Int J Legal Med (2001) 114:244–247

ORIGINAL ARTICLE

R. Vock

Liver rupture caused by isolated blunt force impact: the result of a blow, a kick or a fall?

Received: 21 October 1998 / Accepted: 11 October 2000

Abstract A total of 5534 protocols of judicial and extrajudicial autopsies performed at the Institute of Legal Medicine of the University of Würzburg between 1974 and 1987 were examined to determine whether an isolated liver rupture can be attributed to a blow, a kick or a fall on a level plane or against a hard edge, based on the nature of the injury alone. From the 5534 autopsies examined, 293 cases of falling on level ground or down staircases were found. In 271 cases the abdomen struck against a flat surface, in 21 cases either against a post or an edge and in one case it was not possible to find out which object the abdomen struck against. A liver rupture was found in only four cases. It is highly unlikely that liver rupture will be caused by a fall on a level plane or down steps. This empirical finding is further supported by biomechanical calculations. A fall on a level plane can only cause a liver rupture if the abdomen strikes against a hard edge or a stake-like object. If such an event can be excluded, the most likely cause of the liver rupture is a blow or a kick. In all cases of liver rupture, however, the differential diagnosis must exclude extrathoracic heart massage as the cause.

Keywords Liver rupture · Blow · Kick · Fall · Biomechanics

Introduction

A relationship between the pattern and severity of injuries and the transfer of kinetic energy can usually be established in cases of mechanical trauma such as traffic accidents [15]. In this context the forensic pathologist is occasionally confronted with the task of ascertaining whether a certain type of injury is the result of a blow, a kick or a fall. The differential diagnosis between fall-induced fatal or non-fatal injury versus injury or death caused by intentional physical violence, is especially difficult if both events, e.g. a fall and a blow or kick, have occurred in the same incident [31]. Differentiation between accidentally induced injury and injury caused by intentional physical violence is important not only in cranial-cerebral injuries, but also in blunt force abdominal injuries. Unfortunately, the forensic and clinical literature to date has paid scant attention to this topic [23]. Several cases in which the cause of liver rupture had to be determined, plus a number of reports in the literature, prompted us to take a closer look at this topic.

Dr. Vock died before publication of this manuscript

R. Vock
Institute of Legal Medicine, University of Leipzig,
Johannisallee 28, 04103 Leipzig, Germany

Materials and methods

The protocols of 5534 autopsies performed at the Institute for Legal Medicine of the University of Würzburg between 1974 and 1987 were examined for individuals who had sustained a liver rupture in a fall on a level plane or down steps.

Results

Among the 5534 autopsies examined, 214 cases involved falls onto level ground and 79 falls down steps. In 21 of the 293 cases, the police investigation and/or autopsy revealed that the victim's abdomen struck against a hard edge or a stake-like object, and in one case the object against which the abdomen struck could not be determined. In the remaining 271 cases the abdomen impacted against a flat surface.

The entire group of legal medical autopsies included only four cases of fall-induced liver rupture. Table 1 provides the important data on each of these four cases.

In case 1 it could not be determined whether the victim's abdomen struck a flat surface or the edge of a bedframe or table. Cases 2–4 involved falls on a level plane, with the abdomen striking against a hard edge (i.e. a bathtub rim, a boundary stake and the edge of a bedframe).

Table 1 Cases of fall-induced liver rupture

Case	Sex	Age (years)	Type of accident	Extent of injuries	Cause of death
1	F	30	Lethal fall caused by heart failure secondary to (fatal) fulminant pulmonary thromboembolism. Fall to floor or against edge of a bed frame or table	Hematoma of right frontal scalp, 12-cm-long, 4-mm-deep tear of hepatic capsule of right lobe, 40 ml diffuse haematoperitoneum	Pulmonary thromboembolism
2	M	46	Lethal fall, right side of victim's abdomen striking a bathtub rim, death 3 days after fall	A 14-cm-long deep ventrodorsal tear along inferior aspect of liver, 4 l haematoperitoneum	Hypovolaemia
3	F	65	Lethal fall on level ground, victim striking a boundary stake in a vineyard, death 5 h after fall	Fracture of 8th–10th ribs right, 400 ml haematothorax, grapefruit-sized ventrodorsal rupture of right hepatic lobe, massive haematoperitoneum, no cardiac massage	Hypovolaemia
4	F	86	Victim slipped on bedside rug and fell with right side of the body against edge of bed frame, death 2 h after fall	Serial rib fractures right, 6th–9th ribs along medioclavicular line, $10 \times 2 \times 4$ cm rupture of right hepatic lobe, 1.6 l haematoperitoneum, no cardiac massage	Hypovolaemia

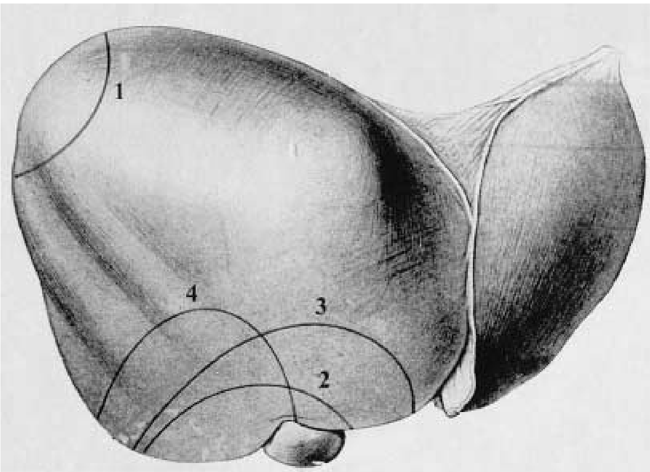

Fig. 1 Localisation of the liver ruptures in cases 1–4 (Illustration of the liver from [33])

The extent of the injuries ranged from a 12-cm-long and 4-mm-deep tear of the hepatic capsule to a grapefruit-sized rupture of the right hepatic lobe (Fig. 1).

Liver disease could be excluded in all cases except case 4 (micronodular liver cirrhosis), two cases involved isolated injury to the liver and in two cases the liver injury was accompanied by serial rib fractures.

Extrathoracic cardiac massage was not performed in any of the 4 cases.

The cause of death in case 1 was a pulmonary thromboembolism, in cases 2–4 hypovolemic shock.

Discussion

Falls on a level plane or down steps rarely cause injury to abdominal organs [5, 12, 13, 14, 27, 32]. Among approximately 1500 persons injured in falls from sidewalks in the former East Berlin, Barbier and Bischitzky [4] found only two cases involving abdominal injury (one traumatic perforation of the ileum, one unspecified injury). This low incidence is all the more surprising since about one-third of the falls occurred while the victim was intoxicated and thus incapable of checking the force of the fall. Similarly, Potondi et al. [23] did not find a single case of abdominal injury among 1001 falls by inebriated individuals (none from a height) in the course of a single year in Budapest.

The present results thus agree with the findings in the literature that liver rupture caused by falls on a level plane or down steps is extremely rare [13, 27]. Nellen [20], for example, found only one instance of liver rupture among 23 falls down steps with fatal outcome and not a single liver injury in 42 falls on a level plane.

The low incidence of injury to the liver in falls can be explained by the fact that the abdomen is protected by the four extremities, the head, and the thorax. Abdominal organs are injured only when these "protective buffers" have been compromised by prior injuries, or are nullified by an overwhelming force on impact, as in traffic accidents or falls from a height. It is not surprising, therefore, that in three of the four cases reported here the sometimes severe liver injury was caused by the abdomen striking a hard-edge such as a bathtub rim, a boundary stake, or a bed-frame. In case 1 (fall secondary to a pulmonary thromboembolism), the facts of the case do not exclude the possibility that the abdomen hit the floor, the liver rupture thus not being caused by impact against a hard edge or stake-like object. It is possible that the cardiac death resulting from the pulmonary thromboembolism rendered the woman unconscious and thus incapable of braking the fall with her arms.

Because extrathoracic heart massage can cause injury to the liver (in addition to heart injuries, and fractures of the spinal column, sternum, and ribs), it must always be included among the differential diagnostic possibilities in cases of liver rupture [1, 2, 3, 6, 7, 8, 9, 10, 11, 16, 17, 18, 21, 22, 24, 26, 30]. Unlike the ruptures described here, however, cardiac massage-induced liver ruptures are preferentially located vertically between the right and left hepatic lobes [19, 28, 31]. Spontaneous liver ruptures are rare and therefore have a low significance for differential diagnosis, and are mainly seen in patients with liver diseases, such as liver tumours, amyloidosis and peliosis hepatis [29].

The following biomechanical calculations support the empirical finding that falls on a horizontal plane cannot cause a liver rupture with a high degree of probability:

The tolerance value reported by Ropohl [25] for a force (F_T) capable of inducing liver rupture lies between 1.2 and 2.0 KN, where F_T represents the change in acceleration per unit of time:

$$F = \frac{\Delta(mxv)}{\Delta t} = \frac{\Delta v}{\Delta t} \qquad (1)$$

This produces a critical impact time (deceleration time) of:

$$\Delta t_{Krit} = \frac{m}{F_T} = \Delta v \qquad (2)$$

where *m* is the liver mass (2 kg), F_T the force threshold necessary to cause liver rupture, and *v* the deceleration after impact.

The velocity (*v*) at impact was calculated according to the formula given in the appendix, namely:

$$v = a\sqrt{\frac{3\,g}{1}} = 4.8\ m/s = 17.2\ km/h \qquad (3)$$

where *a* is the centre of gravity of the liver, *l* is the body length, and *g* is the acceleration at impact. Since the velocity decelerates to null on impact, the change in velocity is:

$$\Delta v = v - 0 = 4.8\ m/s \qquad (4)$$

Insertion of the values thus derived into the formula for calculating the critical impact time (deceleration time) produces the following equation for t_{Krit}:

$$\Delta t_{Kit} = \frac{2}{1.200} \times 4.8 \left[\frac{kg \times m/s}{kg \times m/s^2}\right] = 8 \times 10^{-3} s \qquad (5)$$

The impact time of 8×10^{-3} s or 8 ms is several-fold less than normal impact times for the human body falling on a horizontal plane, which can reach 50 ms for relatively unchecked fall-induced impacts (e.g. the head against concrete). For biomechanical reasons alone, therefore, it appears highly unlikely that liver rupture can result from a fall when the centre of gravity is "*a*" (the present formula represents the maximum variant for the forces involved). Experience shows that a falling person breaks the fall with the hands or arms, thus averting direct impact to the abdomen. Moreover, the manner in which the liver is suspended within the body together with its pliancy further reduce the force of the impact.

In sum, the findings in the four cases reported here, the biomechanical calculations, and the data in the literature all show that with a high degree of probability liver ruptures are not caused by falls on a level plane or down steps. Rupture of the liver is only possible if the abdomen strikes a hard edge or a stake-like object. When confronted with a liver rupture, therefore, the forensic pathologist must assume (unless the aforementioned exceptions apply) an intentional act of violence (such as a kick or blow) as the most likely cause. The differential diagnosis, however, must always exclude extrathoracic heart massage-induced injury.

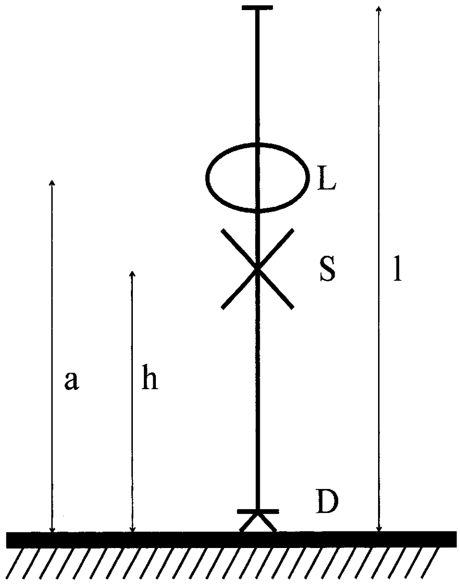

Fig. 2 Data on body mass for body length (*l*), position of the body's centre of gravity (*S*) at height (*h*), location of the liver (*L*) at height (*a*), and location of the pivot (*D*) at the feet

Acknowledgements I thank Prof. Dr. rer. nat. K. Arnold and Prof. Dr. rer. nat. K. Dähnert (Institut für Medizinische Physik und Biophysik der Universität Leipzig) for their calculations of the biomechanical forces involved.

Appendix

Biomechanical model for calculating the velocity on impact

This model represents a person falling forward with outstretched body. The pivot point (*D*) is located at the feet. (cf. Figure 2).

The moment of inertia (Θ) of a person with mass (*m*) is used (analogous to the fall of a stake) as follows:

$$\Theta = \frac{1}{3} \cdot m \cdot l^2 \qquad (6)$$

Applying the law of the conservation of energy:

$$m \cdot g \cdot h = \frac{1}{2} \cdot \Theta \cdot \omega^2 \qquad (7)$$

the angular velocity ω of the toppling body is calculated:

$$\omega = \sqrt{\frac{2 \cdot mgh}{\Theta}} \qquad (8)$$

This produces the impact velocity (*v*) for the liver applying the formula $v = \omega \cdot a$. If the body's centre of gravity is located at the centre of the body length, insertion of the appropriate values produces the following equation:

$$v = a\sqrt{\frac{3g}{l}} \quad (9)$$

References

1. Agdal N, Jørgeson TG (1973) Penetrating laceration of the pericardium and myocardium and myocardial rupture following closed-chest massage. Acta Med Scand 194: 477–479
2. Azuma SS, Mashiyama ET, Goldsmith CI, Abbasi AS (1986) Chest compression-induced vertebral fractures. Chest 89: 154–55
3. Baldwin JJ, Edwards JE (1976) Rupture of the right ventricle complicating closed chest cardiac massage. Circulation 53: 562–564
4. Barbier H, Bischitzky E (1969) Über die Verletzungen der Fußgänger auf den Bürgersteigen der Großstadt. Z Arztl Fortbild 63: 1153–1157
5. Brandt M (1977) Der Sturzunfall im höheren Lebensalter. Ätiologie und Unfalltypik. Z Gerontol 10: 244–253
6. Breederveld RS, Patka P, van Mourik JC (1988) Fractures of the sternum. Neth J Surg 40: 133–135
7. Clark DT (1962) Complications following closed-chest cardiac massage. JAMA 181: 337–338
8. Fosse E, Lindberg H (1996) Left ventricular rupture following external chest compression. Acta Anaesthesiol Scand 40: 502–504
9. Froment P, Savioz D, Robertson M, Morel P (1998) Lésions hépatiques après massage cardiaque externe efficace – une complication iatrogène à ne pas négliger. Swiss Surg 4: 225–227
10. Goldberg RM, Rowan L, Anderson RE (1988) Thoracic vertebral fracture as a complication of cardiopulmonary resuscitation. J Emerg Med 6: 177–178
11. Gopalakrishnan KC, el Masri WS (1986) Fractures of the sternum associated with spinal injury. J Bone Joint Surg 68: 178–181
12. Gruennagel HH, Junkat H (1967) Unfälle im Kindesalter. Eine Zehnjahresübersicht stationär behandelter Unfälle vom Neugeborenenalter bis zum 14. Lebensjahr. Dtsch Med Wochenschr 92: 141–146
13. Hein PM (1982) Der Sturz auf der Treppe und Standfläche als Verletzungsursache. Med. Diss., University of Würzburg
14. Hein PM, Schulz E (1983) Ursachen des Treppen- und Standflächensturzes. Lebensversicherungsmedizin 35: 154–156
15. Karger B, Teige K, Bühren W, DuChesne A (2000) Relationship between impact velocity and injuries in fatal pedestrian-car collisions. Int J Legal Med 113: 84–88
16. Klintschar M, Darok M, Radner H (1998) Massive injury to the heart after attempted active compression-decompression cardiopulmonary resuscitation. Int J Legal Med 111: 93–96
17. Korsgaard F (1995) Hjertemassage, leverruptur og trombolyse (in Swedish). Ugeskr Læger 157: 4467–4468
18. Krischer JP, Fine EG, Davis JH, Nagel EL (1987) Complications of cardiac resuscitation. Chest 92: 287–291
19. Lignitz E, Gillner E, May D (1976) Zur Problematik von Reanimationsschäden. Kriminol Forensisch Wiss 26: 51
20. Nellen HJ (1966) Statistische Studien zur Charakterisierung von Sturzverletzungen. Med. Diss., University of Bonn
21. Noffsinger AE, Blisard KS, Balko MG (1991) Cardiac laceration and pericardial tamponade due to cardiopulmonary resuscitation after myocardial infarction. J Forensic Sci 36: 1760–1764
22. Pezzi A, Pasetti G, Lombardi F, Fiorentini C, Iapichino G (1999) Liver rupture after cardiopulmonary resuscitation (CPR) and thrombolysis. Intensive Care Med 25: 1032
23. Potondi A, Dömötör E, Gabor I, Orovecz B (1965) Sturzverletzungen Betrunkener und ihre forensische Bedeutung. Dtsch Z Ges Gerichtl Med 56: 191–196
24. Rabl W, Baubin M, Broinger G, Scheithauer R (1996) Serious complications from active compression-decompression cardiopulmonary resuscitation. Int J Legal Med 109: 84–89
25. Ropohl D (1990) Die rechtsmedizinische Rekonstruktion von Verkehrsunfällen, vol 5. DAT Deutsche Automobil Treuhand, Stuttgart
26. Rosen J, Tuchek JM, Hartmann JR (1999) Liver laceration in the hemodynamically unstable post-cardiac massage patient: early recognition and management – case report. J Trauma 47: 408–409
27. Schwarz H (1945) Todesfälle durch Sturzverletzungen. Med. Diss., University of Zürich
28. Thaler MM, Krause VW (1962) Serious trauma in children after external cardiac massage. New Engl J Med 267: 500–501
29. Tsokos M, Schulz F (1999) Non-traumatic liver rupture due to a perforated gastric ulcer. Int J Legal Med 112: 321–323
30. Umach P, Unterdorfer H (1979) Massive Organverletzungen durch Reanimationsmaßnahmen. Beitr Gerichtl Med 38: 29–32
31. Vock R (1992) Leber- und Milzrupturen als Komplikation der Herzdruckmassage. Beitr Gerichtl Med 50: 193–203
32. Walcher K (1949) Sturz oder Schlag? Beitr Gerichtl Med 18: 51–61
33. Waldeyer A (1967) Anatomie des Menschen, Part 1, 5th edn. De Gruyter, Berlin, p 195