Traumatic rupture of the thoracic aorta
An autopsy and histopathological study

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Summary
Over the 9-month period 1 March - 30 November 1983, 118 consecutive autopsies were conducted on victims of motor vehicle and train accidents. The thoracic aorta was examined for evidence of con- tusion, partial tearing or rupture, particular attention being paid to the known usual sites of rupture. All lacerations or disruptions were excised together with a segment of surrounding aortic tissue, and processed, sectioned and examined by conventional light microscopy for the presence and extent of aortic tears.

Several findings emerged: (i) in nearly two-thirds of cases there was some degree of aortic disruption; (ii) multiple rather than single tears occurred in 41,2% of the 51 subjects in whom aortic tears were found; (iii) tears of the media occurred in more than 60% of cases, highlighting the involvement of this layer of the aortic wall in traumatic lesions; (iv) there was a high (81,4%) incidence of concomitant multiple injuries; (v) most of the victims (75,4%) were dead on arrival at a medical facility; and (vi) positive blood alcohol levels ranging from 0,04 mg/dl to 0,42 mg/dl were found at autopsy in 80% of the subjects.

Subjects and methods
During the above-mentioned period 118 consecutive victims of motor vehicle and train accidents were examined at the Diepkloof Government Mortuary. Age, sex, race and, where possible, the form of transport involved in each accident (obtained from the police investigation docket) were noted in each case. Whether the subject had been a pedestrian, passenger or driver was also noted (obtained from the investigation docket), as well as whether the subject reached hospital dead or alive and whether the injuries sustained involved a single organ system or anatomical site or were multiple (multiple injuries being defined for the purposes of the study as injuries involving more than one organ system or anatomical site but excluding surface abrasions, which are almost invariably present following road traffic and train accidents).

In each case a routine medicolegal autopsy was performed. During the course of each autopsy the adventitial surface of the thoracic aorta was examined for evidence of bruising or rupture, and its intimal surface examined by means of a hand lens after opening the vessel, particular attention being paid to those areas well recognized as known usual sites of rupture. The aortic isthmus just distal to the origin of the left subclavian artery, the ascending aorta, the lower descending thoracic aorta to the aortic hiatus of the diaphragm, and the mid-arch portion. All lacerations or disruptions noted were excised together with a segment of surrounding aortic tissue and placed in 10% neutral buffered formalin for fixation. On completion of the autopsy a sample of femoral vein blood was withdrawn and submitted to the State Chemical Laboratory in Johannesburg for determination of the ethanol content (this was carried out in all subjects except children, those who had been in hospital and some of the train accident victims).

All specimens were processed and embedded for paraffin sectioning, cut at 5 μm thickness and stained by haematoxylin and eosin. They were then examined by conventional light microscopy for tearing or disruption of the aortic wall. Those cases in which the tear or tears appeared to be confined to either intima alone or intima and inner-third of media on histological examination of the haematoxylin and eosin-stained sections were submitted to recuts from the same block. These were then stained with elastic-van Gieson stain in an attempt

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to delineate the anatomical extent of the tear better (despite the awareness that in the large elastic arteries of the body, which include the aorta and its branches, the outer limit of the tunica intima is demarcated from the tunica media by a poorly defined zone of longitudinally dispersed elastic fibres rather than a discrete elastic lamina as in the case of muscular arteries). Nevertheless, in most cases it was possible to assess the extent of the tear without recourse to special stains since the majority of tears were either extremely superficial, involving only the innermost extent of the intima, or showed clear-cut medial extension.

On completion of histological examination all findings noted were classified into the following categories; (i) no injury; (ii) adventitial haemorrhage alone; (iii) outer-third medial tears; (iv) middle- and inner-third medial tears; (v) tears involving the entire extent of the media; (vi) intimal tears; (vii) intimo-medial tears; and (viii) complete vessel wall transection. In addition, it was noted whether a vessel had sustained a single tear only or multiple tears and, if the latter, the extent of each tear.

Results

Of the 118 subjects who came to autopsy, 94 (79.7%) were male and 24 (20.3%) female. There were 109 blacks (92.4%), 7 coloureds (5.9%) and 2 Indians (1.7%). The subjects ranged in age from 5 to 80 years, with the greatest distribution (33 (27.9%)) in the 21-30-year age group. In descending order, the remaining age distribution was as follows: 31-40 years — 27 (22.9%), 41-50 years — 19 (16.1%), 11-20 and 51-60 years — 10 (8.5%) each, 61-70 years — 5 (4.2%), 71-80 years — 3 (2.5%). The number in the paediatric age group (0-14 years) was 13 (11.0%) (2 of these also fell into the 11-20-year category). These findings obviously reflect that the most active and ambulant age groups are at greatest risk of being pedestrian victims of road traffic accidents, and indeed pedestrians comprised fully 99 (83.9%) of the subjects in the series, while only 1 subject was known to be a driver. In 18 cases (15.3%) it was not known whether the victim was a pedestrian or a driver, and it is possible that the actual percentage of pedestrian victims may be higher. However, the contributory role of alcohol must also be taken into consideration — a positive blood alcohol level, ranging from 0.04 mg/dl to 0.42 mg/dl, was found in 80% of the subjects from whom a sample of femoral vein blood had been withdrawn at autopsy.

Analysis of the injuries sustained showed that 96 (81.4%) subjects had multiple injuries, while there were single-organ injuries in only 22 (18.6%). Craniocebral injuries comprised 17 (77.3%) of injuries in the latter category and cervical spinal fractures 2 (9.1%), while fracture of the base of the skull, a fractured pelvis and pulmonary contusions were each found in 1 subject (4.5%). Eighty-nine subjects (75.4%) were dead on arrival at a medical facility; the other 29 (24.6%) survived for varying periods in hospital.

Regarding aortic injuries sustained, 111 tears were found in 51 subjects, the sites ranging from the aortic isthmus just distal to the origin of the left subclavian artery to the lower descending aorta (Fig. 1) at the aortic hiatus of the diaphragm as well as the ascending aorta and the mid-arch region. Single tears were found in 30 of these subjects (58.8%) and multiple tears in 21 (41.2%). However, altogether 75 subjects (63.6%) sustained some degree of aortic injury in the form of either focal or diffuse adventitial haemorrhage. Among the 43 subjects (36.4%) in whom no aortic injuries were present, 16 had craniocebral injuries alone, 1 had a fractured pelvis, 1 had a fracture of the base of the skull and 1 had a fractured cervical spine. Nineteen (86.4%) of the 22 victims with single-organ injuries did not have thoracic aortic lesions, and in the overwhelming majority of these the site of injury lay outside the thorax.

Multiple aortic tears were found in 21 subjects, of whom 8 had 2 tears (38% of those with multiple tears and 15.7% of the total number of subjects with tears). Four subjects had 3 tears each (19.0% and 7.8% respectively), 4 subjects had 4 tears each (19.0% and 7.8% respectively), 1 subject had 6 tears (4.8% and 2.0% respectively), 1 had 7 tears and 3 subjects had 8 tears each (14.2% and 5.9% respectively).

Twenty-five complete transections of the aorta were seen in 20 of the subjects (39.2% of those with tears — 22.5% of the total 111 tears encountered). Of these transections, 11 (44%) occurred in victims with single tears and 14 (56%) in victims with multiple tears. Eighteen (16.2%) of the 111 tears involved the aortic isthmus, and these were found in 8 (15.7%) of the 51 subjects with tears. Intimomedial tears numbered 33 (29.7%) and occurred in 23 subjects (45%) (Fig. 2). Tears involving the entire transverse extent of the media numbered 19 (17.1%) and occurred in 15 subjects (29.4%). Tears of the outer-third of the media numbered 11 (9.9%) and occurred in 9 subjects (17.6%). Middle- and inner-third (Fig. 3) medial tears numbered 5 (4.5%) and occurred in 3 subjects (5.9%). However, in the absence of ocular micrometry it is extremely difficult to define the precise extent of a tear to an exact one-third of the media, and it is therefore accepted that the above distinction may be too fine. Nevertheless, medial involvement was seen in 68 (61.3%) of the 111 tears, this highlighting the involvement of this layer of the aortic wall in traumatic lesions of the aorta.

Discussion

The mechanism responsible for traumatic rupture of the aorta has been debated for many years, and many theories have been put forward to explain why the aorta is subject to this type of injury. The earliest investigations appear to be those of Rindfleisch who, in 1893, held the opinion that traumatic rupture is produced by a sudden stretching of the vessel and that the upper thoracic portion is most exposed to such stretching. This was followed by the investigations of Oppenheim in 1918; he ligated the branches of human aortas and filled the vessels with water at a pressure of up to 3000 mmHg, and noted that ruptures regularly occurred in the ascending part, just above the semilunar valves. Although such high pressures are unlikely ever to occur in the living,
strangulation, phenobarbitone overdosage, hepatic coma and gunshot wound of the brain to an acute agonal rise of the intrathoracic blood pressure resulting in rupture of the vasa vasorum.

Since these early experiments, various authors\textsuperscript{15} have stressed the importance of the aorta's topography in order to explain the mechanism of rupture. It has been suggested that the fixity of the ascending aorta, arch and descending aorta vary relative to one another, and that torsion and shearing stresses occur not only between these different segments but also between the aorta and other thoracic organs. These authors assumed that at the moment of impact the relatively mobile descending aorta, with its contained column of blood, bends forward at its junction with the fixed aortic arch at the isthmus, generating shearing stress at this site with varying degrees of rupture. This explanation, however, is not universally accepted, and direct crushing injuries have also been implicated in aortic rupture. In addition, it has been suggested that pressure on the abdomen, such as may occur in a pedestrian run over by a car, may result in a pressure wave being transmitted along the column of blood in the aorta, in accordance with Pascal's law.\textsuperscript{14} It has been demonstrated experimentally\textsuperscript{14,15} that a so-called water-hammer effect may be caused by a pressure wave in the column of blood in the aortic arch, and that the magnitude of this effect rises with the degree of velocity change. It has been calculated\textsuperscript{15} that it requires a force of 196 \(g\) to produce a transverse rupture of the isthmus, whereas an analogous rupture of the ascending aorta requires a force of 250 \(g\). In contrast, longitudinal ruptures require greater forces, i.e. 224 \(g\) for a longitudinal rupture of the convex side of the isthmus and 286 \(g\) for a rupture of the convex side of the ascending aorta. It appears, therefore, that multiple mechanisms are responsible for the initiation of the aortic tears and may account for the incidence of 43\% noted in this series.

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REFERENCES


Fig. 2. Section of aortic wall showing a transverse rupture extending from the intima on the right to the adventitia on the left. Extravasated erythrocytes are present within the tear as well as diffusely throughout the adventitia which appears otherwise intact. A smaller tear at the top of the section extends from the intima into the media. The transverse split at the left upper quadrant of the field is artefactual (H and \textit{E} x 51).

Fig. 3. Aortic tear extending from the intima into the inner layers of the media and containing erythrocytes (H and \textit{E} x 132).

Oppenheim surmised that lower levels of increased intraluminal pressure may cause rupture in vivo because the resistance of the aorta to stress during life is lower than after death. Klotz and Simpson\textsuperscript{11} conducted similar experiments in 1932, and found that the aortas of young people resisted an internal pressure of about 1000 mmHg without rupturing, but they nevertheless assumed that a sudden rise in blood pressure ruptured the vessel during accidents. In this regard it is of interest that Schleyer\textsuperscript{12} attributed the adventitial haemorrhages of the thoracic aorta which he found in victims of throttling,