ORIGINAL ARTICLE

Radiological classification of retroperitoneal hematoma resulting from lumbar vertebral fracture

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Abstract

Purpose Lumbar vertebral fracture (LVF) infrequently produces massive retroperitoneal hematoma (RPH). This study aimed to systematically review the clinical and radiographic characteristics of RPH resulting from LVF.

Methods For 193 consecutive patients having LVF who underwent computed tomography (CT), demographic data, physiological conditions, and outcomes were reviewed from their medical records. Presence or absence of RPH, other bone fractures, or organ/vessel injury was evaluated in their CT images, and LVF or RPH, if present, was classified according to either the Orthopaedic Trauma Association classification or the concept of interfascial planes.

Results RPH resulting only or dominantly from LVF was found in 66 (34.2%) patients, whereas among the others, 64 (33.2%) had no RPH, 38 (19.7%) had RPH from other injuries, and 25 (13.0%) had RPH partly attributable to LVF. The 66 RPHs resulting only or dominantly from LVF were radiologically classified into mild subtype of minor median ($n=35$), moderate subtype of lateral ($n=11$), and severe subtypes of central pushing-up ($n=13$) and combined ($n=7$). Of the 20 patients with severe subtypes, 18 (90.0%) were in hemorrhagic shock on admission, and 6 (30.0%) were clinically diagnosed as dying due to uncontrollable RPH resulting from vertebral body fractures despite no anticoagulant medication.

Conclusions LVF can directly produce massive RPH leading to hemorrhagic death. A major survey of such pathology should be conducted to establish appropriate diagnosis and treatment.

Keywords Retroperitoneal hematoma · Lumbar vertebral fracture · Interfascial planes · Blunt trauma

Introduction

Traumatic retroperitoneal hematoma (RPH) remains a mystery [1–5]. Massive traumatic RPHs sometimes can be treated conservatively, whereas smaller RPHs sometimes

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lead to hemorrhagic death [4]. Therefore, Kudsk and Sheldon [1] introduced a treatment principle founded on a location-based classification of traumatic RPH, and Feliciano [6] revised the classification by focusing on vessel injuries. However, we must remember that the scientific treatment of RPH has not yet been established [4, 5], because even the structure of the retroperitoneum is still not completely clarified [5, 7].

Generally, RPH following blunt trauma is believed to arise from pelvic fracture, retroperitoneal organ injury, or major vascular injury [1–6], whereas lumbar fracture has been considered as an infrequent cause [4, 5, 8–10]. This is mainly because lumbar fracture is commonly evaluated in terms of the degree of neurological deficit or structural instability [11, 12] and secondly because lumbar fracture is often a partial injury of multiple traumas: rather than the lumbar fracture itself, other concomitant injuries are considered as the causes of RPH [13, 14]. Exceptionally, only lumbar arterial injury associated with transverse process fracture (TPF)

is considered a direct cause of potential life-threatening RPH associated with lumbar fracture requiring transcatheter arterial embolization (TAE) [4, 9, 10].

However, it is important to remember that lumbar vertebral body fracture (VBF) can also be a source of massive traumatic RPH [4, 5, 8]. It was not until we experienced such RPHs that we noticed that the incidence, characteristics, and severity of RPH due to lumbar fracture had not been systemically reviewed, and a treatment strategy for such RPHs had never been discussed. Fortunately, the concept of retroperitoneal interfascial planes, which is now the prevalent theory for understanding retroperitoneal pathologies among radiologists [15–19], has enabled the evaluation of RPH systematically [4, 5]. Further, lumbar fracture can be evaluated in detail with multidetector-row computed tomography (CT) images [20–22].

Therefore, we aimed to systematically investigate the features of RPH resulting from lumbar fracture by analyzing CT images.

Patients and methods

Patients

We conducted a retrospective study of 947 consecutive patients with suspected blunt abdominal or pelvic trauma who underwent abdominal CT on admission to Senshu Trauma and Critical Care Center, a level I trauma center in Japan, between July 2007 and December 2014 [Electronic supplementary material (ESM)_1]. We reviewed medical records to evaluate demographic information, physiological conditions, Injury Severity Score (ISS) [23], laboratory data, medication review, outcomes of the 947 patients, and causes of death in the deceased patients.

Image acquisition

CT was conducted when the patients were hemodynamically stable on admission or when they achieved, at least temporarily, hemodynamic stability after fluid resuscitation. The CT protocol for blunt abdominal injury involves scanning from the diaphragm to the pelvis following administration of intravenous contrast medium, which was not administered to the patients with renal dysfunction. The scanning was performed with a 64-detector helical scanner (Aquilion; Toshiba Medical Systems, Tokyo, Japan). Axial images of 5-mm thickness were obtained at 5-mm intervals. Multiplanar reconstruction and three-dimensional CT images were created to evaluate lumbar fractures exactly. Contrast medium-enhanced CT (CE-CT) images and angiograms, if available, were concisely evaluated to detect sources of

bleeding. Magnetic resonance imaging (MRI) was not performed in this study.

Assessment of retroperitoneal hematoma

We checked for the presence of RPH, of organ or vessel injuries, and of bone fractures on the CT images. RPH was diagnosed when high-attenuation (> 40 Hounsfield units) lesions in the retroperitoneal tissue were identified on two or more consecutive axial CT images [4]. Intramuscular hematoma or retrocrural hematoma [24] was not considered as an RPH (ESM_2). If RPH was present, it was classified into one of five types according to our classification for traumatic RPH [4, 5] (ESM_3), with which the starting area of the RPH can be traced back based on the concept of interfascial planes: Type 0, having no RPH; Type I, spreading from the anterior pararenal space or the retromesenteric plane; Type II, spreading from the perirenal or posterior pararenal space, the lateroconal plane, or the lateral part of the retrorenal plane; Type III, spreading from the pelvic retroperitoneum; and Type IV, spreading from the combined interfascial plane or the medial or median part of the retrorenal plane. An RPH spreading from multiple areas, which can be classified into the different types, was considered as a complex type. For example, such RPHs are designated as Type II + III or Type III + II + IV. An RPH of the complex type was divided into each segment derived from the different culprit areas [5] indicated by the Roman numerals, and the total volume or that of each segment of the RPH was calculated with a dedicated computer program in the CT scanner. If an RPH of the complex type cannot be clearly divided into different areas, the hematoma in the unclear area was distributed pro rata the amount of the clearly divided area. The sequence of Roman numerals is decided in order of the estimated amount of the RPH starting from the area shown by the Roman numeral. RPHs of the complex and simple type were integrated into "Large Type" plus the initial Roman numeral, e.g., Large Type II. The Large Type IV RPH was compared with the Large Type II or Large Type III RPH, if necessary.

In evaluating CE-CT images and angiograms, not only clear extravasation of the contrast medium but also faint staining near the fracture site by the medium [9] was concisely checked.

Assessment of lumbar fracture

In this study, lumbar fracture was defined as VBF and/or TPF with or without spinous process fracture (SPF), whereas a SPF alone, which cannot directly produce RPH, or a fifth TPF alone complicated with pelvic fracture, which is considered as a part of pelvic fracture [25], was excluded. Further, the patients with lumbar fracture were classified into the VBF group (VBF with/without TPF or SPF) and the TPF

group (TPF without VBF). Each VBF was classified according to the Orthopaedic Trauma Association (OTA) classification [20, 22], which is the most popular system among orthopedic surgeons. Many patients had multiple VBFs, so the severity of the VBFs was graded based on the most serious fracture according to the OTA classification.

Statistical analysis

Most values are expressed as a number, percentage, or mean ± standard deviation unless otherwise indicated. A few data were compared by using the Student's t test or the Chi-square test. A p value less than 0.05 was considered statistically significant.

Results

Characteristics of all patients

Of the 947 patients (Table 1), 266 (28.1%) were in a shock state on admission and 56 (5.9%) died. According to the medical records, the causes of death were brain injury ($n = 21$), RPH ($n = 18$), sepsis ($n = 7$), intra-abdominal hemorrhage ($n = 6$), and chest injury ($n = 4$). CT images revealed RPH in 377 patients (39.8%), lumbar fracture in 193 (20.4%), pelvic fracture in 262 (27.7%), renal and/or adrenal injury in 92 (9.7%), and great vessel injuries in 5 (0.5%) [intimal injury or dissection of the aorta ($n = 4$) and pin-hole injury of the inferior vena cava (IVC) ($n = 1$)]. Many patients had multiple injuries that can produce RPH. For example, 78 (40.4%) of the 193 patients with lumbar fracture sustained concomitant pelvic fractures.

Characteristics of patients with lumbar fracture

In the 193 patients with lumbar fracture, comprising 130 men and 63 women with a mean age of 43.6 ± 19.1 years (ESM_4), 138 VBFs and 421 TPFs were identified (ESM_5). Diffuse idiopathic skeletal hyperostosis (DISH) [26] was identified in eight patients, but neither pathological fracture nor ankylosing spondylitis was identified. The mechanisms of injury were fall [$n = 97$ (50.3%): free fall 90, tumble 7]; traffic accident [$n = 77$ (39.9%): motor vehicle 34, motorcycle 19, pedestrian 12, bicycle 9, et al.]; and others [$n = 19$ (9.8%)]. In the VBF group, 101 patients had 96 Type A fractures, 29 Type B fractures, and 13 Type C fractures in total and were graded into Type A in 61, Type B in 27, and Type C in 13 (ESM_6). In patients with Type B fractures, including Chance fracture [27], intra-abdominal injury was a

Table 1 Demographic data of all patients and those with specific injuries

	Overall	LVF	Pelvic fracture	Renal/adrenal injury
Number of patients	947	193	262	92
Age (years)	41.6 ± 21.3	43.6 ± 19.1	45.9 ± 21.4	38.1 ± 21.0
Male/female	645/302	130/63	155/107	65/27
ISS	18.6 ± 12.6	22.8 ± 12.8	22.9 ± 12.9	24.1 ± 13.1
RPH: n (%)	377 (39.8%)	129 (66.8%)	244 (93.1%)	88 (95.7%)
Mechanism of injury				
Traffic accident	612	77	152	60
Fall	261	97	89	28
Compression	42	14	21	3
Assault	12	0	0	1
Others	20	5	0	0
Concomitant injury				
Abdominal	367	49	72	85
Thoracic	355	86	100	30
Head	311	58	76	31
Pelvic	262	78	–	21
Extremities	452	112	160	38
Shock	266 (28.1%)	78 (40.4%)	130 (49.6%)	42 (45.7%)
Mortality	56 (5.9%)	18 (9.3%)	25 (9.5%)	8 (8.7%)
Death from RPH	18 (1.9%)	9 (4.7%)	12 (4.6%)	2 (2.2%)

Values show the number of patients. Values in parenthesis show the percentage of patients. There are many overlaps among the patients with LVF, with pelvic fracture, and with renal/adrenal injuries. Therefore, the total number of deaths from RPH is smaller than the sum of that in LVF, that in pelvic fracture, and that in renal/adrenal injury

LVF lumbar vertebral fracture, *ISS* Injury Severity Score, *RPH* retroperitoneal hematoma

complication in three cases but neither retroperitoneal organ nor great vessel injury was identified.

Identification of RPH resulting from the lumbar fracture

As shown in Table 2, the 947 patients were classified based on the type of RPH according to our classification (ESM_3): Type 0, 570 (60.2%); Large Type I, 20 (2.1%); Large Type II, 77 (8.1%); Large Type III, 212 (22.4%); and Large Type IV, 68 (7.2%).

Of the 193 patients with lumbar fracture, 64 (33.2%) had no RPH: 19 (9.8%) had neither RPH nor hematoma around the fracture but 45 (23.3%) had paravertebral hematoma, psoas hematoma, or retrocrural hematoma [24] around the fracture (ESM_2). Thirty-eight (19.7%) patients had RPH not derived from the lumbar fracture. In 25 (13.0%) patients, the lumbar fracture contributed less to the formation of RPH than did other injuries [<50% (2–33%, 12 ± 8%; 2–90 mL)]. Of the remaining 66 patients (34.2%), the lumbar fracture contributed dominantly to the RPH formation in 18 [≥ 50% (57–96%, 77 ± 11%)], or entirely in 48. The mean volume of RPH attributable to the lumbar fracture was 163 ± 256 mL (2–1182 mL) (ESM_7). In the above cases, all RPHs involved in the visceral injuries or an aortic intimal injury without RPH were identified only in patients of the TPF group. In one patient, not an L1 fracture of Type A1 but ovarian arterial and minor IVC injuries contributed to the formation of Type I + IV + II RPH. Conversely, in two patients without lumbar fracture, diaphragmatic hematoma produced a Type IV RPH. In contrast, pelvic fracture or renal/adrenal injury without RPH was significantly rarer,

Table 2 Classification of all patients and specific patients based on the type of retroperitoneal hematoma

RPH Detailed type	Total Shock/death	Lumbar fracture Shock/death	(VBF group) Shock/death	(TPF group) Shock/death	Pelvic fracture Shock/death	Renal/ adrenal injury Shock/ death
Type 0	570	64	27	37	18	4
	87/21 (0)	12/3 (0)	5/0	7/3 (0)	4/2 (0)	1/0
Large Type I	20	3	1	2	0	1
	10/2 (1)	3/1 (1)	1/0	2/1 (1)	0/0	1/0
Type I	17	1	0	1	0	0
Type I + II	1	0	0	0	0	1
Type I + IV	1[a]	1[a]	0	1[a]	0	0
Type I + IV + II	1	1	1	0	0	0
Large Type II	77	10	0	10	12	73
	30/5 (1)	4/1 (0)	0/0	4/1 (0)	8/2 (1)	29/5 (1)
Type II	72	6	0	8	7	68
Type II + III	5	4	0	2	5	5
Large Type III	212	50	17	33	212	9
	105/20 (10)	27/5 (2)	11/1 (0)	16/4 (2)	105/20 (10)	7/3 (1)
Type III	181	23	5	18	181	2
Type III + II	7	3	0	3	7	3
Type III + II + IV	3	3	0	3	3	3
Type III + IV	21	21	12	9	21	1
Large Type IV	68	66	56	10	20	5
	34/8 (6)	32/8 (6)	25/8 (6)	7/0	13/1 (1)	4/0
Type IV	50	48	45	3	3	4
Type IV + II	1	1	0	1	0	1
Type IV + III	17	17	11	6	17	0
Total	947	193	101	92	262	92
	266/56 (18)	78/18 (9)	42/9 (6)	36/9 (3)	130/25 (12)	42/8 (2)

Values show no. of patients. Values in parenthesis show numbers of patients dying from uncontrollable RPH

RPH retroperitoneal hematoma, *VBF* vertebral body fracture, *TPF* transverse process fracture, *VBF group* patients with VBF with/without TPF, *TPF group* patients with TPF only without VBF

[a] This patient died from RPH and intraperitoneal bleeding due to severe mesenteric arterial injuries

in 6.9 and 4.3% of patients, respectively, than lumbar fracture without RPH. Moreover, pelvic fracture or renal/adrenal injury contributed to the formation of Large Type III or Large Type II RPH at significantly higher rates of 80.9 and 79.3%, respectively, than the lumbar fracture produced Large Type IV RPH.

Radiological classification of RPH resulting from lumbar fracture

The 66 Large Type IV RPHs resulting from lumbar fracture were classified radiologically into 4 subtypes (Table 3). In 35, the RPH was small (mean volume: 19 mL) and was localized ventral to the VBF, within the median part of the retrorenal plane (minor median subtype, Fig. 1). In 11, the RPH (mean volume: 391 mL) arose from the medial part of the retrorenal plane near the TPF and often extended into the other planes (lateral subtype, Fig. 2). In 13, the median RPH (mean volume: 241 mL) clearly displaced both the aorta and IVC ventrally and extended beyond the median retrorenal plane: into the medial ($n = 13$) and lateral ($n = 4$) parts of the retrorenal plane and into the

retromesenteric plane ($n = 11$) (central pushing-up subtype, Fig. 3). In 7, massive RPH (mean volume: 386 mL) had characteristics of both the lateral and central pushing-up subtypes (combined subtype, Figs. 4, 5). For reference, among the 25 patients with RPH partly attributed to lumbar fracture, the RPH was the minor median subtype in 13 and the lateral subtype in 12.

Table 4 lists the presence and distribution of extravasation and staining of the contrast medium depicted in CE-CT or angiograms. The clear extravasation around VBF was identified in only half of the patients with the central pushing-up or combined subtype on CE-CT, whereas it was depicted around the TPF (Fig. 2b) in all patients with the lateral subtype. However, we must note that clear extravasation from within the VBF was identified in two patients with Type C fracture and in one with DISH (Fig. 5a, b). In the remaining patients with such RPH, faint staining, instead of clear extravasation, was often depicted (Figs. 3a, 4a). Aortography also showed staining of the contrast medium overlapping with the vertebral shadow in 10 of 11 patients with a central pushing-up or combined RPH (Figs. 3d, 4c, 5d). Selective arteriography suggested that the staining was attributed to

Table 3 Classification of large Type IV retroperitoneal hematoma resulting from lumbar fracture

	Minor median	Lateral	Central pushing-up	Combined	Total
Number	35	11	13	7	66
Age	38.4 ± 14.3	32.4 ± 17.5	41.8 ± 22.2	46.1 ± 25.6	38.9 ± 17.9
Male/female	24/11	9/2	7/6	4/3	44/22
ISS	17.0 ± 8.9	30.0 ± 14.8	26.0 ± 8.1	30.1 ± 14.9	22.5 ± 12.0
Shock	17.1%	72.7%	84.6%	100%	48.5%
Mortality	2.9% (0%)	0% (0%)	30.8% (23.1%)	42.9% (42.9%)	12.1% (9.1%)
Volume (ml)	19 ± 17	391 ± 404	241 ± 221	386 ± 208	163 ± 256
Mechanism of injury					
Traffic accident	8	7	1	4	20
Fall	24	3	12	2	41
Others	3	1	0	1	5
Patients with TPF					
VBF group:TPF group	16:0	1:10	11 (2):0	4 (3):0	32 (5): 10
Grade of VBF					
A1:A2:A3	4:2:14	0:1:0	0:0:4 (2)	0:0:1 (1)	4:3:19 (3)
B1:B2:B3	8:6:0	0:0:0	1 (1):1:0	1 (1):1 (1):0	10 (2):8 (1):0
C1:C2:C3	0:1:0	0:0:0	3:4:0	2:1:1	5:6:1
Concomitant pelvic fracture[a]					
None:Type A:Type B: Type C	29:4:2:0	5:2:3:1[b]	8:5 (3):0:0	4 (2):0:3 (1):0	46 (2):11 (3):8 (1):1[b]
IIA injury: Pelvic TAE	1:0	4:4	2:1	2 (1):0	9 (1):5

Values in parenthesis show the number or percentage of patients dying from uncontrollable retroperitoneal hematoma (RPH)

ISS Injury Severity Score, *TPF* transverse process fracture, *VBF* vertebral body fracture, *VBF group* patients with VBF with/without TPF, *TPF group* patients with TPF only without VBF, *IIA* internal iliac artery and the branches, *Pelvic TAE* transcatheter arterial embolization of the internal iliac artery

[a]Pelvic fracture was also classified according to the Orthopedic Trauma Association classification [22]

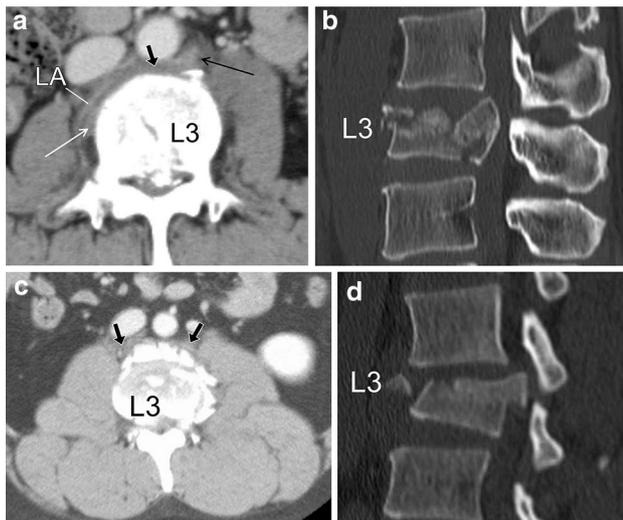[b]This patient belonged to the TPF group

Fig. 1 Minor median subtype. **a, b** A 47-year-old man fell from 5 m. CT images show a thin retroperitoneal hematoma (Type IV, thick black arrow) with contrast medium stain (thin black arrow) ventral to the fractured spine and paravertebral hematoma (white arrow). Note the lumbar artery (LA) running around the fractured L3 of type A3. **c, d** A 30-year-old man fell from 6 m. CT images show a thin retroperitoneal hematoma (Type IV, black arrows) ventral to the L3 vertebral fracture of type B1. They were treated conservatively
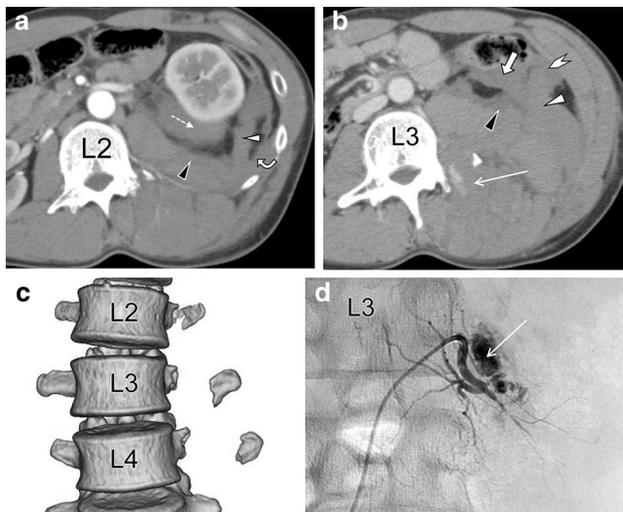
Fig. 2 Lateral subtype. A 38-year-old male motorcycle rider collided with an automobile. **a** CT image shows retroperitoneal hematoma (RPH) (Type IV + II) spreading in the medial (black triangle) and lateral (white triangle) parts of the retrorenal plane and the subfascial plane [4, 5, 7, 19] (curved arrow) and in the perirenal space (white dotted arrow) from renal injury. **b** Extravasation of contrast medium (thin white arrow) near the transverse process fracture (TPF) was identified. RPH spread from the retrorenal plane (black and white triangles) into the lateroconal (arrowhead) and retromesenteric (thick white arrow) planes. **c** Three-dimensional CT shows only the left three TPFs. **d** Extravasation of contrast medium from the distal part of the left third lumbar artery (thin white arrow) is identified. After transcatheter arterial embolization, he recovered from shock
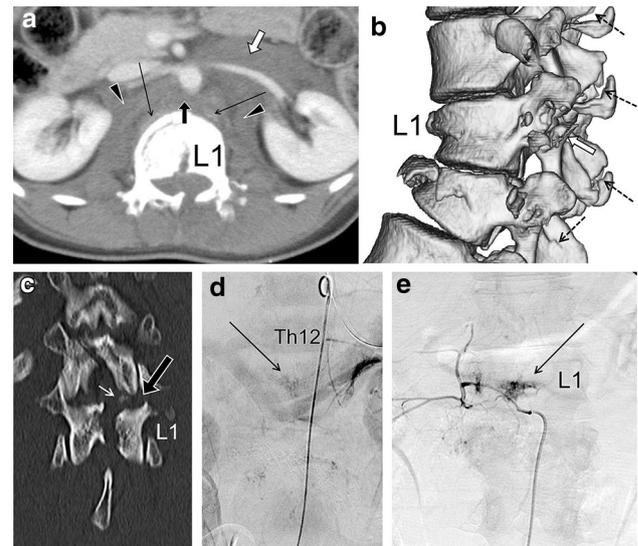

Fig. 3 Central pushing-up subtype. A 20-year-old woman fell from 40 m. **a** CT image shows retroperitoneal hematoma (Type IV), which is mainly located in the median (thick black arrow) and medial (black triangles) parts of the retrorenal plane, displacing both the aorta and inferior vena cava ventrally, and extending to the retromesenteric plane (thick white arrow). Note the faint stains of contrast medium (thin black arrows). **b** Three-dimensional CT revealed an L1 fracture of Type C2.1.3 with spinous process fractures (black dashed arrows), articular process fracture (thick white arrow), and L2 fracture of Type B1. **c** Coronal CT reconstruction image reveals the left unilateral dislocation of the Th12/L1 facet joint (thick black arrow) and a bone fragment near the joint (white arrow). **d** Aortogram shows staining of contrast medium overlapping with the fractured L1 vertebra (black arrow). **e** An arteriogram of the first right lumbar artery shows extravasations of contrast medium overlapping with the vertebral shadow (black arrow). After transcatheter arterial embolization of the bilateral first and second lumbar arteries, she recovered from shock

the extravasation of contrast medium from the proximal part of the lumbar arteries. (Figs. 3e, 4d).

Clinical features of RPH resulting from lumbar fracture

As shown in Table 3, of these 66 patients, 32 (48.5%) were in a shock state on admission, and 6 (9.1%) died from uncontrollable RPH. The rates of shock and mortality due to the RPH were comparable to those (49.5 and 4.7%, respectively) due to the Large Type III RPHs resulting from pelvic fracture (Table 2).

Fall from height was the major cause of injuries in both the minor median (68.6%) and central pushing-up (92.3%) subtypes, whereas traffic accident was the major cause in the lateral (63.6%) and combined (57.1%) subtypes. Fifty-six patients sustained VBF graded as Type A ($n = 26$), Type B ($n = 18$), and Type C ($n = 12$). DISH (Fig. 5c) was identified in four patients (each two with central pushing-up and combined RPHs with a Type A3- or Type B1-graded fracture).
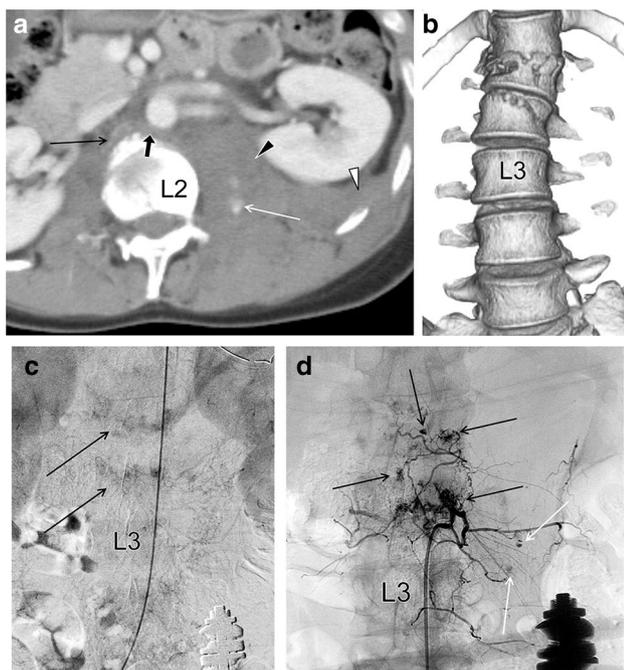
Fig. 4 Combined subtype. A 23-year-old female front-seat passenger was involved in a motor vehicle collision and sustained a concomitant pelvic fracture. **a** CT image shows retroperitoneal hematoma (Type IV+III), spreading in the median (thick black arrow), medial (black triangle), and lateral (white triangle) parts of the retrorenal plane displacing both the aorta and inferior vena cava ventrally. Faint stain or extravasation of contrast medium (thin black arrow) was identified ventral to the fractured spine and near the transverse process fracture (TPF) (white arrow). **b** Three-dimensional CT shows L1 fracture of Type C1 and L2 fracture of Type B2 and bilateral multiple TPFs. **c** Aortogram shows staining of contrast medium overlapping with the L1 and L2 shadows (black arrows). **d** The left second lumbar arteriogram shows extravasations of contrast medium overlapping with the L1 and L2 shadows (black arrows) and those from the distal lumbar arteries (white arrows). After transcatheter arterial embolization into six lumbar arteries, she recovered from shock
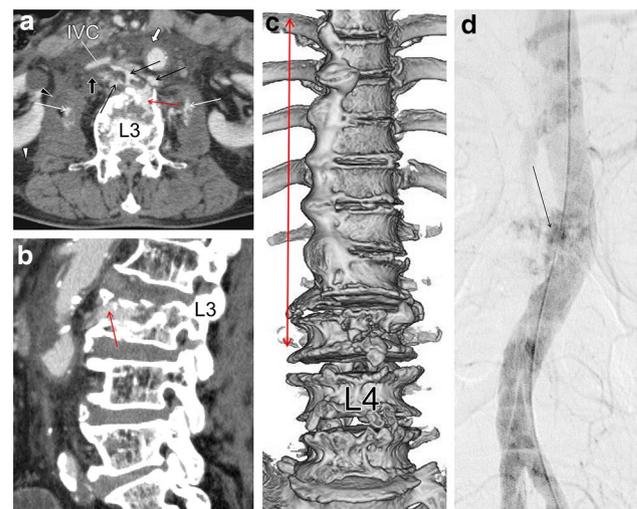
Fig. 5 Combined subtype in a patient with diffuse idiopathic skeletal hyperostosis. An automobile ran over the back of a 77-year-old man. **a** CT image shows a retroperitoneal hematoma (RPH) (Type IV) spreading in the median (thick black arrow), medial (black triangle), and lateral (white triangle) parts of the retrorenal plane displacing both the aorta and inferior vena cava (IVC) ventrally and in the retromesenteric plane (thick white arrow). Extravasations of contrast medium are identified in the RPH (thin black arrows) and in the psoas muscles (thin white arrows). The contrast medium in the RPH has extravasated from within the fractured vertebral body through the injured bone cortex (thin red arrow). **b** Sagittal CT reconstruction image also shows contrast medium extravasated (thin red arrow) from within the fractured L3 vertebral body of Type A3. **c** 3D-CT shows 5 or more vertebral bodies with continuous ossification of the anterior longitudinal ligaments (red double-headed arrow) and bilateral multiple transverse process fractures. **d** Aortogram shows staining of contrast medium overlapping with the fractured L3 shadow (black arrow). Failure to selectively catheterize the lumbar artery led to his death

Treatment for RPH resulting from lumbar fracture and prognosis

Of the 12 patients graded as Type C, 11 had a central pushing-up or combined RPH, whereas another patient with a Type C2 fracture of L1 had retrocrural hematoma and minor median RPH. One other patient in this study with an L1 fracture of Type C1 had only retrocrural hematoma (ESM_6A). The 66 patients with Large Type IV RPH received neither an anticoagulant nor hemodialysis, whereas 7 of the other 127 patients received an anticoagulant. There was no significant difference in the value of %prothrombin time on admission between the 66 and 127 patients (80.3 ± 21.3 vs $84.0 \pm 20.7\%$).

The RPHs in 44 patients (of whom 8 were in a shock state) were treated conservatively (Table 5). Of them, only one

with liver cirrhosis died from concomitant brain injury. TAE was first performed in 14 patients, and it achieved hemostasis without complications in all patients. In five patients, TAE was planned but was not achieved. Of them, one did not undergo the procedure because of his family's refusal and concomitant severe head injury (central pushing-up, Type A3) and another died from RPH during preparation for angiography (combined, Type B2). In the three other patients, selective cannulation of the lumbar arteries was not achieved: one (lateral, TPF group) survived following surgical hemostasis but two died with (combined, Type B1) or without successive laparotomy (Fig. 5). Surgical hemostasis with retroperitoneal exploration [3, 6] was selected for three patients (all central pushing-up, 2 of Type A3 and one of Type B1 with DISH), one of whom was followed by TAE, but the procedure failed in arresting the retroperitoneal bleeding.

A massive transfusion protocol [28] was applied in four patients (Table 5). Neither pelvic packing nor resuscitative

Table 4 Extravasation or faint staining of contrast medium around the vertebra in CE-CT or angiogram

Radiological finding	Minor median	Lateral	Central pushing-up	Combined
CE-CT/all patients	24/35	10[a]/11	13/13	7/7
Around VBF only	4	0	8	0
(Clear extravasation)	0	0	6 (46.2%)	0
[Bleeding from within VBF]	0	0	[1]	0
(Faint staining around VBF)	4 (16.7%)	0	2 (15.4%)	0
Around TPF only[b]	0	10 (100%)	0	0
Around both VBF and TPF[b]	0	0	3	6
(Clear extravasation)	0	0	0	3 (42.9%)
[Bleeding from within VBF]	0	0	0	[2]
(Faint staining around VBF)	0	0	3 (23.1%)	3 (42.9%)
Aortogram	0	8	7	4
Staining overlapping VBF	0	0 (0%)	6 (85.7%)	4 (100%)
Selective lumbar arteriogram	0	7	6	3
Extravasation around VBF only	0	0	4 (66.7%)	0
Extravasation around TPF only	0	6 (85.7%)	0	0
Extravasation from both sites	0	0	2 (33.3%)	3 (100%)

Values show the number of cases, values in parenthesis show the percentage of the patients who underwent the examination shown above. Values in square brackets show the number of the patients whose CT images showed bleeding from within the fractured vertebral body

CE-CT contrast medium-enhanced computed tomography, *TPF* transverse process fracture, *VBF* vertebral body fracture

[a]One patient underwent angiography and transcatheter arterial embolization before CT scanning

[b]Extravasations of contrast medium into only the erector muscles of the spine or subcutaneous muscle were also included

endovascular balloon occlusion of the aorta [29] was applied in any of the 66 patients. Emergent spinal decompression was performed in four patients whose neurological defect rapidly worsened (three minor median subtypes, Types A3, B1, and C2, and one central pushing-up subtype, Type C1), whereas others were temporarily stabilized with a vacuum fixing bed (VACUFORM: Schmidt, Garbsen, Germany).

Discussion

It has been known since the 1930s that lumbar fractures can produce RPH [8]. However, it is often difficult to distinguish among the RPH resulting from only the lumbar fracture, that resulting from visceral, vessel, or other bone injuries, and that resulting from both the lumbar fracture and the other injuries because lumbar fracture is often a partial injury of multiple traumas that can produce RPH [4, 5, 12–14, 30, 31]. To conquer this complexity, we improved our classification of traumatic RPH [4, 5] by focusing on RPHs derived from multiple injuries. Therefore, this is the first study, to our knowledge, to provide a systematic review of the RPHs resulting from lumbar fracture and their characterization. RPH only or dominantly resulting from lumbar fracture was identified in only 34.2% of the patients with lumbar fracture. Particularly, considerable attention must be paid to RPHs

of the central pushing-up or combined subtype because they often induced shock and sometimes (in 23.1 or 42.9%, respectively) led to hemorrhagic death, comparable to a severe pelvic fracture. In contrast, we may deal with RPHs of both the minor median subtype, which may be considered as a prevertebral hematoma, and the lateral subtype, which can be successfully treated by TAE, as previously reported [9, 10].

We believe that the characteristics of this study group, with its typical distribution of age and typical level and type of lumbar fracture [11, 12, 20], are universal but have been long overlooked. The reason for this oversight is assumed to be the much lower rate of RPHs produced compared to pelvic fracture or renal/suprarenal injury, and to be misunderstood as RPH derived from pelvic fracture or unknown origin. It is noteworthy that the representative paper on RPH from lumbar arterial injuries [9] covered a patient group similar to ours: of the 12 patients reported, 10 fell from height and 10 VBFs and 22 TPFs were identified. The authors noted that the lumbar arterial injuries were associated with pelvic fracture although one patient sustained no pelvic fracture and only 7 had concomitant hypogastric arterial injuries. In their study, hemostasis was achieved by TAE in all patients who underwent it. We suspect that their patients' RPHs, probably consisting of Types III + IV, IV + III, and IV, were partly the central pushing-up or combined subtype, because

Table 5 First treatment for retroperitoneal hematoma resulting from lumbar fracture and prognosis

Treatment	Minor median	Lateral	Central pushing-up	Combined
Conservative	35	4	4	1
Mortality	1 (0)	0	0	0
Fracture type in the above	B1	–	–	–
TAE	0	6	5	3
Mortality	0	0	0	0
Unachieved or failed TAE				
Refusal or unachieved	0	0	1	1
Failed	0	1[b]	0	2[b]
Mortality	0	0	1 (0)	3 (3)
Fracture type in the above	–	–	A3	A3[a], B1[b], B2
Retroperitoneal exploration	0	0	3[bb]	0
Mortality	0	0	3 (3)	0
Fracture type in the above	–	–	A3[b], A3, B1[b]	–
Transfusion				
RCC [units]	3 [2.7 ± 1.8]	5 [15.1 ± 7.1]	10 [9.2 ± 11.0]	6 [7.5 ± 4.0]
FFP [units]	3 [2.7 ± 1.8]	5 [10.0 ± 5.0]	8 [9.3 ± 7.9]	3 [8.9 ± 5.8]
PC [units]	0	4 [14.0 ± 8.2]	5 [9.6 ± 5.5]	1 [14.5]

Values show the number of cases, values in parenthesis show the number of patients dying from uncontrollable retroperitoneal hematoma. Values in square brackets show the mean ± standard deviation of the administered blood product among the patients who were transfused. The amounts of the blood products were converted to units used in the United States

TAE transcatheter arterial embolization, *RCC* red cells concentrates, *FFP* fresh frozen plasma, *PC* platelet concentrates

[a]This patient had diffuse idiopathic skeletal hyperostosis (Fig. 5)

[b]Massive transfusion protocol was applied in the patient. The number of superscript b marks indicates the number of applied patients

"staining" of contrast medium overlapping with the vertebral shadow in the aortogram [9] was described as shown in the present study. This radiological finding has not been fully discussed since their study was published, but we take the finding seriously as a sign indicating hemorrhage from a VBF. Additionally, we found similar staining of contrast medium ventral to the fractured vertebra and captured bleeding from within the fractured vertebra on CT images. Such extravasation would be derived from the injured proximal part of the lumbar arteries [9] and/or hemorrhage from the VBF through the injured anterior longitudinal ligament (ALL). We believe that such bleeding characterizes the RPH resulting from VBF and causes the difficulty in treatment. We suspect that "untouchable bleeding" from the psoas muscle described on page 138 in Hirschberg and Mattox' book [3] might indicate such hemorrhage as shown in Fig. 5a.

It is natural that Type C fractures mostly produced the central pushing-up or combined RPH subtype because a Type B3 or Type C fracture is regarded as a qualification to disrupt the ALL [20]. We suspect that the ALL and crura of the diaphragm inhibit RPH formation from a VBF or contain the hematoma within the retrocrural space. However, Type A and Type B fractures also sometimes produced central pushing-up or combined RPH. In fact, six patients with Type A3, B1, or B2, not Type C, fracture died from uncontrollable RPH. We suppose that three of them died because of offhand retroperitoneal exploration, and the other three died because of an unperformed or failed TAE. Because some MRI studies revealed that a milder fracture than Type B3 occasionally disrupts the ALL [32–34], lethal RPH resulting from Type A or B fracture is not a paradox. Moreover, lumbar fracture in patients with DISH might easily produce lethal RPH because of the vulnerability of the vertebra and ALL [26, 34]. In this study, however, further discussion is impossible because no MRI examinations that would prove injury to the ALL [32–34] were performed.

TAE was often effective for the RPH of the central pushing-up and combined subtypes. Because blood flow to the vertebral body is supplied by many intra-osseous arteries arising from the proximal lumbar arteries [35], TAE to the lumbar arteries would suppress bleeding from the VBF. However, time-consuming catheterization of the lumbar arteries and the possibility of spinal cord infarction [9] might be weak points of this procedure. In contrast, offhand surgical hemostasis might exacerbate retroperitoneal bleeding because of the destruction of the interfascial planes, within which the RPH can be contained [5, 7]. We suppose that the highest priority should not be given to retroperitoneal

exploration for the deepest RPHs, which were located posterior to both the aorta and IVC and often resulted from bleeding from a VBF, in the Zone I area described by Sheldon et al. [1, 2] unless injuries to the great vessels are complicated. Now, we have adopted the principle that TAE and transfusion are prioritized over retroperitoneal exploration if CT images show the RPH resulting not from injuries to the great vessels but from lumbar fracture. In addition, this study might contribute to clarifying the structure of the central retroperitoneum (ESM_8, 9).

The RPHs shown in this study must be distinguished from other RPHs. It is well known that seatbelt injury [36] sometimes produces a Chance fracture [27], which often produces massive RPH from concomitant major vessel and/or retroperitoneal visceral injuries [30, 31]. In this study, however, RPH (Type I + IV + II) resulting from IVC injury was identified in only one patient with a VBF of Type A1, and RPH resulting from visceral injuries was identified only in patients without VBF, probably because a three-point seatbelt instead of a lap belt is required by law in Japan. Morphologically, spontaneous RPH in patients receiving an anticoagulant or chronic hemodialysis [37, 38] resembles the RPH in this study, especially the lateral-subtype RPH. Such spontaneous RPH often results from hemorrhage from the lumbar artery [37, 38]. The cause suggested is that excessive strain on the psoas or iliac muscle or compression by the muscle's own weight might induce minor injury of the lumbar artery [38]. Although no such case was identified in this study, RPH resulting from lumbar fracture could be enhanced by anticoagulation.

The limitations of this study are that it is a small single-center study, that classification of the fracture types is imperfect because of the lack of MRI examination, which is rarely available in the emergency setting, and that non-responders to fluid resuscitation were not evaluated with CT. To elucidate the relationship between mortal injuries and lumbar fracture, autopsy imaging should also be performed.

In conclusion, we analyzed life-threatening massive RPHs resulting from VBF, which has long been neglected. A large multicenter study is required to elucidate the detailed pathology.

Compliance with ethical standards

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