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CASE REPORT

Unique paleopathology in a pre-Columbian mummy remnant from Southern Peru—severe cervical rotation trauma with subluxation of the axis as cause of death

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Abstract We describe the multidisciplinary findings in a pre-Columbian mummy head from Southern Peru (Cahuachi, Nazca civilisation, radiocarbon dating between 120 and 750 AD) of a mature male individual (40–60 years) with the first two vertebrae attached in pathological position. Accordingly, the atlanto-axial transition (C1/C2) was significantly rotated and dislocated at 38° angle associated with a bulging brownish mass that considerably reduced the spinal canal by circa 60%. Using surface microscopy, endoscopy, high-resolution multi-slice computer tomography, paleohistology and immunohistochemistry, we identified an extensive epidural hematoma of the upper cervical spinal canal—extending into the skull cavity—obviously due to a rupture of the left vertebral artery at its transition between atlas and skull base. There were no signs of fractures of the skull or vertebrae. Histological and immunohistochemical examinations clearly identified dura, brain residues and densely packed corpuscular elements that proved to represent fresh epidural hematoma. Subsequent biochemical analysis provided no evidence for pre-mortal cocaine consumption. Stable isotope analysis, however, revealed significant and repeated changes in the nutrition during his last 9 months, suggesting high mobility. Finally, the significant narrowing of the rotational atlanto-axial dislocation and the epidural hematoma probably caused compression of the spinal cord and the medulla oblongata with subsequent respiratory arrest. In conclusion, we suggest that the man died within a short period of time (probably few minutes) in an upright position with the head rotated rapidly to the right side. In paleopathologic literature, trauma to the upper cervical spine has as yet only very rarely been described, and dislocation of the vertebral bodies has not been presented.

Keywords Peruvian mummy · Axis · Rotation trauma · Epidural hematoma

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Introduction

Today, trauma to the upper cervical spine frequently occurs during traffic accidents. However, despite this high trauma incidence, fractures and luxations of the upper cervical vertebrae are rare. Those are seen mostly in cases associated with severe skull and/or polytrauma. Then, cases present with fractures of either the vertebral body (e.g. the atlas), the occipital condyles, the vertebral arches (as in the so-called hanged man's fracture of C2) [9], or the dens axis. In rare instances, severe rotational trauma leads to dislocation of vertebral bodies without fracture leading to a broad range of clinical symptoms between transient neurological affection and rapid death of the individual due to acute bleeding.

In paleopathologic literature, trauma to the upper cervical spine has as yet only very rarely been described [2], and dislocation of vertebral bodies has not been presented. In the present report, we describe a unique case from South America, Nazca civilisation (Peru), where typical characteristics of a severe and presumably lethal rotational trauma to the upper cervical spine were identified. Using a multidisciplinary approach, we are able to delineate the trauma pathophysiology and its immediate consequences providing data on the final time course of the affected individual. In consequence, we present a speculation on the underlying cause and the events leading to death.

Case report

The pre-Columbian head with the first two vertebrae attached of a mature (40–60 years old) male (anthropologically based) had been excavated by the ethnologist Heinrich Ubbelohde-Doering from the University of Munich/Germany between 1923 and 1933 at the cemetery of Cahuachi, Southern Peru [10]. Archaeologically, the finding was dated to the Nazca period (0 until 700 AD), which was confirmed by radiocarbon dating indicating a living period between 120 and 750 AD (315 AD$\pm 2\sigma$).

The skull and the two firmly attached upper cervical vertebrae are the only residues of the individual's skeleton; unfortunately, the postcranial skeleton was not preserved. Additionally, scalp with some hair was preserved. Joined to portions of the hair was a colourful woven fabric (circa 14×12 cm) with at least seven different colours of stained wool indicating a high-quality material.

Analytical techniques applied

We applied a multidisciplinary approach to the object. Following external macroscopic inspection, we used surface microscopy and endoscopic inspection of skull cavities to study bony surfaces, soft tissue residues (such as ligaments, dura, presumed brain remnants and an amorphous brownish material attached to the dura) and skull surface and to remove small tissue samples for histology and immunohistochemistry. Paleohistochemical preparation of the samples followed previous descriptions [6] including the preparation of histochemical stainings (H&E, van-Gieson stain, Periodic acid Schiff's stain (PAS), Prussian blue stain) and immunohistochemical stainings for glycophorin-C (ZytomedVision, Berlin, Germany) for the identification of erythrocytes. A hair sample was investigated for the presence of cocaine, a widely used psychoactive drug in South American cultures, as previously described [7]. An additional hair strain of circa 9 cm length was used for the determination of stable isotope ratios, in particular δ^{13}C and δ^{15}N, as previously done [3].

Subsequently, skull and vertebrae were examined using computer tomography (Siemens RMA). The slice thickness was 0.6 mm with a table advance of 36 mm/s and a reconstruction interval of 0.4 mm (scanning parameters 220/440 mA, 140 kV, and pitch 1.5; total spiral length 30 cm; overlapping reconstruction 50%). Three-dimensional surface reconstructions in multivolume rendering technique were obtained, which enabled to differentiate between the various osseous (skull, atlas and axis) and non-osseous structures (ligaments and bleeding residues) and to create a virtual geometry of the brain. Morphometric data were obtained to describe the position of both vertebrae and their relation to the skull base. The anatomical structures were extracted and colour-coded using semiautomatic evaluation of thresholds providing a realistic depiction of the immediate post-mortal situation. All reconstructions were made at the Silicon Graphic Workstation using 3D software of Algothek (Israel).

Observations

On external inspection, the skull shows signs of an external deformation with significant elongation of the parietal zone, termed *deformatio fronto-occipitalis erecta*, a typical artificial deformation carried out during infancy and frequently performed in South American cultures (Fig. 1). The head exhibits no evidence of fracture with the exception of slight artificial post-mortal damage of the nasal aperture. The skull and skull base are focally covered by dry soft tissue remnants; the hair scalp had been retained

Fig. 1 Skull in three-quarter frontal view showing the flattened elongated frontal bone and the flat steep occipital bone

separately from the skull showing a wig-like bulk of dark-brown interwoven hair bundles. There is poor dentition with numerous missing teeth (mostly post-mortal losses) and moderate abrasion of the teeth.

The most remarkable pathological findings are seen at the two attached vertebrae C1 and C2, which are well visible in part from the external inspection, but also identifiable on surface microscopy and endoscopy. The best overview of these lesions, however, is obtained from the CT scans with three-dimensional reconstruction: atlas and axis are connected to each other by desiccated soft tissues, mainly the remnants of ligaments. While the atlas is in correct position to the skull base, the axis presents with a severe rotational dislocation, with the spinal process shifted to the right side (Fig. 2). The displacement of the axis between the posterior tubercle of the atlas and the spinal process of the axis is measured to be 38° (Fig. 3). As a result of this dislocation, the size of the vertebral canal is significantly reduced at the left side (Fig. 4). The cross-sectional area of the spinal canal at the level between atlas and axis is further diminished by a bulging "amorphous brownish mass", which is attached to the spinal surface of the atlanto-occipital membrane, mainly on the left side. This membrane shows a few small vertical ruptures along with remnants of the vertebral artery. In total, the size of the vertebral canal has only circa 30–40% of its original size.

The posterior longitudinal ligament follows the torsion of the axis and is intact. The degree of torsion between the two vertebrae is easily recognised upon inspection of the

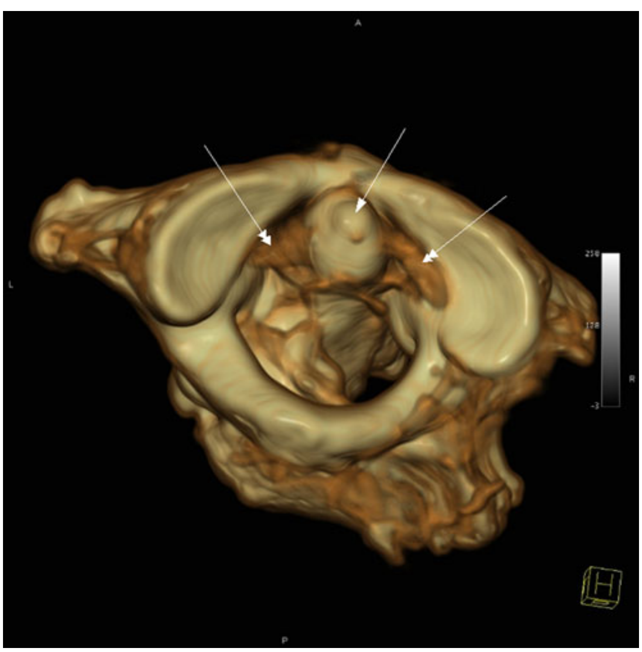


Fig. 2 Three-dimensional reconstruction of atlas and axis viewed from cranial. Tip of the dens (*arrow*) with a remnant of apical ligament (*ochre*) and with both alar ligaments (*double arrows*)

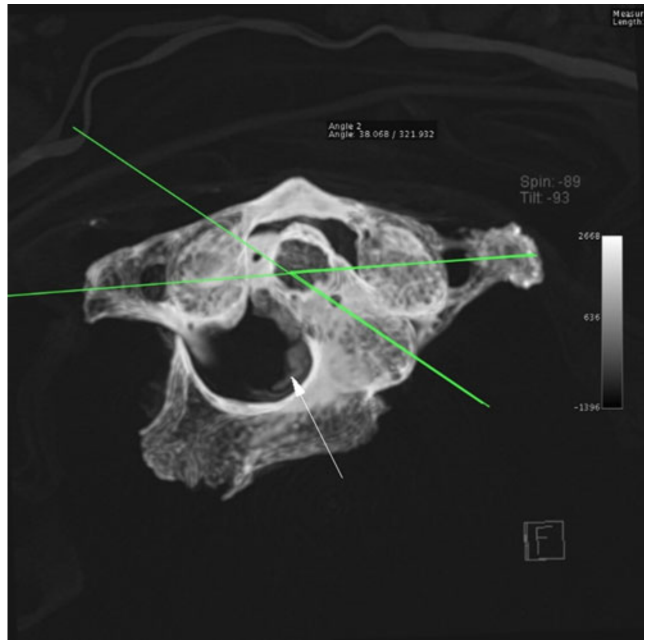


Fig. 3 Axial CT scan of atlas and the rotated axis (dislocation angle=38°). The narrowed bony spinal canal is additionally reduced by hematoma on its left wall (*arrow*)

partly preserved anterior longitudinal ligament. Also identifiable is the intact transverse atlantal ligament, which runs just posterior to the dens as it transverses the ring of the atlas (Fig. 5). Similarly, the alar ligaments are almost intact (Fig. 6) except for their disrupted cranial ends running from both sides of the dens into their usual directions to the anterior and medial surface of both occipital condyles of the foramen magnum. However, instead of ending here, where a part of the ligaments is disrupted from its attachment to the condyles, the corresponding free ends are visible near both superior articular facets of the atlas (Fig. 7). Finally, remnants of the torn apical ligament of the dens are recognisable at the apex of the dens, enveloped by the anterior atlanto-occipital membrane and the trias of longitudinal fascicles of the cruciform ligament and deep and superficial layers of the tectorial membrane. There is no macroscopic evidence of fractures of any osseous structure.

As indicated before, between atlas and axis, there is a large intraspinal bulging mass, which is seen between the spinal dura with the tectorial membrane and the vertebral bodies. On further endocranial endoscopy, large remnants of detached dura mater are seen on the side of the right hemisphere within the skull cavity, together with significantly shrunken brain tissue and a flat brownish layer covering the left temporo-parietal region. The CT scans confirm that this mass is connected to a flat, half-moon-like layer of dry substance extending into the left skull being at least partly covered by a thin layer of dura mater, thereby indicating epidural localisation. The material spreads up to

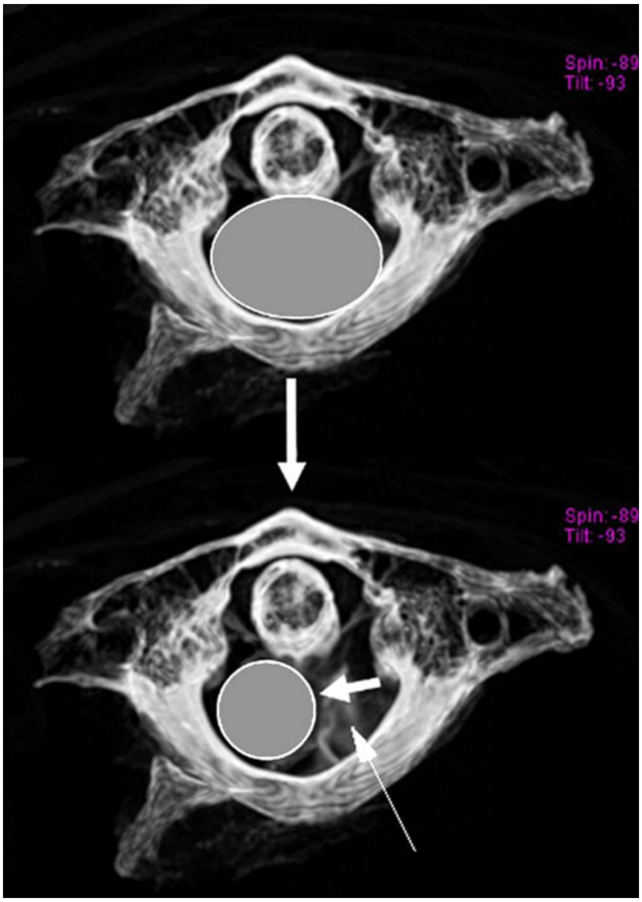


Fig. 4 Schematic drawing indicating the extent of compression of the spinal cord. *Upper panel*, expected normal size of the spinal cord (*encircled area*); *lower panel*, in the affected individual the hematoma (*arrow*) reduces the spinal cord diameter to circa 50%

the parietal and temporal regions without forming a circumscribed mass (Fig. 8).

Both endoscopy and CT scans show that the temporal bones exhibit normal internal and narrow external auditory canals with small foramina of Huschke bilaterally, defects of the anterior bony wall of the external meatus. An inspection of the auditory canals reveals both tympanic membranes lacking, but the six ossicles are preserved in correct anatomic arrangement and position.

Subsequent histomorphological studies on small tissue samples removed from the bulging mass and adjacent structures after careful preparation reveal an excellently preserved broad connective tissue layer of the dura mater with focal residues of a significantly less well-preserved tissue identified on histochemical stains as brain residues (Fig. 9). The amorphous brownish material presents as a partly corpuscular substance that does not react with numerous histochemical stains, in particular with connective tissue staining, PAS staining and Prussian blue stain of haemosiderin deposits. However, when an immunohistochemical staining for glycophorin-C is applied, this material selectively and strongly reacts positive, proving the presence of erythrocytes in that material (Fig. 10). All other structures (dura mater and brain tissue) remain unstained (Fig. 11), and control reactions (pre-immune serum control and cytokeratin antibodies) do not show a positive reaction. In conclusion, the “brownish amorphous material” is identified as a fresh hematoma as the result of an acute epidural bleeding in the spinal canal and skull.

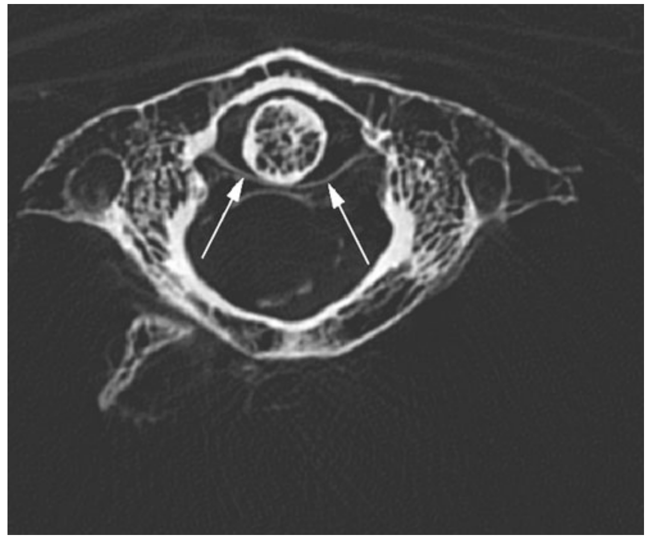


Fig. 5 Axial CT scan of the atlas and the dens, which is articulated with the transverse atlantal ligament posteriorly (*arrow*)

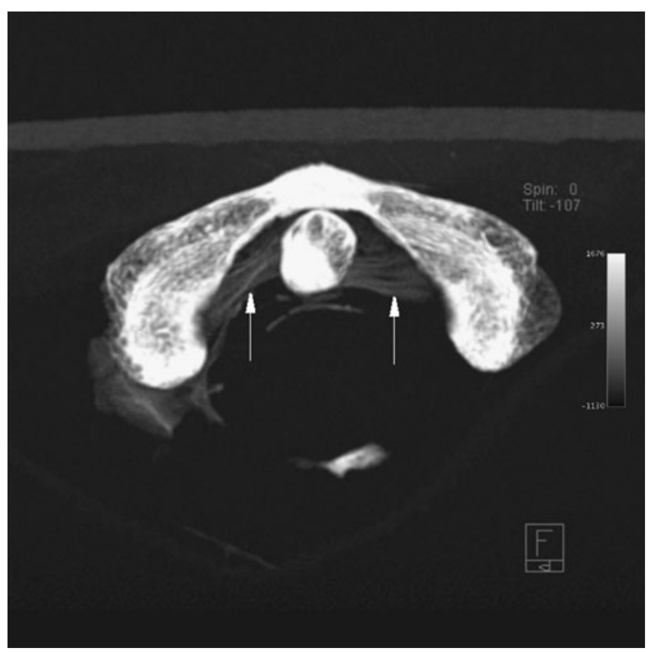


Fig. 6 Axial CT scan of the posterior arch and the two lateral masses of the atlas embracing the dens with the intact alar ligaments (*arrows*)

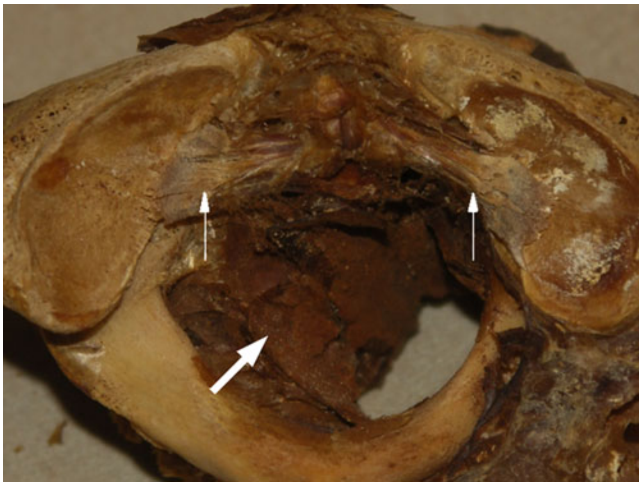


Fig. 7 Cranial view on the atlas with its superior articular facets of the lateral masses, which medially seem to be connected with the cranial endings of both alar ligaments (*arrows*). *Fat arrow* points to the dry intraspinal brownish hematoma

Finally, we performed a GC-MS analysis of a hair bundle to search for psychoactive substances that might have been applied to the individual during lifetime. In particular, cocaine consumption was to be investigated. However, no evidence for cocaine consumption was seen in the material, thereby fairly ruling out chronic drug consumption. However, an acute pre-mortal consumption of cocaine cannot be ruled out.

A subsequent stable isotope analysis of the hair sample with increasing distance to the head revealed considerable changes with time. Assuming an average growth of 1 cm of hair per month [8], the analysed hair strand of circa 9 cm length represents dietary changes of the last 9 months of

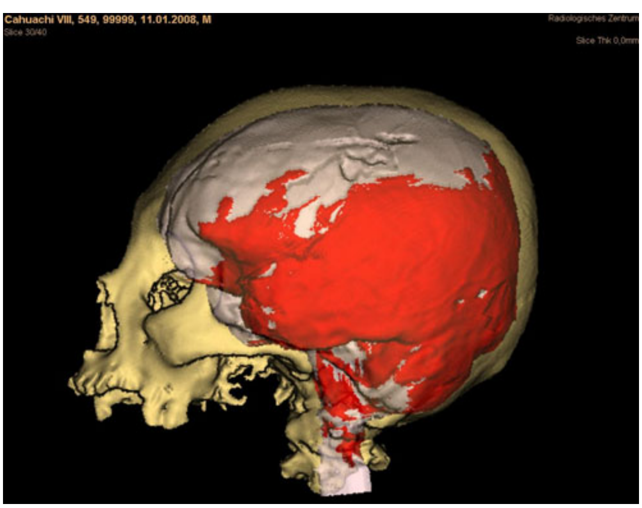


Fig. 8 Three-dimensional reconstructed skull with atlas and sub-luxated axis in the *left profile view* showing the extension of the intracranial and intraspinal hematomas (*red*)

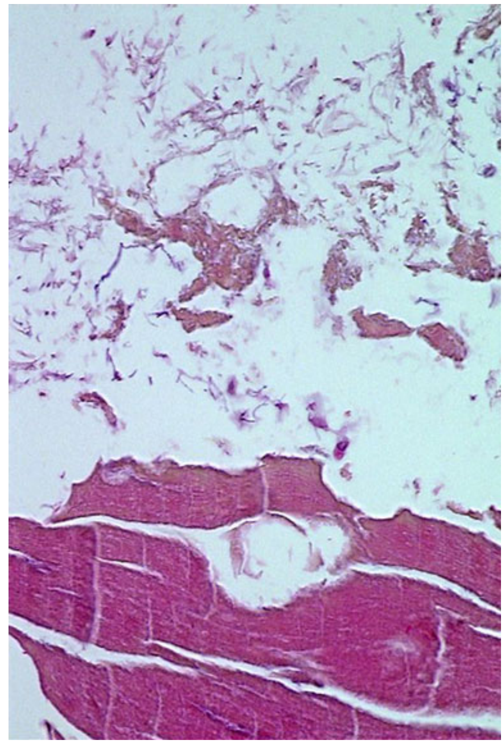


Fig. 9 Histological aspect of the hematoma margin. *Upper half*, amorphous brownish material; *lower half*, typical brain tissue structures with layered neurons (H&E; original magnification, ×400)

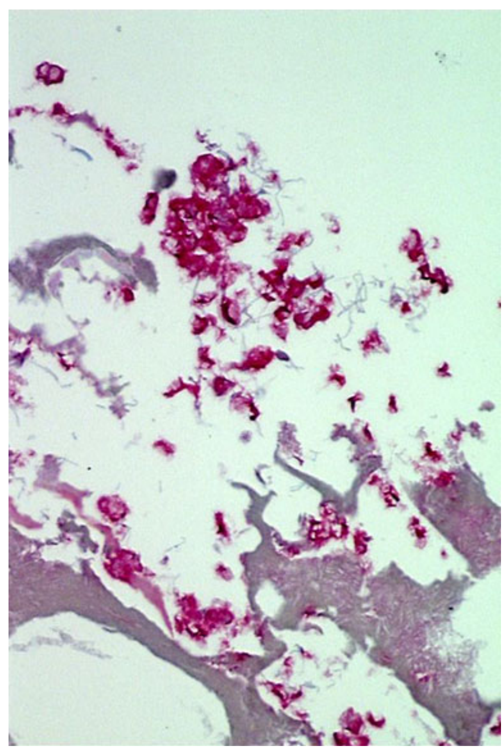


Fig. 10 Immunohistochemical staining for erythrocytes (glycophorin-C). *Upper half*, positively stained corpuscles with a diameter of 5–10 µm highly suggestive for erythrocytes. (Immunohistochemistry; original magnification, ×400)

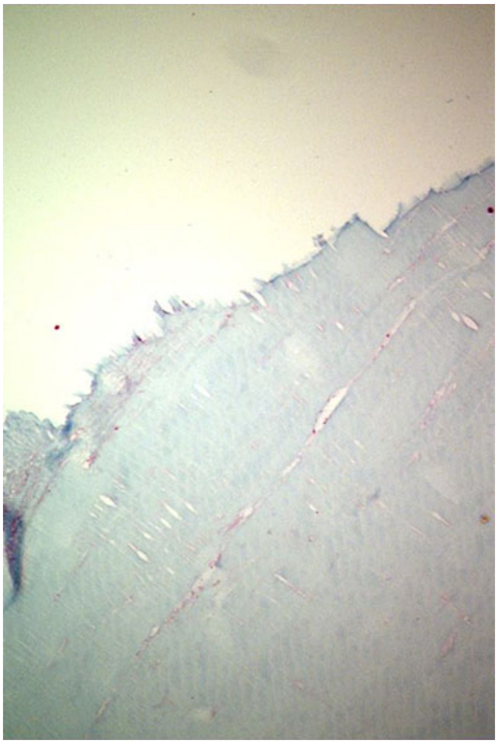


Fig. 11 Immunohistochemical staining for glycophorin-C in a dura sample showing negative staining results (negative control). (Immunohistochemistry; original magnification, ×400)

life of the individual. Low δ^{15}N and δ^{13}C values are suggestive for terrestrial food, and high δ^{15}N and δ^{13}C indicate a high content of marine food diet. In our mummy, we detected a decrease in both stable isotope values from 9 to 3 months before death and again an increase from 1 month prior to death until death (Fig. 12). The range of values indicates a change from a more marine to a more terrestrial nutrition and a return of the nutritional habit to marine food again in the last month before death.

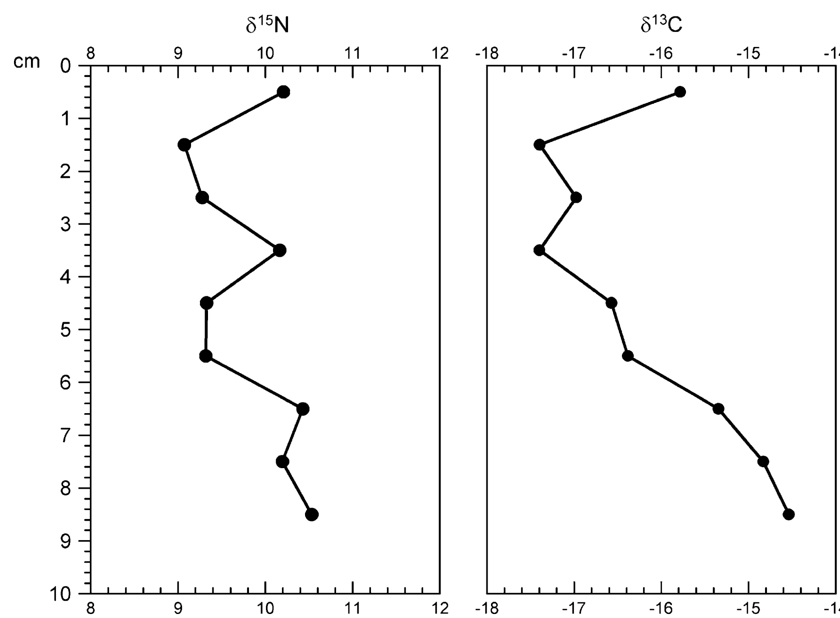
Discussion

In this report, we describe in the paleopathological a hitherto literature not reported case of a massive rotational trauma to the upper cervical vertebra leading to an acute and very extensive bleeding—most presumably from the left vertebral artery—extending into the epidural space of the upper cervical vertebra and the left skull. This type of lesion is today rarely seen, and descriptions are limited to case reports or smaller series.

We therefore provide circumstantial evidence that the massive right-sided dislocation of the axis led to a significant acute hematoma of the upper cervical spine extending into the skull cavity as an epidural hematoma of the left side. Unfortunately, in the 1930s, only the skull with the two attached vertebral bodies was transferred to Europe so that no further information on additional trauma sequels etc. is obtainable.

Additionally, we have only very limited data on the individual and its history as evidenced by the information given by the excavator, Dr. Ubbelohe-Döring. The individual, a mature man, was buried in a cemetery at the site of Cahuachi (South Peru), dating both archaeologically and by radiocarbon analysis into the era of the Nazca civilisation, which dominated the region of Southern Peru and Northern Chile for several centuries (between 0 and 700 AD). The artificial skull deformation of our individual is well in line with typical manipulations that have been performed frequently in that region and time period for cosmetic

Fig. 12 Nitrogen (δ^{15}N) and carbon isotope (δ^{13}C) ratios of hair. The *y*-axis indicates the hair length starting proximal. Low δ^{15}N and δ^{13}C values are indicative for increasing terrestrial food, and high δ^{15}N and δ^{13}C data indicate a proportionally higher share of food from marine sources respectively in the diet. During the last 9 months of the lifetime, the nutrition changed from mainly marine to terrestrial and again to marine sources



reasons. It remains unclear whether the colourful woven fabric of a high-quality material with at least seven different colours of stained wool may indicate higher social status of the individual or not.

As to the cause of death, we provide some evidence that the subluxation of the axis with the lesion of the left vertebral artery and a subsequent significant acute hematoma led to an acute compression of the spinal cord and/or medulla oblongata resulting in the death of the individual within a few minutes. This is assumed because of the significant narrowing of the cross-sectional area of the spinal canal to circa 30–40% of normal size. Thereby, the rotation trauma may have ruptured the wall of the left vertebral artery at the site, where the artery passes through the posterior atlanto-occipital membrane to enter the subdural space.

This hypothesis seems to be the most probable one. To the best of our knowledge, a similarly severe trauma comparable with the injury of this case has not been published. The still beating heart caused subsequent epidural and partly subdural hematomas at the level of both vertebrae, which enhanced the compression of the spinal cord. Furthermore, the hematoma extended between dura and bone within the skull on the left-hand side. The presence of an acute hematoma is confirmed by the immunohistochemical finding of only "fresh" erythrocytes in the "brownish material" by the positive glycophorin-C reaction. There was no evidence for old or recurrent bleedings due to a lack of haemosiderin.

Besides the subluxation and hematoma formation, the rotation trauma may have induced also a direct lesion of the medulla oblongata; while the spinal cord remained in a fixed position due to the stabilising effect of the denticulate ligaments, the medulla oblongata follows the rotation due to the external force. For most, cranial denticulate ligament inserts at the dura are only a few millimetres distant from the entrance of the vertebral artery into the subdural space [5].

Even another potential cause for the death of the individual can be discussed, based on anatomic variations of the vertebral arteries [4]. In case the left vertebral artery was the dominant source of supply to the basilar artery and consequently to the perforators of the brainstem, then its traumatic disruption as seen in our case would cause sudden brain stem ischemia and instantaneous death.

Finally, we may also discuss the underlying cause for the rotational trauma in this individual. There is the possibility that the affected individual received the trauma accidentally by falling from greater height—e.g. into a trap—and that the rotational trauma occurred when he hit the ground. However, in this case, we might have to expect in a considerable number of cases concomitant trauma lesions of the skull, e.g. skull fractures, etc., which have not been detected in our case. Alternatively, the male individual may have been subjected to an intentional homicide—e.g. as a religious sacrifice. This latter situation has generally been described in South American cultures frequently, although religious sacrifices have mostly been performed on young females, then, however, often associated with hits to the skull. Those victims additionally showed consumption of psychoactive drugs, such as cocaine, which our individual lacks.

Some further information on the individual comes from an additional analysis of stable isotope analysis, which provides insight into the nutrition of a deceased individual. Interestingly, the circa 9-cm-long hair sample shows a switch from a more marine diet (as evidenced by higher $\delta^{13}C$ isotope values along with nitrogen isotope values greater than 10‰) to a more terrestrial nutrition (suggested by low carbon isotope values around −20‰) [1, 3] and a further change again to a more marine nutritional intake during the last month of life. Although we can only speculate on the exact composition of the individual's nutrition, these changes are highly suggestive for mobility from a coastal area to a landside region and back to a region close to the seaside. At least for the last 9 months of the lifetime of the individual, we can conclude from the stable isotope analyses that he lived in a realm with either seasonally changing food sources or he moved his centre of life seasonally more close to the coast.

In conclusion, we present here the first known case of a severe rotational trauma to the upper cervical spine resulting in an acute lethal injury by acute epidural hematoma—extending into the skull. We have shown that modern scientific methods applied to a pre-Columbian mummy may yield information about an event dating back more than 1,000 years. Although the exact pathophysiologic mechanism of this trauma appears to be clear, we can only speculate about the underlying reason—for instance the probability of an intentional homicide.

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Conflicts of interest None.

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