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ORIGINAL ARTICLE

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The distinction between lacerations and cuts in ligaments and tendons

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Abstract In contrast to skin wounds the characteristic forensic features of lesions of ligaments and tendons have rarely been investigated. However, in a suspected homicide the question became crucial whether an isolated discontinuity of the posterior atlanto-occipital membrane was caused by a rupture mechanism or by a cut. In order to re-evaluate the associated criteria experimental lesions were made in ligaments and tendons and examined histologically. From these experiments the following criteria could be established: *Lacerations* exhibit complete destruction of the tissue texture with microruptures and splitting of fibres in the adjacent region. Such wound edges have an irregular structure and fibres near the rupture site exhibit variable thicknesses due to traction. *Incisions* exhibit smooth wound edges with no disturbance of the tissue texture. The thickness of fibres near the rupture site is regular. These results were obtained by light microscopical examination and confirmed using electron microscopy. Under controlled experimental conditions the forces necessary to rupture tendons with a diameter of 1 mm varied between 50–70 Newton (N). In the suspected homicide, the lesion of the posterior atlanto-occipital membrane was examined visually and histologically and was compared with the experimentally established criteria. Based on these criteria the lesion could be identified as an incision which had probably been caused accidentally while severing the medulla during the first autopsy and was therefore not connected with the cause of death.

Key words Tendons and ligaments · Ruptures and cuts · Mechanical forces · Morphology

Introduction

The distinction between incisions and lacerations of the skin and subcutaneous tissues is well established and problems very seldom occur (e.g. Kratter 1921; Hofmann & Haberda 1927; Mueller 1975; Polson & Gee 1973; Knight 1991). The criteria are:

- cut wounds or incisions characteristically show a wedge-shaped profile, straight and smooth margins, sharp angles and lack contusion at the lower edge
- lacerations ("split wounds") characteristically show an irregular shape with jagged and notched margins, blunt angles and with resistant structures such as nerves and vessels bridging the lesion

However Janssen (1977) pointed out that severed fibres and blood vessels can exhibit irregular surfaces caused by retraction and these discontinuities can therefore sometimes resemble lacerations.

In a case of suspected homicide it became increasingly important to determine the mechanisms by which a discontinuity of the posterior atlanto-occipital membrane had been caused. Since no references existed relative to this particular question, experimental studies were also performed.

Case report

A 40-year-old woman had been found dead in her home lying on the sofa, wearing normal indoor clothing and with no signs of a disturbance. The body showed no injuries and no bruising with the exception of a narrow (0.5 cm wide) and short (5–6 cm long) horizontal skin abrasion mark to the right anterior neck at the larynx level with scanty haemorrhages in the underlying skin and soft tissue. The remaining neck circumference showed no lesion. Several petechiae were present in the skin of the face and in both conjunctivae. Fracture of the right cornu superius of the cartilago thyreoidea. Edema of the lung. The soft tissues of the anterior and posterior trunk and the limbs revealed no relevant bruising. After extensive histopathology and toxicology without any further relevant findings the experts concluded that this was an atypical form of strangulation. The husband was charged with murder but claimed that his wife had fallen downstairs a few hours before death and attributed the cause of death to this accident. Initially this was excluded because of a lack of related findings. The husband was therefore finally convicted.

After persistant demands from the defence lawyers the corpse was exhumed 1 year after the incident and a second autopsy car-

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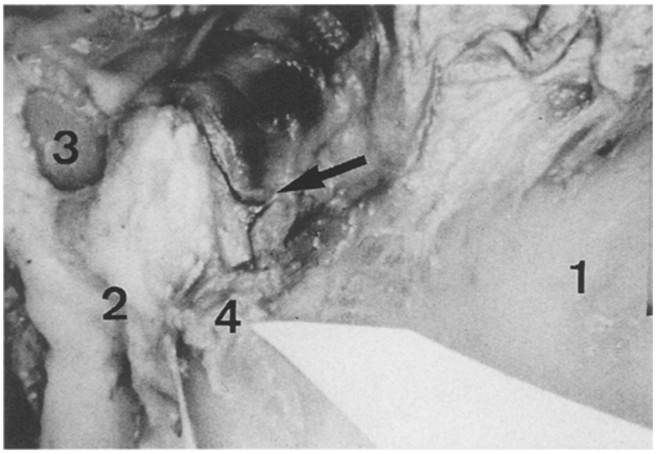

Fig. 1 Macroscopical lesion of the membrana atlanto-occipitalis in the suspected homicide case. Sagital section through the atlanto-occipitalis region. 1 Squama ossis occipitalis, 2 Lig. nuchae, 3 arcus post. atlantis, 4 margo post. foram. occipit. magn. ← indicates disruption in the atlanto-occipital membrane

ried out. In this investigation, an isolated discontinuity of the posterior atlanto-occipital membrane was found and designated a "laceration". This was now considered to be of traumatic etiology, i.e. due to the stair fall and therefore relevant to the cause of death. Other experts were involved subsequently and relative to the membrane discontinuity a third expert opinion was invoked. Since the skull/spine specimen together with the membrane was perfectly dissected and fixed in formalin, the membrane still being in connection with its osseous fixation points, an appropriate state for a morphological re-examination still existed. However, the discontinuity was now showing the macroscopical features of sharp force injuries (Fig. 1) which was attributed to the first autopsy i.e. an unintentional cut during severing of the medulla. The two contrary statements were extensively discussed and other circumstances included as well e.g. the absence of a fall-related injury pattern and the extremely improbable occurrence of such lesions in isolation. It was also doubted that the mechanical forces originating from this stair fall were strong enough to break the membrane. – The court finally excluded the accidental origin. Since the medico-legal literature contained nothing to this rather rare differential diagnosis we had to apply established knowledge from other tissues. We have therefore also performed experiments and studies and would like to describe the results obtained.

Materials and methods

Control specimens were obtained from cases of sudden heart death, where prior consent had been given. Ages varied between 40 and 60 years. The postmortem interval varied between 24–48 hours. The following specimens were obtained:

- 10 (posterior) atlanto-occipital membranes in conjunction with their osseous fixations (atlas, part of os occipitalis)
- 20 strips of the dura mater each strip measuring 4 × 1 cm (from 10 corpses)
- 20 tendons of the extensores digitorum muscles (from 10 corpses)

The diameters of the tendons were measured to calculate the cross sectional area. Five atlanto-occipital membranes were divided in the mid-line giving ten halved and five complete specimens. The mechanical forces were applied and measured with the stretch machine with variable force increase up to 1000 Kp, maximal stretch up to 20 cm. The speed of stretching was varied between 10 and 50 mm/min. The specimens could be mounted with appropriate clamps (holders). Stretch experiments with the machine alone were static. For dynamic stretch experiments, one end of the specimen was fixed as usual on the machine while the loose end was attached to a weight (10 kg), which was dropped from varying heights between 15 cm and 100 cm. The machine recorded forces for both types of experiments. The force necessary to tear the tissue was recorded.

Besides these experiments for which 80% of all specimens were used, the remaining ones were used for the application of clean cut injuries (n = 2 membranes, n = 4 tendons, n = 4 strips) and for superficial clean cuts combined with a subsequent tear. The lesions (discontinuities) were investigated visually, by histology and electron microscopy.

Results

The mechanical properties of the tissues investigated were in accordance with those noted in previous investigations (e.g. Claes 1987). After the initial phase of elastic deformation with a corresponding increase in length, which could be explained by a parallel alignment of the previously wave-like collagen fibres, increasing viscous behaviour was registered before complete tearing occurred.

The forces necessary for a complete rupture were roughly of the same order, both under dynamic and static conditions. Statistical evaluations were not performed because of the small number of specimens, but there was only some interindividual variation in the range of approximately ± 20%.

The strips of dura mater (1 cm width) ruptured after 100 N and the atlanto-occipital membranes, which were 3–4 cm wide required 400 N. Tendons with a diameter of approximately 1 mm ruptured after 50 N, and thicker tendons (2–3 mm diameter) ruptured after 350–500 N. – When specimens with superficial cuts were stretched rupturing always occurred at lower forces as would have been expected from the extent of the cut e.g. a cut extending over approximately 25% of the cross section was associated with a much higher decrease in the rupture force.

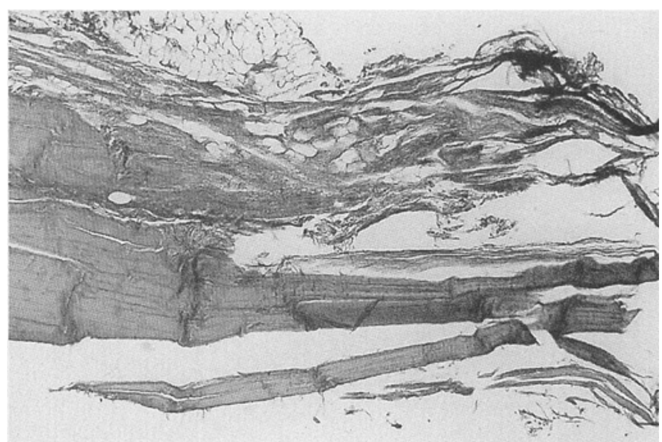

Fig. 2 Laceration of a tendon. Rupture margin on the right hand side. Splitting and irregular tear at the margin with microruptures, texture changes, clefts also at a distance from the primary site; thickness changes (160 ×)

Fig. 3 Cut of dura mater. Smooth fibre dissection at the margin. Wedge-shaped profile. Thickening of the severed fibre. No alteration to tissue located at a distance from the primary site (100 ×)

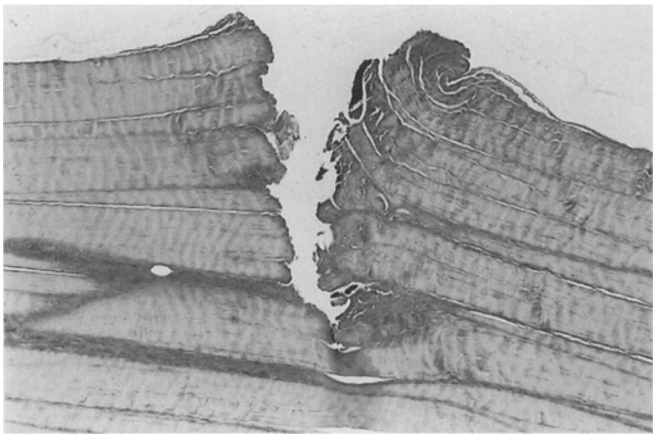

Fig. 4 Cut of a tendon. Wedge-shaped profile. No changes of fibres adjacent wound margin (160 ×)

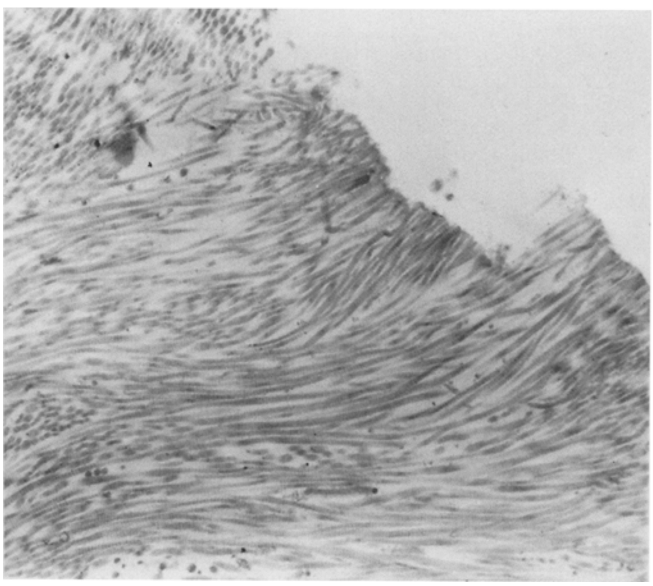

Fig. 5 Cut of a tendon. Smooth fibre dissection without texture disturbance (electron microscopy 4.400 ×)

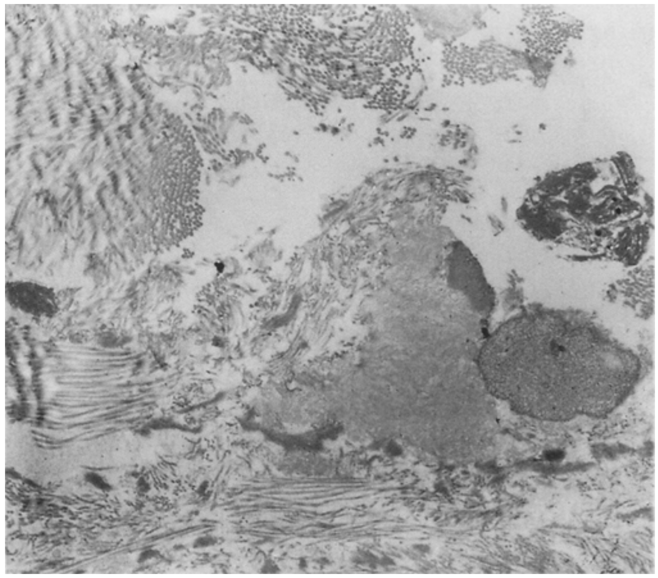

Fig. 6 Laceration of a tendon. Irregular wound margin with microruptures and texture disturbance (electron microscopy 4.400 ×)

Table 1 Histological changes associated with cuts and lacerations

Histological changes	Cuts	Lacerations
Fibre structure at wound edges	Smooth, retracted	Irregular, retracted
Fibre structure adjacent to wound edges	Unchanged	Fibre splitting microruptures
Fibre thickness	Unchanged	Irregular
Fibre texture	Regular	Disturbed

Morphology

In the histological preparations, a complete disruption of the normal tissue structure was always observed adjacent to the rupture site. The fibres and fibre bundles lost their systematic arrangement and showed abundant microruptures with the formation of smaller fibre segments. The thickness of the collagen fibres showed a distinct reduction in ruptures when compared to normal fibres. Microruptures could also occasionally be observed at a distance of more than 1 cm from the discontinuity. Shifts between adjacent bundles with the formation of clefts were also observed (Figs 2 and 6). Cuts showed similar changes only in the immediate vicinity of the discontinuity.

Incisions showed an abrupt and straight line discontinuity with no alteration to the adjacent tissue, but occasionally "retractions" of bundles could be observed with or without the formation of bulges (Figs. 3 and 4).

The electron microscopical examination also revealed the same types of changes, e.g. stretching artefacts, microruptures, disarrangements, microshifts (Figs. 5 and 6, Table 1).

Discussion

The maximum loads of human tissues have often been tested on many specimens such as ligaments of the cervical spine (Sances et al. 1981: cited in Unterharnscheidt 1992), and the Achilles tendon (Stucker 1951; Wilhelm et al. 1973). The minimum force necessary for rupturing of the anterior ligamentum longitudinale of the lumbar spine was 380 N, for the posterior ligament 180 N and for the ligamentum flavum 315 N. Stucker (1951) and Wilhelm et al. (1973) reported that the Achilles tendon was ruptured after a static load of 3.900 N and 4.400 N respectively, but with an individual variation ranging between 1.300 N and 6.500 N. In our experiments a force of 100 N was necessary to rupture the strips of dura mater (1 cm width) and a force of 400 N for the atlanto-occipital membrane (3–4 cm). These findings correspond to the results of Sances et al. (1981).

The finger tendons (musculi extensores digitorum) showed cross-sectional areas ranging between 0.8 and 7 mm^2, which correspond to the range of forces necessary for disruption (50–500 N), and also to the forces necessary to disrupt the stronger Achilles tendons (Wilhelm et al. 1973).

Generally the force necessary for rupturing varies between 50–70 N/mm^2 and is roughly in the same order of magnitude in all tissues tested. This corresponds to the findings of Unterharnscheidt (1992) who reported that the resistance of ligaments to tearing is dependent on the cross-sectional area. This is probably due to the structural similarity of all collagen fibre bundles (Bargmann 1977), but experiments with human skin demonstrated that its physical properties are very different (Zink 1965).

It is possible that postmortem changes and also the age, gender, constitution and pre-existing diseases of an individual may influence the structural stability of tissues, however, in our opinion the extent of such influences is insignificant, because tendons are particularly stable under various conditions such as metabolic disturbances and infections and the range of other studies is similar although with different postmortem time intervals.

With respect to the particular case a fall downstairs from a height of approx. 2 m and an acceleration of 9.81 m/s^2 would result in an impact speed of about 6 m/s ($V = \sqrt{2 \cdot g \cdot s}$). If the duration of the impact would be ca. 5–10 msec, this would result in a deceleration of ca. 600–1200 m/s^2. After correction for a reduced body mass of approximately 10–20 kg, this would result in an effective force of ca. 6000–24000 N.

From the experimental findings and these estimations we conclude that the forces necessary to rupture the atlanto-occipital membrane could occur after a stairfall. However, it is extremely unlikely that such ruptures could occur in isolation, i.e. without additional lesions of the adjacent and surrounding structures of the cervical spine and the skull base. – The morphological criteria to discriminate between incision wounds and ruptures are classical.

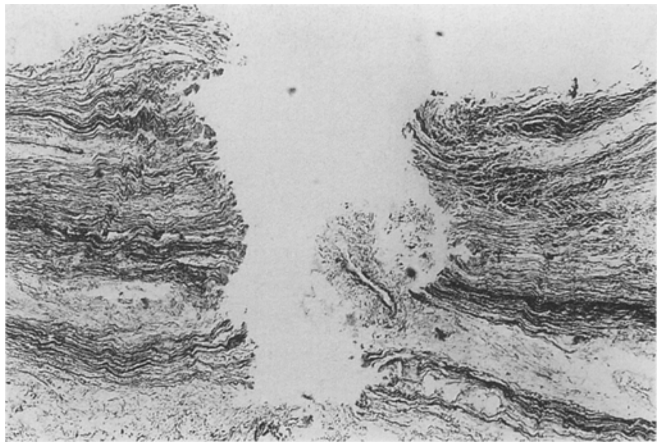

Fig. 7 Microscopical changes of the membrana atlanto-occipitalis in the suspected homicide case. Smooth wound margins without texture disturbance (160 ×)

They can also be applied to collagen tissues with short and longer postmortem times.

In the case reported it was concluded that the lesion (Fig. 7) could not have been caused by a rupture mechanism. Re-examination of the atlanto-occipital regions in 100 autopsy cases has shown that the same type of lesion was produced inadvertently in approx. 40% by cutting the membrane while severing the medulla oblongata.

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