study was to evaluate differences in age and gender distribution in multiple fractures dependent on severity of trauma. Furthermore, affected anatomic regions and frequently associated fracture regions were investigated.

Methods Patients who had sustained multiple fractures between 2000 and 2012 were included in this study. At hospital admission, patients were divided according to trauma severity (high- vs low-traumatic), gender, and age for demographic analysis. Fractures were grouped in anatomical regions, and multiple fracture event probabilities as well as frequently associated regions were calculated.

Results In total, 25,043 patients at an age range of 0–100 years (5.8% of all fracture patients; 14,769 male and 10,274 female patients) who sustained 57,862 multiple fractures were included. The lumbar/thoracic spine, cervical spine, femoral shaft, skull, and pelvis showed a probability of more than 40% of the presence of further fractures in each high-traumatic fracture event. In high-traumatic fracture events, male patients were more affected ($p < 0.001$). Considering low-traumatic fractures, female patients had a significantly higher proportion ($p < 0.001$) of multiple fractures among all fractures than male patients.

Conclusions As a novelty, gender as well as age distributions in multiple fracture patients and a probability statement with the most affected anatomic regions, the risk of presence of further fractures for every region, and the frequently associated fracture regions including the percentage of occurrence are provided. These aspects yield new opportunities for clinical work and may reduce the high rate of overlooked fractures stated in the literature.

Keywords Multiple fractures · Fracture patterns · Associated regions · Fracture probability

Introduction

The focus of the research literature has mostly been on isolated fractures. Although multiple fractures have been mentioned in a small number of studies [1, 2], reports solely addressing the epidemiology of multiple fractures are scarce [3]. Previous studies have indicated an age-dependent increase in multiple fractures—reaching an incidence of 202.8/100,000 per year in patients aged 80 years or older [4]—with an influencing effect on survival [3, 5].

For fracture risk prevention and clinical management, it is important to differentiate between high- and low-traumatic multiple fractures. While high-energy severe polytrauma mainly effects younger patients, low-traumatic multiple fractures are more common in elderly patients [6–11].

Clement et al. described a clear association between multiple fractures and low-energy trauma origin in patients 65 years of age and older. Less is known about young patients, pre- and perimenopausal subjects, as well as similarly aged men [3]. No studies have addressed different anatomical regions or differences in high- and low-trauma origin.

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The hypothesis of this study was to test whether or not patients with multiple fractures differ with regard to age, gender and severity of trauma, and whether or not fracture patterns concerning the anatomic regions vary between different age groups and trauma severities.

The primary objective was to investigate gender and age differences in patients who had sustained multiple fractures due to one trauma event depending on trauma severity.

The secondary objectives included:

- To investigate fracture patterns of different anatomic regions in multiple fractures depending on age and high- and low-trauma origin.
- To provide information about concomitant fractures regions and their probability of occurrence.

Methods

A retrospective analysis with a 13-year observation period from January 2000 to December 2012 was performed. The study was approved by the general management of the Austrian Workers' Compensation Board (AUVA) and the ethics committee of St. Vincent Hospital in Vienna (201501-EK07). The AUVA runs seven trauma hospitals with a total of 918 beds (including 54 intensive-care beds) across Austria. Treatment in these hospitals covers accidents that occur during leisure time as well as occupational accidents and is not limited to any population group. With an annual treatment load of more than 300,000 and an approximate catchment area of more than 4 million, the patients treated in these trauma hospitals are representative of the entire Austrian urban and rural population at all stages of life [12].

The fracture localizations and medical diagnoses were elaborated by an experienced trauma surgeon and were coded related to the ICD-10 codifications. Controlling for correctness and plausibility was performed by another independent and experienced trauma surgeon. All patient data were anonymized and electronically extracted [12, 13]. The patients were categorized into groups with high clinical impact based on skeletal maturation, bone modeling, bone remodeling, and patients' gender according to earlier studies in the field of bone metabolism [14, 15]. Age 0–15 years—childhood, age 16–30 years—bone growth, age 31–53 years—peak bone mass, age 54–70 years—postmenopausal (and similarly aged men), and age > 70 years—aging bone [13]. Analyses were performed with regard to age and gender, defined anatomical regions, and causes of accident (high- and low-traumatic).

Inclusion and exclusion criteria

Data on all patients with fresh multiple fractures in the observation period were extracted from the database. The patients were divided as to high- and low-trauma fractures, which—as a unique procedure—was encoded at the time of admission to the hospitals. Fractures occurring through no or through minimal trauma were defined, as stated by Siris et al. in a position paper to be diagnostic for osteoporosis, as low-traumatic [e.g., a fall from standing height (less than 1 m)] [13, 16]. Fractures occurring through higher trauma were classified as high-traumatic fractures. For the reason of clinical relevance and due to known fracture mechanisms [13, 17–19], the fractures were grouped in 26 anatomical regions: skull, facial bones, cervical spine, thorax, shoulder girdle, proximal humerus, humeral shaft, distal humerus, proximal forearm, forearm shaft, distal forearm, carpus, metacarpus, finger, thumb, lumbar/thoracic spine, pelvis, proximal femur/hip, femoral shaft, distal femur, patella, proximal lower leg/shaft, distal lower leg, hindfoot, midfoot, and forefoot. Fractures which were coded as pathologic except for osteoporosis (e.g., cancer, infection, and bone cyst) or those in the presence of malignant disease at the time of admission were excluded from this database.

Statistical analysis

The fractures, as well as the percentage of fractures per anatomical region, age, and fracture cause (high- and low-traumatic types), were based on the recorded fractures. The proportion of the three associated fractures among all associated fractures was outlined. For the comparison of age, gender and high- and low-traumatic groups, two sample z tests for two proportions were performed and their magnitudes of effects, confidence intervals and p values were calculated. p values less than 0.05 were considered statistically significant. The statistical analyses were performed with the statistical software R version 3.33 [20].

Results

During the investigational period, a total of 433,471 male and female patients with 574,766 fresh fractures were recorded. The patient age of these ambulatory and hospitalized subjects ranged from 0 to 100 years. Of this total, 25,043 (5.8%) had sustained 57,862 multiple fractures. According to the inclusion and exclusion criteria defined

Table 1 Absolute number of patients with fractures and multiple fractures and percentage of patients with multiple fractures among all fracture patients subdivided into gender and age

	Number of patients with fractures			Number of patients with multiple fractures			Percentage of patients with multiple fractures among all fracture patients		
	Male	Female	Total	Male	Female	Total	Male (%)	Female (%)	Total (%)
(0–15)	53,398	34,270	87,668	979	488	1467	1.8	1.4	1.7
(16–30)	56,051	22,384	78,435	3011	742	3753	5.4	3.3	4.8
(31–53)	77,501	44,807	122,308	6372	1869	8241	8.2	4.2	6.7
(54–70)	30,388	43,599	73,987	2938	2596	5534	9.7	6.0	7.5
(> 70)	17,080	53,993	71,073	1469	4579	6048	8.6	8.5	8.5
Total	234,418	199,053	433,471	14,769	10,274	25,043	6.3	5.2	5.8

Table 2 Comparison of groups showing differences (%), confidence intervals, and *p* values

	Differences (%)	95% CI	*p* value
Gender			
Male vs female (all fractures)	1.14	[1.0; 1.3]	< 0.001
Male vs female (high-traumatic)	2.54	[2.4; 2.7]	< 0.001
Male vs female (low-traumatic)	− 1.03	[− 1.3; − 0.8]	< 0.001
Fracture causes			
High-traumatic vs low-traumatic	0.2	[0.1; 0.4]	0.004
Age			
> 70 vs 0–15	6.84	[6.6; 7.1]	< 0.001
> 70 vs 16–30	3.72	[3.5; 4.0]	< 0.001
> 70 vs 31–53	1.77	[1.5; 2.0]	< 0.001
> 70 vs 54–70	1.03	[0.8; 1.3]	< 0.001

in this study, 118 patients with 306 fractures did not fulfill the inclusion criteria.

Age and gender distribution in patient population

Overall, 14,769 male and 10,274 female patients with 35,087 and 22,775 multiple fractures (2.32 fractures per fracture event in male patients; 2.17 fractures per fracture event in female patients), respectively, were included. While in contrast, a continuous increase was observed in female patients with age, a continuous increase with a maximum value in the age range of 54–70 and a slight decrease thereafter were found in the male population (Table 1). In total, males showed significantly higher proportions of multiple fractures among all fractures than the female population (Table 2). The absolute number of patients with multiple fractures per age group relative to the Austrian population showed an increase of multiple fractures with age especially in the female population (Fig. 1) [21].

Comparing the age group of > 70—in which most of the multiple fractures in proportion to all fractures occurred in total—and the other age groups, statistically significant differences were seen in each group. The differences relative to age group of > 70 declined with increasing age (Table 2), reflecting the age-dependent growing amount of multiple

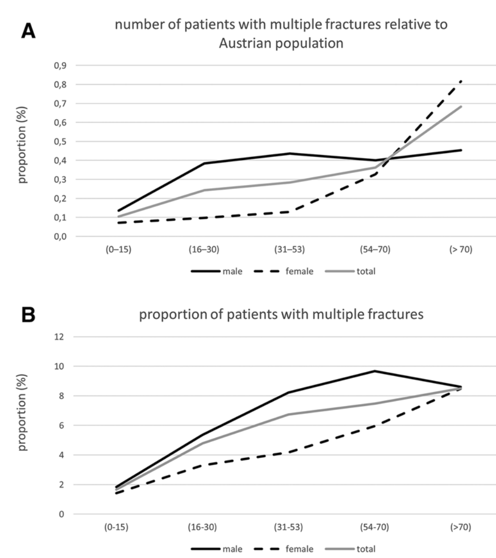

Fig. 1 Absolute number of patients with multiple fractures relative to the Austrian population (**a**) and proportion (%) of patients with multiple fractures among all fracture patients (**b**) subdivided into age and gender

fractures. All comparisons showed very narrow confidence intervals due to the large sample size and were highly significant (all *p* values below 0.001).

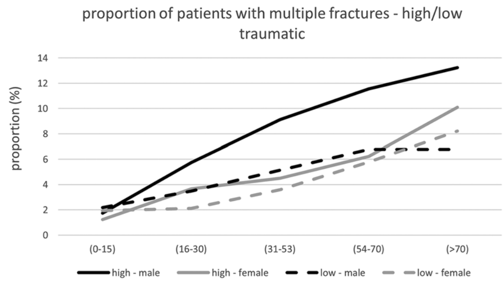

Fig. 2 Proportion (%) of patients with multiple fractures among all fracture patients subdivided into severity of accident (high-/low-traumatic), age, and gender

Patient population divided as to high- and low-traumatic fractures

In the group of patients with high-traumatic fractures, the number of multiple fractures in relation with all fractures steadily increased both in men and in women, with the highest proportion in the age group of > 70 years (Fig. 2). Taking into account only high-traumatic fractures, men had sustained more multiple fractures than women in absolute terms as well as in proportion of all fractures (Table 3).

In the low-traumatic multiple fracture group, the proportion of multiple fractures among all fractures also increased in all age groups in both men and women (Fig. 2). In total, the female group showed higher absolute numbers of low-traumatic multiple fractures and a higher share in relation with all fractures, contrary to the high-traumatic group (Tables 3, 4).

These gender differences in both the high- and low-traumatic groups were altogether statistically significant. The height of the total proportion of high-traumatic multiple fractures differed significantly from that of the low-traumatic multiple fractures (Table 2).

Fracture patterns of anatomic regions in multiple fractures

While the thorax, in absolute numbers, was the most frequently involved fracture region in high-traumatic multiple fractures, the lumbar and thoracic spine showed the highest proportion of multiple fractures among all fractures. When fractures occurred in the cervical spine, femoral shaft, skull or pelvis, the probability that there were multiple fractures was more than 40% for each of the regions. The three most frequently associated fracture regions of the lumbar/thoracic spine were the thorax, pelvis, and shoulder girdle, which together accounted for 57%. The cervical spine often fractured in combination with the thorax, the lumbar/thoracic spine and the shoulder girdle. In 58% of the skull fractures, fractures of the facial bone, thorax or shoulder girdle were also found (Fig. 3).

Table 3 Absolute number of patients with high-traumatic fractures and multiple fractures and percentage of patients with high-traumatic multiple fractures among all high-traumatic fracture patients subdivided into gender and age

	Number of patients with high-traumatic fractures			Number of patients with high-traumatic multiple fractures			Percentage of patients with high-traumatic multiple fractures		
	Male	Female	Total	Male	Female	Total	Male (%)	Female (%)	Total (%)
(0–15)	41,649	24,988	66,637	723	309	1032	1.7	1.2	1.5
(16–30)	47,058	17,444	64,502	2697	638	3335	5.7	3.7	5.2
(31–53)	60,040	28,566	88,606	5474	1286	6760	9.1	4.5	7.6
(54–70)	18,409	17,020	35,429	2126	1061	3187	11.5	6.2	9.0
(> 70)	4819	7399	12,218	638	747	1385	13.2	10.1	11.3
Total	171,975	95,417	267,392	11,658	4041	15,699	6.8	4.2	5.9

Table 4 Absolute number of patients with low-traumatic fractures and multiple fractures and percentage of patients with low-traumatic multiple fractures among all low-traumatic fracture patients subdivided into gender and age

	Number of patients with low-traumatic fractures			Number of patients with low-traumatic multiple fractures			Percentage of patients with low-traumatic multiple fractures		
	Male	Female	Total	Male	Female	Total	Male (%)	Female (%)	Total (%)
(0–15)	11,749	9282	21,031	256	179	435	2.2	1.9	2.1
(16–30)	8993	4940	13,933	314	104	418	3.5	2.1	3.0
(31–53)	17,461	16,241	33,702	898	583	1481	5.1	3.6	4.4
(54–70)	11,979	26,579	38,558	812	1535	2347	6.8	5.8	6.1
(> 70)	12,261	46,594	58,855	831	3832	4663	6.8	8.2	7.9
Total	62,443	103,636	166,079	3111	6233	9344	5.0	6.0	5.6

anatomic region	total number of fractures	total number of multiple fractures	proportion of all fractures	Most associated fracture region	2nd most associated fracture region	3rd most associated fracture region	Top 3 percentage of all associated regions
lumbar/thoracic spine	2097	1180	56.27%	thorax	pelvis	shoulder girdle	57%
cervical spine	698	336	48.14%	thorax	lumbar/thoracic spine	shoulder girdle	49%
femoral shaft	1715	796	46.41%	proximal lower leg/shaft	thorax	pelvis	31%
skull	1100	485	44.09%	facial bone	thorax	shoulder girdle	58%
pelvis	5391	2157	40.01%	thorax	lumbar/thoracic spine	proximal lower leg/shaft	35%
distal femur	978	387	39.57%	proximal lower leg/shaft	patella	thorax	36%
thorax	15611	4694	30.07%	shoulder girdle	pelvis	lumbar/thoracic spine	45%
humeral shaft	1538	409	26.59%	thorax	pelvis	shoulder girdle	31%
patella	2068	482	23.31%	proximal lower leg/shaft	femoral shaft	distal forearm	26%
proximal femur/hip	3900	875	22.44%	pelvis	thorax	distal forearm	35%
shoulder girdle	14036	2978	21.22%	thorax	facial bone	pelvis	54%
hindfoot	10140	1898	18.72%	midfoot	distal lower leg	proximal lower leg/shaft	58%
proximal lower leg/shaft	13653	2544	18.63%	distal lower leg	thorax	pelvis	38%
carpus	7374	1274	17.28%	distal forearm	metacarpus	proximal forearm	55%
proximal forearm	7890	1205	15.27%	distal forearm	carpus	thorax	33%
distal humerus	2570	380	14.79%	proximal forearm	distal forearm	pelvis	36%
facial bone	18116	2146	11.85%	thorax	distal forearm	shoulder girdle	35%
proximal humerus	7847	913	11.64%	thorax	pelvis	proximal lower leg/shaft	32%
midfoot	22585	2100	9.30%	hindfoot	distal lower leg	forefoot	55%
metacarpus	17298	1584	9.16%	finger	distal forearm	carpus	38%
forearm shaft	12612	1122	8.90%	distal forearm	thorax	facial bone	36%
distal forearm	34269	3032	8.85%	carpus	thorax	forearm shaft	31%
distal lower leg	33128	2533	7.65%	proximal lower leg/shaft	hindfoot	midfoot	51%
thumb	12080	512	4.24%	finger	metacarpus	distal forearm	52%
finger	53707	1205	2.24%	metacarpus	thumb	distal forearm	49%
forefoot	39763	794	2.00%	midfoot	distal lower leg	proximal lower leg/shaft	54%

Fig. 3 High-traumatic multiple fractures divided into anatomic regions sorted in descending order by the proportion of multiple fractures among all fractures

In the low-traumatic multiple fracture group, the distal forearm was in absolute numbers by far the most frequently fractured region in absolute numbers. The highest percentage of multiple fractures among all fractures was recorded in the cervical spine, lumbar/thoracic spine, humeral shaft, and distal femur. In more than 24%, a fracture of the cervical spine appeared in combination with other fractures and was not isolated. Most frequently, the cervical spine was in combination with fractures of the thorax, skull, or facial bone (66%). More than 21% of all low-traumatic fractures in the lumbar/thoracic spine occurred as multiple fractures. The thorax, pelvis, and shoulder girdle were the most frequently associated fracture regions for fractures in the lumbar/thoracic spine (73%). A percentage of more than 75% for the three most common associated fracture regions was seen for both the hindfoot and the carpus (Fig. 4).

Dividing the study population into age groups as described above, the spine (cervical spine or lumbar/thoracic spine) showed the highest proportion of multiple fractures among all fractures in the groups of 0–15, 54–70 and > 70 years. In the two groups between 16 and 53 years of age, the femoral shaft was the region that was most often

anatomic region	total number of fractures	total number of multiple fractures	proportion of all fractures	Most associated fracture region	2nd most associated fracture region	3rd most associated fracture region	Top 3 percentage of all associated regions
cervical spine	140	34	24.3%	thorax	facial bone	skull	66%
lumbar/thoracic spine	679	145	21.4%	thorax	pelvis	shoulder girdle	73%
humeral shaft	1998	308	15.4%	proximal humerus	facial bone	distal forearm	63%
distal femur	858	132	15.4%	proximal lower leg/shaft	distal forearm	distal lower leg	45%
hindfoot	3996	596	14.9%	midfoot	distal lower leg	proximal lower leg/shaft	78%
pelvis	6804	1004	14.8%	distal forearm	proximal femur/hip	proximal humerus	54%
skull	925	131	14.2%	facial bone	thorax	shoulder girdle	66%
femoral shaft	886	124	14.0%	proximal femur/hip	distal forearm	proximal humerus	51%
carpus	6897	951	13.8%	distal forearm	proximal forearm	metacarpus	77%
proximal lower leg/shaft	4720	639	13.5%	distal lower leg	hindfoot	distal forearm	64%
facial bone	10056	1188	11.8%	distal forearm	proximal humerus	thorax	50%
proximal forearm	8681	997	11.5%	distal forearm	distal humerus	proximal humerus	41%
shoulder girdle	6037	658	10.9%	thorax	proximal humerus	proximal femur/hip	62%
proximal humerus	16619	1762	10.6%	proximal femur/hip	distal forearm	pelvis	44%
patella	3484	368	10.6%	distal forearm	facial bone	proximal humerus	46%
distal humerus	3617	382	10.6%	proximal forearm	distal forearm	proximal humerus	56%
thorax	14630	1544	10.6%	shoulder girdle	distal forearm	proximal humerus	39%
midfoot	7118	695	9.8%	hindfoot	distal lower leg	distal forearm	66%
thumb	2444	214	8.8%	distal forearm	metacarpus	proximal humerus	47%
metacarpus	9732	746	7.7%	finger	distal forearm	carpus	53%
distal forearm	43740	3241	7.4%	carpus	proximal femur/hip	facial bone	40%
forearm shaft	8205	603	7.3%	distal forearm	proximal forearm	proximal femur/hip	64%
proximal femur/hip	22018	1547	7.0%	distal forearm	proximal humerus	pelvis	60%
distal lower leg	13830	935	6.8%	proximal lower leg/shaft	hindfoot	midfoot	67%
finger	10552	661	6.3%	metacarpus	distal forearm	facial bone	55%
forefoot	4602	238	5.2%	midfoot	distal forearm	distal lower leg	46%

Fig. 4 Low-traumatic multiple fractures divided into anatomic regions sorted in descending order by the proportion of multiple fractures among all fractures

affected in combination with other fracture regions (49.4% and 57.1%, respectively). In 68% of the multiple fractures of the lumbar/thoracic spine in the group older than 54, the thorax, pelvis, and the shoulder girdle were associated (Fig. 5).

Discussion

In the present study, including 25,043 patients across all age groups who had sustained multiple fractures, different peak values were shown to depend on gender, age, and trauma severity. Furthermore, differences were established in the most frequently affected anatomic regions and their associated fracture regions between high- and low-traumatic fractures, as well as between the different age groups.

The literature on multiple fractures is very limited. To date, only one study has solely focused on multiple fractures. Clement et al. described multiple fractures in patients aged 65 years and older. That investigation included 119 patients who had sustained multiple fractures [3]. In the present study, 5.8% of all fracture patients in the observational period had sustained multiple fractures, which are comparable to the previous findings (5.1% and 5.8%, respectively) with less patients included [3, 5]. The mortality rate, which shows the clinical relevance of these fractures, was seen to increase significantly in the previous studies in patients who had sustained multiple fractures. Fracture combinations involving the proximal humerus and the proximal femur showed a 1-year mortality risk of 47.1% [3].

In the present study, age was divided into five groups which in the previous studies had been defined with regard to bone modeling, bone remodeling and skeletal maturation [13]. Based on the broad range of age, and in contrast to other studies, we were able to go into greater detail, particularly with respect to the younger age groups. In absolute terms, the largest number was in the male age group of 31–53 years and in the female age group > 70 years. Court-Brown et al. described a higher number of multiple fractures in female patients in all age groups of > 65 years [8]. In absolute terms, the results shown in this patient cohort are similar. However, this study presented a cross over regarding patients' gender in the age group of 54–70 years. As changes in sex steroids over the lifespan are well known for both genders, they may also be the reason for the cross over in multiple fracture patients in this age group [22, 23]. Not only postmenopausal changes, but also perimenopausal changes seem to have a relevant influence on fracture occurrences. The absolute number of patients per age group shown in this study has to be seen with caution as class widths of groups—based on skeletal maturation—are not equal. Therefore, absolute numbers of multiple fractures recorded in AUVA hospitals in relation with the Austrian population are shown (Fig. 1a). The results of each age group have to be interpreted in relation with the other age groups, as only AUVA data is included. Considering the proportion of multiple fractures among all fractures, there was a continuous increase in the male patients, with a maximum value in the age range of 54–70 and a slight decrease thereafter, whereas a steady increase was identified in the female patients. Our data clearly showed that in the age group of > 70 years, the proportion was significantly higher ($p < 0.001$) than among the younger age groups. The differences may be due to

	anatomic region	total number of fractures	total number of multiple fractures	proportion of all fractures	Most associated fracture region	2nd most associated fracture region	3rd most associated fracture region	Top 3 percentage of all associated regions
0-15	cervical spine	6	2	33.3%	facial bone	shoulder girdle	pelvis	100%
	lumbar/thoracic spine	31	7	22.6%	pelvis	thorax	facial bone	56%
	femoral shaft	330	39	11.8%	proximal lower leg/shaft	shoulder girdle	midfoot	40%
	skull	136	13	9.6%	shoulder girdle	proximal lower leg/shaft	distal lower leg	54%
	hindfoot	631	59	9.4%	distal lower leg	midfoot	proximal lower leg/shaft	77%
16-30	femoral shaft	682	337	49.4%	proximal lower leg/shaft	pelvis	facial bone	33%
	cervical spine	172	79	45.9%	thorax	lumbar/thoracic spine	facial bone	48%
	proximal femur/hip	289	129	44.6%	pelvis	thorax	femoral shaft	36%
	lumbar/thoracic spine	644	270	41.9%	thorax	pelvis	shoulder girdle	49%
	pelvis	1434	526	36.7%	thorax	lumbar/thoracic spine	facial bone	32%
31-53	femoral shaft	569	325	57.1%	proximal lower leg/shaft	thorax	proximal femur/hip	31%
	lumbar/thoracic spine	1375	651	47.3%	thorax	pelvis	shoulder girdle	58%
	distal femur	438	202	46.1%	proximal lower leg/shaft	thorax	patella	37%
	cervical spine	378	174	46.0%	thorax	lumbar/thoracic spine	shoulder girdle	49%
	pelvis	2648	994	37.5%	thorax	lumbar/thoracic spine	distal forearm	36%
54-70	lumbar/thoracic spine	525	273	52.0%	thorax	pelvis	shoulder girdle	68%
	cervical spine	165	74	44.8%	thorax	facial bone	shoulder girdle	53%
	femoral shaft	329	110	33.4%	proximal femur/hip	thorax	proximal lower leg/shaft	36%
	skull	477	154	32.3%	facial bone	thorax	shoulder girdle	66%
	shoulder girdle	2843	869	30.6%	thorax	facial bone	pelvis	61%
>70	lumbar/thoracic spine	201	124	61.7%	thorax	pelvis	shoulder girdle	68%
	cervical spine	117	41	35.0%	thorax	facial bone	shoulder girdle	63%
	shoulder girdle	2280	594	26.1%	thorax	pelvis	proximal femur/hip	61%
	distal humerus	864	208	24.1%	proximal forearm	proximal humerus	proximal femur/hip	43%
	proximal forearm	1928	453	23.5%	proximal humerus	proximal femur/hip	distal forearm	44%

Fig. 5 Study population divided into age groups sorted in descending order by the proportion of multiple fractures among all fractures for each age group

the increasing number of osteoporotic fractures in elderly patients [2] as well as the higher number of high-energy trauma in male adults [24].

Because of differences in trauma mechanisms and severity of trauma in the different age groups, it is indispensable to divide the patient population as to high- and low-traumatic multiple fractures to produce meaningful results. To date, no study has taken this essential distribution into account for the different age groups. Due to unclear information concerning exact trauma mechanism especially in unconscious patients and the higher clinical applicability in emergency rooms and accident departments, distribution of patients was not performed more precisely. Regarding low-traumatic fractures, female patients had a significantly higher proportion of multiple fractures among all fractures than male patients, and vice versa in high-traumatic fractures ($p<0.001$). The highest proportion of multiple fractures among all fractures was seen in > 70-year-old male patients in the high-traumatic group, reflecting the importance of multiple fractures in advanced age for both gender groups. A percentage of 13.2% is nearly three times as high as the average value of all age groups.

To date, no study has investigated frequently affected anatomic regions in multiple fracture patients divided into different age groups and as to trauma severity. Some case reports and studies including less patients have focused on one or two fracture regions, yet no systematic overview has described the probabilities and associated fracture regions for both high- and low-traumatic events [25–29]. Fracture diagnostics is a major problem in orthopedics. Especially, due to poor communication conditions in unresponsive patients as well as in infants, fracture search may prove challenging both in life-threatening trauma cases in the emergency room and in not life-threatening cases in the accident departments. As an approximately 30% error rate has been documented in radiographic interpretation, isolated or multiple fractures also seem to be overlooked occasionally [30, 31]. A probability statement of involved anatomic regions and information about the probability of further fractures and associated fracture regions would have potential to reduce the number of missed fractures. This study provides clear data regarding affected anatomic regions and the probability of existing further fractures. Consequently, more accurate fracture diagnosis will be possible, both in treating multiply injured patients in emergency departments and not life-threatening cases in accident departments. These data additionally suggest strategies for planning further radiological examinations (e.g., additional computed tomography scans) in patients at a high risk of multiple fractures. Detecting one fracture, a probability statement regarding the presence of further fractures and information concerning the most associated anatomic regions provides support and new possibilities in diagnosing fractures and serves to reduce the high error rate described in the literature. As a further novelty, the present study provides a list of fracture regions divided into trauma severity (high- and low-traumatic) as well as into five age groups. The data underlying this investigation facilitate improved estimations of fracture probability as well as involved regions. At the same time, they serve as a basis for both clinical applications and further scientific studies, going even into more detail in terms of separate "fracture partners".

Strengths and limitations

The strength of this study is its high consecutive number of patients in comparison with other studies. No study has so far recruited nearly as many patients in investigating multiple fractures [3, 8]. Furthermore, the distinction between high- and low-traumatic fractures as well as different age groups enables veracious calculation and data interpretation.

A limitation of this study is that not all national trauma centers were included, as trauma severity classifications are missing in several hospitals. However, the previous studies have confirmed the representative validity of these trauma centers [12, 13, 32]. Another limitation is the lack of comorbidity and mortality data.

Conclusion

This study provides, as a novelty, different peak values depending on gender and age as well as on trauma severity in a high number of multiple fracture patients. Considering these data, more or less intensive diagnostic strategies according to probability and risk statements for each age and gender group should be performed. Probability calculations of the presence of further fractures for any anatomic region—for both high- and low-traumatic events, as well as different age groups in combination with the most associated fracture regions for every fracture—yield new opportunities for clinical work. Hence, the error rates in fracture diagnostics in emergency and accident departments could be reduced in the future.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no competing interests.

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