Original Article

Fractures of the manubrium sterni: treatment options and a possible classification of different types of fractures

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Background: Sternum fractures are mostly located on the sternal corpus, seldom on the manubrium. Fractures of the sternal manubrium are, however, more frequently associated with severe concomitant injuries of thoracic organs, and therefore deserve special attention. In addition, in its function as a capstone in between the anterior chest wall and the shoulder girdle, it is exposed to a multiplicity of forces. Therefore the questions arise what types of fractures are observed in today's clinical practice, how to classify them and which treatment options are available. This study reports on different types of fractures which involve the manubrium sterni.

Methods: Between January 2012 and October 2014, data was collected from all severely injured patients (ISS ≥16), which received a CT scan of the thorax in our Level-I-Trauma Center and retrospectively analyzed concerning sternal fractures. Fracture type, collateral injuries, age, and information about the circumstances of the accident were noted.

Results: Of 890 evaluable patients, 154 (17.3%) had a fracture of the sternum and 23 (2.6%) of the manubrium. Fractures of the manubrium appeared in following types: A-type—transverse fracture (n=11) in 1st intercostal space by direct blunt trauma or flexion of the torso with sagittal instability; B-type—oblique fracture (n=9) by seat belt injury with rotatory instability; C-type—combined, more fragmentary fracture (n=3) by direct blunt trauma with simultaneous flexion of the torso and multi directional instability. Fractures only little dislocation were treated conservatively, and unstable fractures were surgically stabilized (n=10).

Conclusions: In summary, three main types of fractures could be found. A-type fractures were stabilized with a longitudinal plate osteosynthesis and B-type fractures with transverse positioned plates. To treat complex C-type fractures, plates with a T- or H-form could be a good solution.

Level of evidence: Level III retrospective prognostic cohort study

Keywords: Sternum fracture; manubrium fracture; classification; sternal fracture; anterior chest wall

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Introduction

From the end of the 19th century up to the mid of the 20th century, fractures of the sternum were mentioned with an incidence of under 1% and increased with the number of car accidents to 5–8% of all bone injuries (1-6). The number is even higher in multiple trauma patients (3.9% isolated sternum fractures) in combination with other rib fractures (7.8–11.2%) and in flail chest injuries (10.8–21.2%) (6). These percentages demonstrate that the sternum plays a key role for the stability of the thoracic cage.

Scheyerer mentioned the relevance of the fracture localization in the sternum and underlined that especially fractures of the manubrium have a special clinical relevance for the stability and additionally indicate a higher risk for concomitant injuries (7). The sternum has different fracture types, depending on the injury mechanism since direct blunt trauma, indirect impact, and forced traction of muscles can cause sternal fractures (1). While fractures of the corpus sterni are mainly caused by direct forces, i.e., the impact to the steering wheel, manubrium fractures from other fracture mechanisms appear to be relevant (3,7,8). Gurlt reported in 1864 that all patients with oblique manubrium fractures had died (9). The first report about a living patient suffering from an oblique fracture was published in 1998 by Velutini (10). A systematic review of trauma scans in a Level 1 Trauma Center in Germany proved that oblique fractures of the manubrium have a higher incidence than expected, often lead to mediastinal hematoma, and are usually accompanied by severe injuries due to road traffic accidents. Oblique manubrium fractures are mainly caused by a combination of seat belt impact and a retroflexion of the shoulder (8).

Transverse fractures of the manubrium sterni can occur after direct impact or indirect forces like a flexion/compression mechanism which is then often accompanied by additional vertebral fractures known as sternovertebral-injury with a posterior displacement of the manubrium (9,11-14).

Therapeutic approaches for sternal fractures are based on case series and biomechanical principles. Plates with locking screws have proven to be the method of choice for osteosynthesis of sternal fractures (15,16). Sagittal dislocations can be avoided by applying a longitudinal plate. Oblique fractures of the manubrium tend to dislocate laterally and can be stabilized by transversal plates (8,17). Indications for plate osteosynthesis have been summarized by Harston: displaced and overlapped fractures that cannot be corrected by closed reduction, sternal instability, chronic nonunion and severe pain making with restriction of respiratory movements (15). Non-displaced and stable fractures can be treated conservatively (15)

In the literature, neither classifications of sternal fractures can be found nor a classification of the bony thorax in general that refer to the AO classification, yet (18). The presented study therefore focuses on clinical data and CT scans of trauma patients of a level I trauma center in detail with the intention to analyze regularities in fractures of the manubrium sterni, their epidemiology and possible treatment options.

Methods

Study design

A retrospective analysis was carried out on patients who presented over our level I trauma center between January 2012 and October 2014 and fulfilled the criteria for an emergency trauma room alert (*Figure 1*).

An approval of the ethics committee was not necessary in this retrospective study. No experiments on humans had been done.

Inclusion criteria were: (I) age of 16 years and older; (II) ISS ≥16; (III) whole-body trauma CT scan; (IV) fracture at the manubrium sterni.

Exclusion criteria: isolated brain injury.

Imaging

A whole-body trauma CT scan (Somatom definition AS, 128 slices, Siemens, Munich, Germany) had been performed with a slice thickness of 1.5 mm and multiplane reconstruction. The collected CT-data was examined for the presence of a sternal fracture and underwent a 3D reconstruction when indicated. Co-injuries were collated at the same time. Sternal fractures were analyzed by its precise localization and exact course by interpretation of the axial, sagittal, and coronal plane slices and use of the VRT-Mode for a 3D reconstruction (*Figure 2*).

We differentiated between fractures of the manubrium sterni, the angulus Ludovici, and the corpus sterni.

Clinical findings

On finding a manubrial fracture, the case history was made anonymous regarding to the circumstances of the accident,

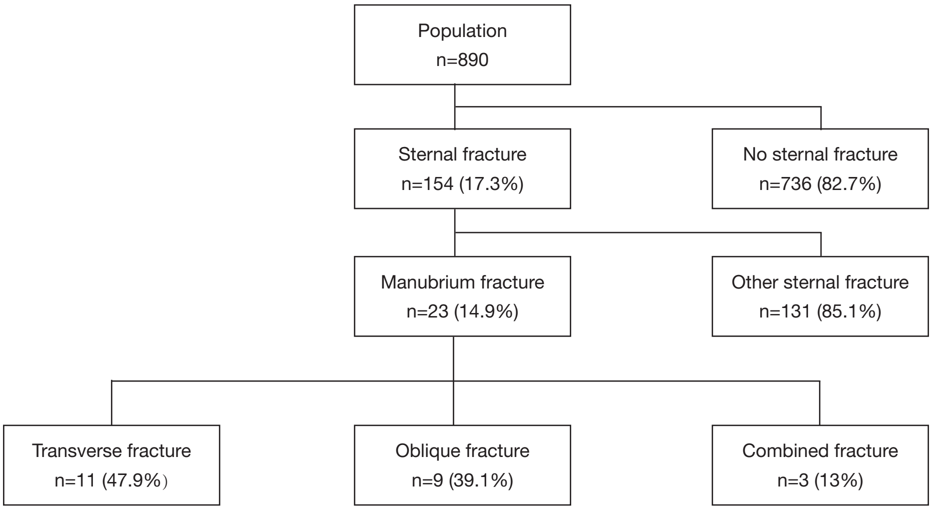

Figure 1 Population. About 14.9% out of the sternum fractures involved the manubrium, thereunder 47.9% transverse fractures, 39.1% oblique fractures and 11% combined fractures.

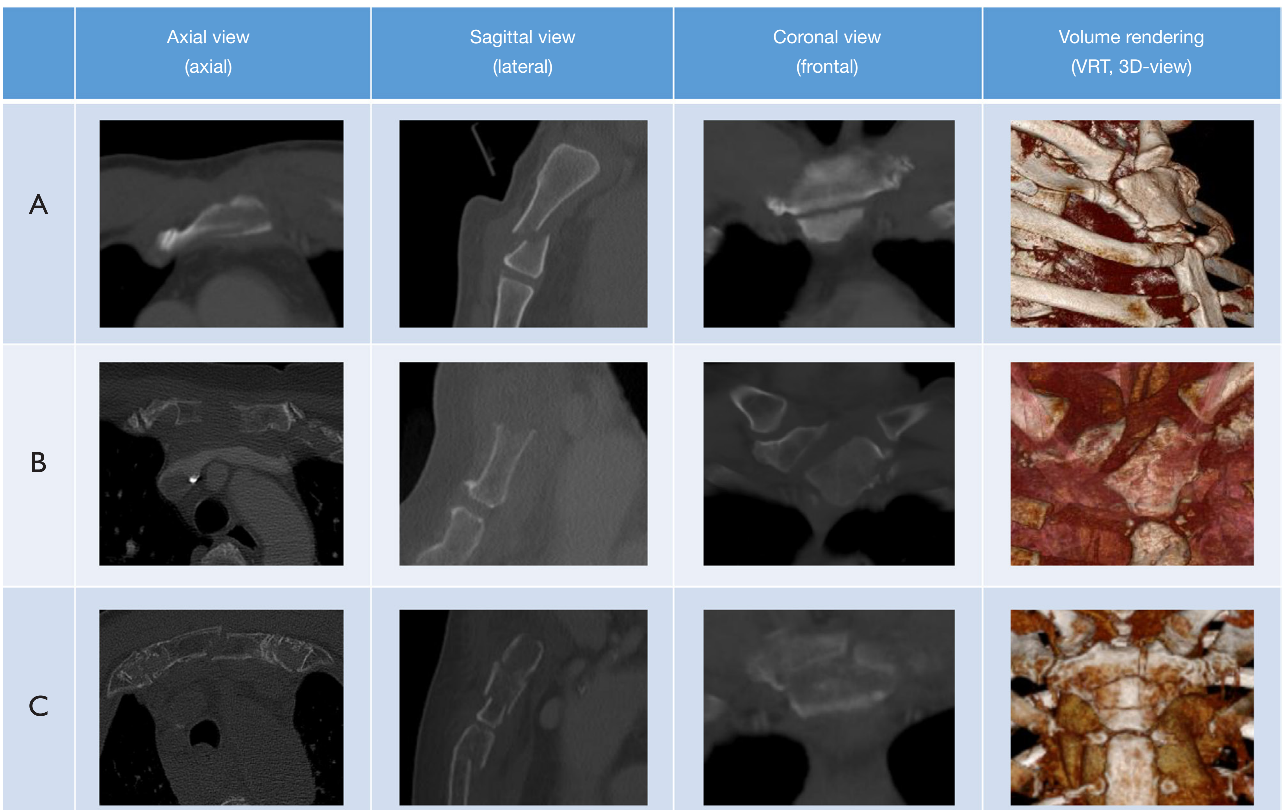

Figure 2 X-ray findings in Manubrium fractures (CT-scan). Three planes of imaging (multiplanar reconstruction, MPR) are necessary to evaluate the fractures of the manubrium sterni: the axial view shows the rotational instability in B- and C-type fractures, as well as horizontal splits in some transverse fractures. The sagittal view shows the sagittal instability in A- and C-type fractures. In severe dislocation the displaced part of the sternum might be non-visible in B-type fractures. The coronal view shows transverse fractures (A) as wells the oblique (B) and the combined (C) ones. The 3D-reconstruction shown as a volume rendering view gives a clear overview of the fractures' topography.

findings on admission, co-injuries, course of the illness and treatment modalities. Special attention was given to the question if the fracture showed instability during the secondary survey examinations (*Table 1*). Signs of instability included visible and palpable paradoxic movements of the sternum as well as any crepitation during palpation.

Additionally, we analyzed the follow-up examinations 6 and 12 weeks after the accident using conservative treatment. Radiological examinations were performed only in case of persistent instability, pain and after surgical treatment.

The treatment

Both, the clinical and radiological findings had been evaluated for the need of an operative treatment. Surgical fixation was selected as the treatment of choice for the patients with displaced or unstable fractures of the manubrium. The indication had been made by a senior surgeon with approval of the head of department (*Table 1*, *Figure 3*).

The procedure was then performed under general anesthesia after stabilization of the overall condition of the patient, and a consent form was signed. Access to the manubrium sterni was achieved by a median skin incision from the fossa jugularis to the angulus Ludovici and a layer-by-layer dissection down to the sternum. The pectoral muscles were dissected up to the manubrial margins, and the fracture site was completely exposed. Any trapped soft tissues were removed from the fracture to ensure anatomical reduction and a proper interpretation of the type of instability. Internal fixation was carried out by a locked plate osteosynthesis using plates of low-profile-design of 1.5 mm thickness made out of titanium (MatrixRib®, DePuySynthes CMF, Oberdorf, Switzerland). These were attached to each fragment by the usage of locked and self-tapping screws with 2.9 mm in diameter.

Transverse fractures were fixed by longitudinal plating, and oblique fractures were fixed by transverse plating crossing the first pair of the ribs (*Figure 3*) (17).

Multiple fractures were fixed by a special plate or a combination of a transverse and a longitudinal plate in case they showed a combination of transverse and longitudinal instability.

In cases of additional displaced fractures, for example, of the neighboring ribs and/or other areas of the sternum, they were treated during the same procedure by using the method of a locked plate osteosynthesis. After stability of the anterior chest wall had been restored, wound irrigation and insertion of a drain were carried out. For a layer-wise wound closure, reconstruction of the muscular and connective tissue layers was performed by suturing the pectoral muscles and the fasciae. For optimal cosmetic results, the subcutaneous and intracutaneous layers were sutured. Postoperative care included a close clinical monitoring, removal of the drainage tube, mobilizing of the patients, and discharge after complete wound healing. To ensure a correct implant positioning, a X-ray of the chest in 2 planes were carried out immediately postoperatively in addition to 6 and 12 weeks postoperatively to evaluate the status of lung as well as the reduction and healing of the fractures.

Statistical analysis

The data has been interpreted using EXCEL (Microsoft® Excel® 2016, Santa Rosa, California, USA) SPSS (Version 21, IBM, Armonk, USA)

The review of the collective and confirmation of the normal distribution of variables using the Q-Q diagram was performed in order to apply parametric tests. For the comparison of the three fracture types the one-factorial analysis of variance (ANOVA test) was used to compare more than two groups taking into account the variance homogeneity by Levene's test.

The operated patients were examined for different types of fractures for differences in length of stay and surgery times (ANOVA test; *Table 2*). In addition, the entire collective of manubrium fractures was examined to determine whether the operative therapy influenced the length of stay statistically significantly. For this comparison of 2 independent samples, the *t*-test was used for 2 independent samples (op *vs.* conservative treatment).

Results

From 890 trauma patients which were included to this study the evaluation of the CT-trauma scan revealed that 154 (17.3%) patients had a sternal fracture, thereunder 23 (14.9%) at the manubrium sterni. Out of them 11 (7.1%) showed a transverse fracture, 9 (5.8%) had an isolated oblique fracture, and 3 (1.9%) suffered multiple fractures combining both directions (*Figures 1,2*).

In the transverse fractures instability either presented as a sagittal dislocation of the cranial fragment posteriorly and caudally (cases 8–11), each of them stacking behind the

Table 1 Patients with fracture of the manubrium sterni

No.	Gender	Age (years)	Type of fracture	Classification	Dislocation	Mechanism of injury	Treatment	Concomitant injuries
1	Female	58	Transverse	A	No dislocation	Low fall	Conservative	Complex fracture of midface
2	Female	52	Transverse	A	No dislocation	Car accident	Conservative	Polytrauma: lung contusion bilateral, serial rib fracture monolateral, hemo- and pneumothorax, rupture spleen, fracture of the scapula
3	Male	21	Transverse	A	Moderate dislocation	Fall, 5 m	Conservative	Polytrauma: lung contusion monolateral, fracture of the scapula, complex fracture of the midface
4	Female	74	Transverse multiple	A	Moderate dislocation	Fall, 3 m	Conservative	Polytrauma: lung contusion, retrosternal hematoma, pelvic ring and acetabular fracture, upper limb fractures,
5	Female	85	Transverse	A	Moderate dislocation	Low fall	Conservative	Lung contusion, rib fractures monolateral
6	Male	47	Transverse	A	Moderate dislocation, instability	Car driver	ORIF two longitudinal plates	bilateral anterior serial rib fractures II–VII: flail anterior
7	Male	49	Transverse	A	Moderate dislocation, instability	Truck driver	ORIF longitudinal plate	Polytrauma: Bilateral anterior and lateral serial rib fractures II–VII: bilateral flail chest antero-lateral (bilateral rib plates), femur fracture
8	Male	27	Transverse	A	Severe dislocation	Motorcyclist crashed against car	ORIF two plates longitudinal	Clavicle fracture mid-shaft left (ORIF plate), vertebral spine cervical 6th, 7th, thoracic 1st
9	Male	19	Transverse	A	Severe dislocation	High fall	ORIF two longitudinal plates	Polytrauma: vertebral column fractures (4th thoracic vertebra), paraplegia, contusion cerebri
10	Male	63	Transverse	A	Severe dislocation, instability	Fall on the back	ORIF two plates longitudinal	Vertebral column fractures (5/6th thoracic vertebra
11	Female	85	Transverse	A	Severe dislocation	Fall on the back	ORIF two plates longitudinal	Vertebral column fractures (4/5th thoracic vertebra
12	Female	42	Oblique	B	Moderate dislocation	Car accident, restrained driver	Conservative	Polytrauma: lung contusion bilateral, serial rib fracture bilateral, hemo- and pneumothorax, fracture of clavicle, retroperitoneal hematoma
13	Female	88	Oblique	B	Moderate dislocation	Car accident, restrained co-driver	Conservative	Lung contusion, rib fractures
14	Female	57	Oblique	B	No dislocation	Car accident, restrained driver	Conservative	Rib fractures monolateral, contusion cerebri

Table 1 (*continued*)

Table 1 (*continued*)

No.	Gender	Age (years)	Type of fracture	Classification	Dislocation	Mechanism of injury	Treatment	Concomitant injuries
15	Female	60	Oblique	B	No dislocation	Car accident, restrained co-driver	Conservative	Polytrauma: lung contusion bilateral, rib fractures monolateral, fracture of clavicle, lumbar spine fracture, blunt abdomen injury, fracture of the tibia
16	Female	47	Oblique	B	No dislocation	Car accident, restrained co-driver	Conservative	Polytrauma: lung contusion bilateral, pneumothorax monolateral, fracture of the femur
17	Female	44	Oblique	B	No dislocation	Car accident, restrained driver	Conservative	Lung contusion bilateral, pneumothorax monolateral, serial rib fracture monolateral
18	Male	52	Oblique	B	Moderate dislocation	Car accident, restrained driver	Conservative	Polytrauma: lung contusion bilateral, retrosternal hematoma, blunt abdomen injury
19	Male	53	Oblique	B	Severe dislocation	Car accident, restrained occupant	ORIF 2 plates transverse	Polytrauma: severe head injury, midface fractures, vertebral column fractures (cervical-, thoracic- and lumbar spine)
20	Female	20	Oblique	B	Severe dislocation	Car accident, restrained driver, trapped	ORIF plate	Polytrauma: lung contusion bilateral, pneumothorax bilateral, bilateral carotid dissection, cerebral infarction, midface fractures, rupture of liver and spleen
21	Female	76	Bilateral oblique and transverse	C	Moderate dislocation	Car co-driver	Conservative	Polytrauma: vertebral column (cervical and thoracic spine fractures), serial rib fracture monolateral, hemo- and pneumothorax, lung contusion, rupture of liver and spleen
22	Female	64	Oblique manubrium and corpus	C	Severe dislocation, instability	Car accident, restrained driver, trapped	ORIF 3 plates transverse and one plate longitudinal	Polytrauma: vertebral column (thoracic and lumbar spine fractures), serial rib fracture monolateral, proximal fracture of the tibia, complex fracture of the distal tibia and talus opposite site
23	Female	80	Two level transverse and midline split	C	Moderate dislocation, multidirectional unstable	Fall on the back, 4 m, impact of the chin	ORIF “H”-plate (customized)	Polytrauma: traumatic brain injury; vertebral column fractures (5th thoracic vertebra), fracture of the mandibular, bilateral fracture of the clavicle
	15 female, 8 male	54.96 (range, 19–88; SD =20.63)	11 transverse, 9 oblique, 3 multiple	A: 11; B: 9; C: 3	Dislocation (none/ moderate/severe): A (2/5/4); B (4/3/2); C (0/1/2)	–	10 operation treatment monolareral fractures: A (6/11); B (2/9); C (2/3)	12 lung contusion; 4 bilateral, 6 monolateral rib fractures; polytrauma (A: 5/11, B: 6/9, C: 2/3)

The degree of dislocation (none < cortical thickness, moderate < shaft thickness, severe ≥ shaft thickness) was measured in the CT scan, the instability was examined clinically (palpable crepitation or visible movements). Those which had been treated operatively are presented in bold letters. A-type-fractures were stabilized in 6 out of 11 cases due to either unstable sternovertebral injury (indirect mechanism; cases 8-11) or anterior flail chest (direct impact; cases 6+7), B-type-fractures were caused by lap belt injuries in all cases and had been stabilized in severe dislocation and instability (cases 19+20), C-type-fractures occurred in polytrauma and had been stabilized in moderate or severe dislocation and instability (cases 22+23). SD, standard deviation. ORIF, open reduction and internal fixation.

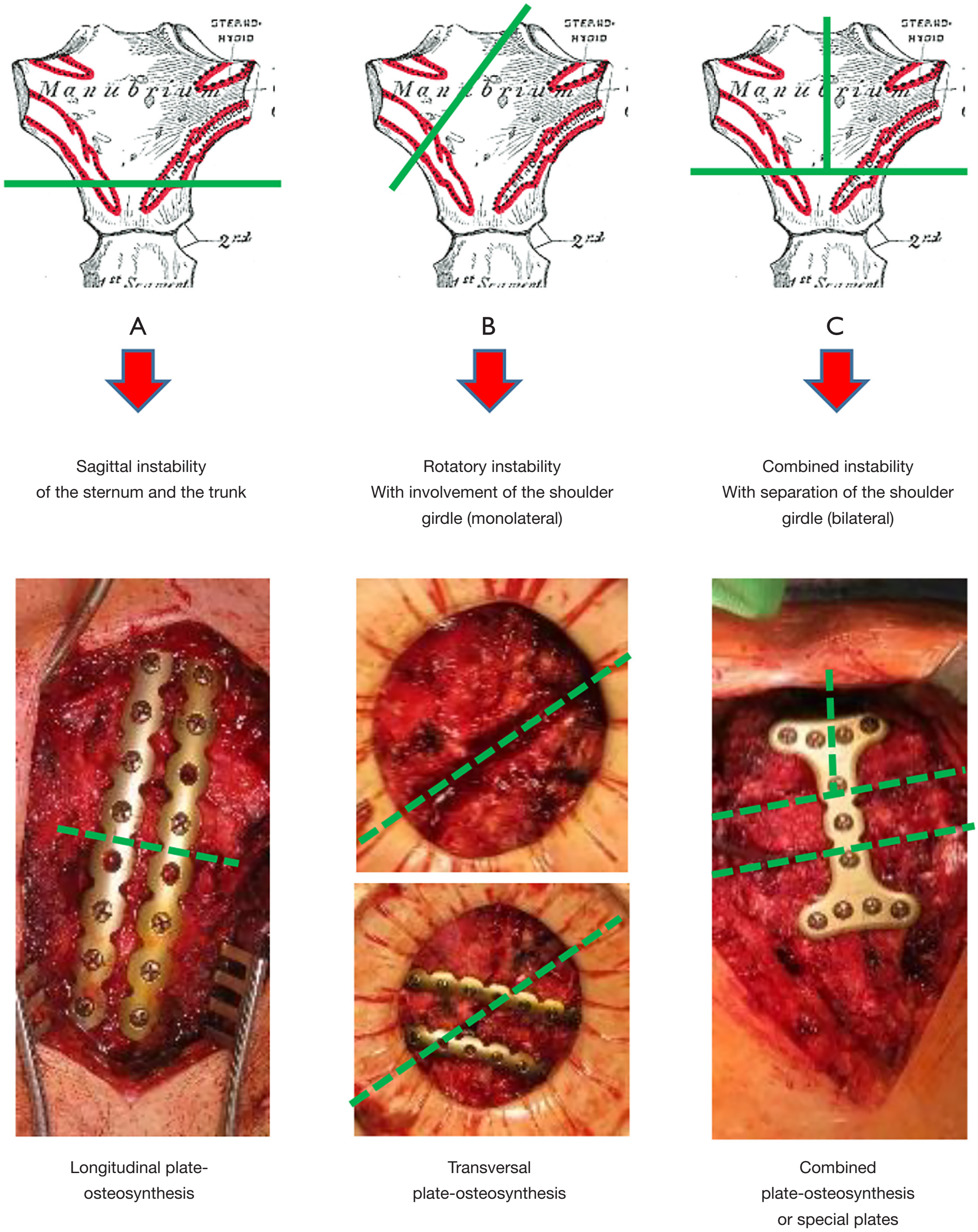

Figure 3 Different types of manubrium fractures. A-type shows transverse fracture and sagittal instability of the trunk. Unstable fractures are best treated with longitudinal plating. B-type shows oblique fracture and rotatory instability of the shoulder girdle. Unstable fractures are best treated with transverse plating. C-type shows combined instability. Unstable fractures need to be stabilized in both directions—sagittal and coronal. Either a combination of transverse and longitudinal plates could be employed or special plates, e.g., in T or H-shaped forms.

Table 2 Treatment parameters and follow up

No.	Classification	Type of fracture	Length of stay (days)	OP time sternum	Treatment	Complications reported
1	A	Transverse	1	–	Conservative	Sternum uneventful
2	A	Transverse	12	–	Conservative	Prolonged chest tube (7 days), sternum painful but decreasing pain and stable
3	A	Transverse	16	–	Conservative	Prolonged pain scapular (6 weeks), sternum uneventful after 6 weeks
4	A	Transverse multiple	11	–	Conservative	Moderate deformity 12 weeks
5	A	Transverse	11	–	Conservative	Pain left ribs 6 weeks, 12 weeks significant improvement
6	A	Transverse	8	48	ORIF two longitudinal plates	Quick recovery. No complications
7	A	Transverse	30	38	ORIF longitudinal plate	Haematoma postoperative
8	A	Transverse	17	36	ORIF two plates longitudinal	Persistent pain in the back, sternum uneventful
9	A	Transverse	45	33	ORIF two longitudinal plates	Persistent paraplegia, sternum uneventful. Wheelchair- driving possible
10	A	Transverse	9	69	ORIF two plates longitudinal	Well recovered, uneventful healing
11	A	Transverse	24	42	ORIF two plates longitudinal	Prolonged impalement in mobilization due to age (6 weeks). Sternum uneventful
12	B	Oblique	27	–	Conservative	Pneumonia, prolonged pain ribs and sternum (6 weeks), moderate persistent deformity sternum
13	B	Oblique	4	–	Conservative	No complications reported
14	B	Oblique	2	–	Conservative	No complications reported
15	B	Oblique	27	–	Conservative	Persistent pain in the back and at the ribs. Sternum healed uneventful
16	B	Oblique	14	–	Conservative	Chest tube, complicated mobility (femur; 12 weeks), sternum uneventful after 12 weeks
17	B	Oblique	7	–	Conservative	No complications reported
18	B	Oblique	16	–	Conservative	Pain chest wall and breathing 6 weeks, moderate persistent deformity manubrium, only little symptoms 12 weeks
19	B	Oblique	101	65	ORIF 2 plates transverse	Manubrium uneventful, avulsion with loss of right arm, complicated soft tissue closure
20	B	Oblique	31	117	ORIF plate	Traumatic brain injury, persistent impalement of consciousness Manubrium: bleeding mammary artery; healing uneventful

Table 2 (*continued*)

Table 2 (*continued*)

No.	Classification	Type of fracture	Length of stay (days)	OP time sternum	Treatment	Complications reported
21	C	Bilateral oblique and transverse	19	–	Conservative	Hemothorax left side, manubrium uneventful
22	C	Oblique manubrium and corpus	59	75	ORIF 3 plates transverse and one plate longitudinal	Chest wall uneventful. Complicated healing lower leg
23	C	Two level transverse and midline split	36	53	ORIF "H"-plate (customized)	Manubrium uneventful, clavicle uneventful conservative, pleural effusion right side

Length of stay (days): A-type, 16.7 (range, 1–45), SD =12.7; B-type, 25.4 (range, 2–101), SD =30.2; C-type, 47.5 (range, 36–59), SD =17.6 (P=0.320). OP time sternum: A-type, 44.3 (range, 33–69), SD =13.2; B-type, 91 (range, 65–117), SD =36.8; C-type, 64 (range, 53–75), SD =11 (P=0.049<0.05). ORIF, open reduction and internal fixation.

corpus sterni which then had to be released and resettled. Alternatively the caudal fragment in connection with the adjacent ribs was instable equivalent to an anterior flail chest. In these cases, bilateral connection between the manubrium, clavicle, and first rib were intact and hence the shoulder girdle stable.

Oblique fractures showed a lateral dislocation of the manubrium fragment, which generally broke between the jugulum and the first intercostal space. Connected to this fragment was the costoclavicular complex, containing the sternoclavicular joint and the first rib. In one of the cases, a dehiscence of 40 mm was detectable, and the upper mediastinum was exposed including a gigantic hematoma (case 20). Reduction of this fracture type was achieved by elevation and inner rotation of the ipsilateral arm and supported by reposition forceps and special threaded wires with pointed balls (compression wires). A rotational instability of the ipsilateral shoulder girdle was clinically detectable with palpation of the manubrium and the clavicle and the movement of the arm, whereas the contralateral side was still connected to the sternum and showed no instability.

Three cases presented as complex fractures. Two of them showed two oblique fractures originating from the first intercostal space and unifying in the middle towards the jugulum (cases 21,22). This triangle type fracture is equivalent to instability of both shoulder girdles combined with a sagittal instability. One of these fractures was reduced and fixed with a custom plate (MatrixRib® DePuySynthes, custom-made device, case 22). Another case showed two oblique fractures of which involved the manubrium and one the upper corpus. In combination with another transverse fracture right above of the angulus sterni, a rotational and sagittal instability resulted (case 23). This fracture was stabilized by one longitudinal and one transverse plate in combination.

Post-operative follow-up assessments showed well-healed wounds without complications; drains could be timely removed.

X-rays of the chest in 2 planes at 6 and 12 weeks postoperatively proved the healing of the fractures, and no dislocation of fractures or material could be detected. Except for one, all treated patients could resume the same mobility as before the accident. Resumption of professional life was achieved by all patients who were still working. One patient with an oblique manubrium fracture who had been stabilized surgically suffered additionally from a severe traumatic brain injury with constant neurological impairment. Due to this condition, motoric function was not satisfactorily assessable. In this case, a dissection of carotid and vertebral arteriae was caused by a hyperextension of the neck (case 20).

Concerning the mechanism of the accident, 7 of the 11 transverse fractures were caused indirectly by falling on their back, and the other four were caused by direct trauma, for example, through the steering wheel. All of the 9 oblique fractures were caused by the safety belt of front seat occupants. Two of the multiple fractures had been caused by the seat belt in addition to a rollover of the vehicle. The third multiple fractures were caused by a fall on the back from a 4-m height accompanied from an impact of the chin to the manubrium. As a consequence of the severe injury mechanism and osteoporotic bone, the patient sustained fractures of the mandible as well as of the 5th and 6th thoracic vertebral body. So, all complex fractures were caused by indirect force due to a flexion and compression injury (fall and rollover) in combination with a second direct hit to the sternum from a seatbelt and/or chin.

Table 2 gives details regarding treatment and observations during follow-up. Verification of the variance homogeneity of the different types of fractures using the Levene test revealed a significance of P=0.403 for the residence time and P=0.058 for the op time and was therefore not significant for both (P>0.05). It can thus be assumed that the variances are equal and the ANOVA can be carried out.

For the residence time (P=0.320) showed no significant difference in the three fracture groups.

For the Op period, there is just a significant difference between the three groups of P=0.049. With very small numbers of cases, however, further investigations on larger groups are necessary in order to substantiate the result statistically valid.

For the comparison of the samples (op *vs.* conservative), the nonparametric Mann-Whitney U test with P=0.08 did not reach a statistical significance level (P>0.05) for the length of stay. Thus, the operative therapy does not seem to significantly affect the length of stay, even if this relationship should also be examined in a larger collective and depends crucially on the overall injury pattern.

Discussion

As we mentioned above, the manubrium has a special anatomic and functional importance for the stability of the shoulder girdle and the thorax with a high clinical relevance. For that reason, we primarily focused on this region. In addition, this case series confirmed that manubrium fractures are often associated with severe collateral injuries, which is less commonly described in corpus fractures of the sternum, as well as a loss of stability of the shoulder girdle (7). Although the results of the present study are based on a rather small case series, it impressively shows that not all fractures of the manubrium sterni are equal.

Morphology of the fractures

In this study, there are two different types of dislocation of manubrium fractures, and, in combination, these two fractures created a third type with complex instability.

Transverse fractures were constantly found in the 1st intercostal space (ICS) between the 1st rib and the angulus sterni and not above this level.

Oblique manubrium fractures always showed the same morphology with a fracture side from the jugulum to the first ICS. This is comparable to an osseous removal of the ipsilateral shoulder girdle with its manubriocostoclavicular complex and may lead to a severe instability.

The combination of a transverse fracture with a sagittal instability of the sternum and an additional oblique fracture of the manubrium thus resulted in a bilateral instability of the manubriocostoclavicular complex.

Mechanism of trauma

A direct trauma mechanism could result in any of the three types of fractures of the manubrium. In transverse fractures it mostly causes the posterior dislocation of the lower fragment as well as concomitant rib fractures which are often seen bilaterally and well known as a “steering- wheel-injury” (cases 2,6,7) (12). Oblique fractures were the result of direct blunt trauma to the sternum and in all of the cases related to the seat belt during car accidents.

Indirect trauma with a flexion-/compression injury mechanism to the torso led to a dislocation of the cranial part of the manubrium behind the sternal body which results in a transverse fracture and thus a loss of stability of the ventral chest wall (12,14,19). A hyperextension/distraction injury could also lead to a transverse disruption of the sternum, which is only mentioned in single cases (20). We did not find that mechanism in our study involving the manubrium sterni.

The combination of direct and indirect forces caused the complex types of fractures in our collective (cases 21–23).

Treatment options

The conservative treatment of stable and undisplaced fractures is the method of choice in fractures of the chest wall (6,8,15). Dislocated and unstable fractures, on the other hand, may be a useful indication for surgical stabilization, which was then performed by means of a locked plate osteosynthesis based on the best known results of this technique without any complications like wire-dislocation (21,22).

Longitudinal plating was the best way to neutralize the load vector in transverse fractures which showed instability in the sagittal plane. Longitudinal plate osteosynthesis was the best way to neutralize the load vector in transverse fractures that showed instability in the sagittal plane. Especially important is the stabilization of the sternum fractures with simultaneous fractures of the cervical and thoracic spine, as the anterior chest wall acts as the fourth column of torso stability (*Figure 3*) (19,23,24).

Oblique fractures, however, cause a rotational instability in the horizontal plane. In these cases, we performed a reduction of the fracture and a transverse plate osteosynthesis to the first rib pair with locked screws for more stability compared to a wire-cerclage which is well known in median osteotomies of the sternum and which is comparable to this kind of fracture (*Figure 3*) (22).

To neutralize both of the load vectors in the complex fractures, an osteosynthesis was performed in one case with an individual designed plate (*Figure 3*) or a combination of a transverse and longitudinal plate osteosynthesis.

Classification

Comparing the morphology of the fractures and their possible dislocation, it would be possible to use the well-known AO/OTA classification of extremity fractures close to the joint. A-type describes a transverse fracture without joint involvement similar to the jugular part of the manubrium. B-type describes partial articular fractures with an oblique fracture line and instability of one column of the joint while, the second one remains stable. That would be comparable to a unilateral fracture of the sternoclavicular complex with a lateral dislocation. C-type describes a combination of transverse fractures with an additional joint involvement and a complex instability similar to the sagittal and transverse manubrium axis (*Figures 2,3*).

An unambiguous allocation of fractures in different groups makes it easier to compare patient populations and the further conservative or operative treatment of different fracture types. To determine the right treatment strategy and to evaluate the prognosis, different factors must be considered such as the localization of the fracture with its morphology as well as the collateral injuries (*Figures 2,3*).

Limitations of the study

Due to the fact that only 23 patients out of the whole population (n=890) showed a fracture of the manubrium sterni (2.58%, *Figure 1*) the specific findings of these rare fractures need to be validated on larger collectives.

Another limiting factor is the retrospective study design, with which clinical findings and treatment courses are difficult to compare for subgroups. On the other hand, a retrospective cohort study allows the inclusion of all patients of a period without recruitment losses in the collective. Standardized CT imaging made it possible to describe the fracture morphology in this study. This meets exactly the requirements for a descriptively based classification of fractures, as also known from the AO/OTA for the human skeleton.

Conclusions

In trauma, surgery classifications are essential to describe different fracture types. This study describes different types of manubrium fractures for the first time since a classification of fractures of the bony thorax is still missing.

In summary we found three different types of instability (i.e., sagittal, rotatory, and a complex instability) of the manubrium. To create a reproducible classification, we propose to divide these fractures into A-, B-, and C-types.

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Footnote

Conflicts of Interest: S Schulz-Drost is a member of the AO Thoracic Expert Group (THEG) and has a consultant agreement with DePuySynthes. The other authors have no conflicts of interest to declare.

Ethical Statement: This study does not include research involving human participants or animals. All data has been collected retrospectively.

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