ANTHROPOLOGIE • LVI/3 • pp. 143–162 • 2018

DORIS SCHAMALL, † HANNS PLENK Jr., MARIA TESCHLER-NICOLA

A CASE OF LYTIC METASTASES OF A CARCINOMA FROM THE OSSUARY AT HALLSTATT (UPPER AUSTRIA)

ABSTRACT: A cranium of a mature male (45–55 years) from a charnel house in Hallstatt, Upper Austria (set up in the 12th century and in use until modern times) exhibits multiple perforations that were most probably caused by a malignant tumour. The lesions vary between 44 and 4 millimetres in diameter and concern nearly all parts of the cranium (frontal, parietal, and occipital bone, maxilla), hereby pertaining to all cranial layers to a different degree. Osteolytic changes accompanied by some sclerotic bone formations are indicative of an active as well as chronic process at the time of death of the individual. Differential diagnosis was carried out by macroscopic inspection, the use of conventional radiography, computed tomography and scanning electron microscopy in the secondary electron- and backscattered electron-mode. Pathology-mimicking effects, diagenetic, and taphonomic damage as causative processes can be excluded. The same applies for various infectious diseases (mycotic, bacterial, tuberculous conditions) as well as several tumorous forms (Langerhans-cell histiocytosis, bone angioma, medullary plasmocytoma). The palaeopathological and clinical diagnostical criteria used suggest a secondary carcinoma.

KEY WORDS: Metastatic carcinoma – Cranium – Hallstatt charnel house – Austria – Modern times – Differential diagnosis by CT and SEM

PROLOGUE

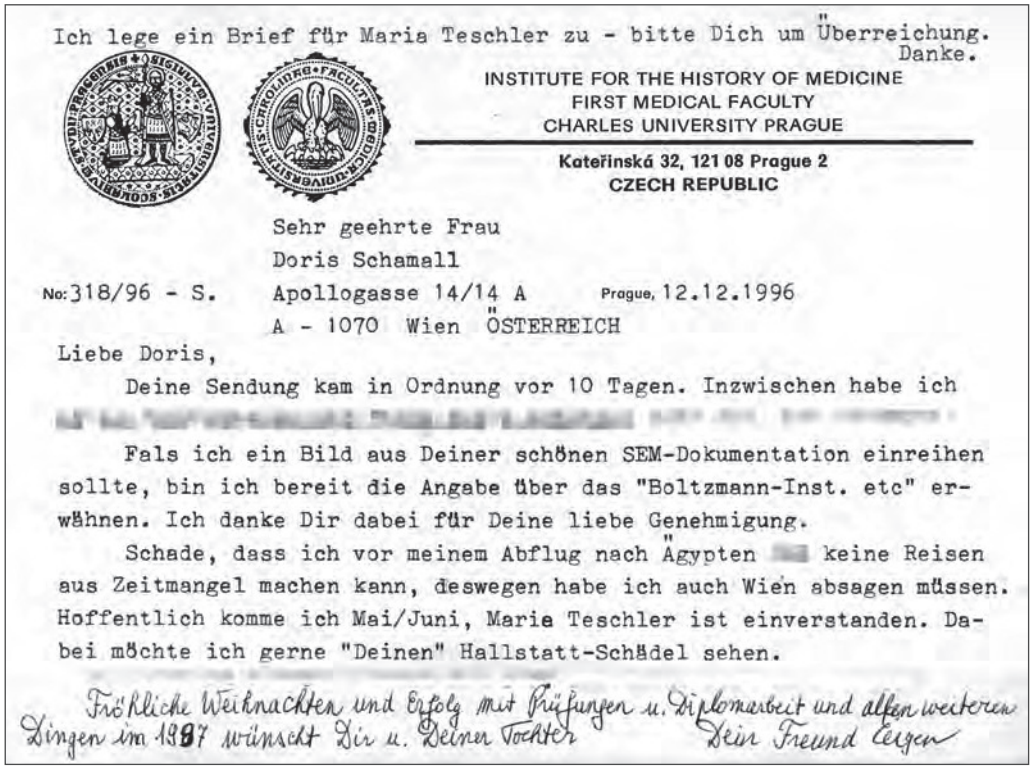
It is well known that Eugen Strouhal, physician and expert in a very broad variety of medical historical, archaeological, egyptological and anthropological, palaeopathological studies, was particularly interested in the history and paleopathology of neoplastic diseases. According to Zink (2012) "his deep interest in this topic was already apparent in his early publications on different neoplasms in ancient Egyptian remains" (Strouhal 1976, 1978a, b).

Received 20 June 2017; accepted 25 October 2017.

DOI: https://doi.org/10.26720/anthro.17.10.25.1

Among the tremendous number of his clear and detailed descriptions of the pathological evidence are several outstanding cases of unusual benign tumors, e.g., of (angio) fibromas and osteomas (Strouhal *et al.* 1996), calcified myomae uteri (Strouhal, Jungwirth 1977), and a very rare case of a sacral neurilemmoma (see Strouhal, Jungwirth 1970). The majority of his contributions dealt with the differential diagnosis of malignancies, e.g., multiple myelomas (among them the middle Neolithic specimen from Mauer/Vienna, Strouhal 1991a), a (probable) epipharyngeal carcinoma (Strouhal 1978a), and different forms of (mixed) metastatic carcinomas), see Strouhal 1976, Strouhal 1978b, Strouhal 1980, Strouhal, Vyhnánek 1981 and 1987, Strouhal 1989, Strouhal, Kritscher 1989 and 1991, Strouhal 1991b, and 1991c, 1992, 1993, 1994, 1995a and 1995b, Strouhal *et al.* 1995, Němečková *et al.* 1995, Strouhal *et al.* 1996, 1996a, and 1996b, Strouhal 1996a and 1996b, Duhig *et al.* 1996, Mays *et al.* 1996, Strouhal 1997, Strouhal *et al.* 1997, Horáčková *et al.* 1997, Strouhal 1998a, 1998b, 1998c, 1998d, and 1998e, Vyhnánek *et al.* 1998, Němečková *et al.* 1998a and 1998b, Wakely *et al.* 1998, Vyhnánek *et al.* 1999, Strouhal 2000, Strouhal *et al.* 2000, Strouhal 2001, Šefčáková *et al.* 2001, Strouhal, Němečková 2004 and 2008, Strouhal 2009, Strouhal *et al.* 2009, Němečková *et al.* 2009, Strouhal *et al.* 2010, 2010a, and 2010b). Thus, his efforts were always oriented to "establish profound differential diagnoses for malignant tumours that appeared to be very difficult to distinguish in dry bones" (Zink 2012). This interest was also already mirrored in a statement in 1994, where he attempted to "collect all available published evidence, thus creating a database for more detailed study" of malignant tumours. Moreover, he also asked for the sending of "news of new findings of malignancies" that he would deeply appreciate (Strouhal 1994).

In 1996, he became attracted to a skull originating from the Hallstatt-charnel house (inventory number of the NHM Vienna: MN 7632), that was under study by one of the authors (Schamall 1996, *Figure 1*). In terms of features, this case resembles a specimen from an ossuary at Křtiny (Czech Republic) that was diagnosed by Strouhal *et al.* (1996) as a "unanimously [...] presence of osteolytic metastases of carcinoma". In view of the fundamental need he pointed out already many years ago (Strouhal 1994) and in regard of the still actual scientific relevance of this topic, we aim to enlarge the database of malignancies he suggested by the present study of the Hallstatt-skull.



Ich lege ein Brief für Maria Teschler zu - bitte Dich um Überreichung.
Danke.

INSTITUTE FOR THE HISTORY OF MEDICINE
FIRST MEDICAL FACULTY
CHARLES UNIVERSITY PRAGUE

Kateřinská 32, 121 08 Prague 2
CZECH REPUBLIC

Sehr geehrte Frau
Doris Schamall
Apollogasse 14/14 A
A - 1070 Wien ÖSTERREICH

No: 318/96 - S. Prague, 12.12.1996

Liebe Doris,

Deine Sendung kam in Ordnung vor 10 Tagen. Inzwischen habe ich

Fals ich ein Bild aus Deiner schönen SEM-Dokumentation einreihen sollte, bin ich bereit die Angabe über das "Boltzmann-Inst. etc" erwähnen. Ich danke Dir dabei für Deine liebe Genehmigung.

Schade, dass ich vor meinem Abflug nach Ägypten keine Reisen aus Zeitmangel machen kann, deswegen habe ich auch Wien absagen müssen. Hoffentlich komme ich Mai/Juni, Marie Teschler ist einverstanden. Dabei möchte ich gerne "Deinen" Hallstatt-Schädel sehen.

Fröhliche Weihnachten und Erfolg mit Prüfungen u. Diplomarbeit und allen weiteren
Lingen im 1997 wünscht Dir u. Deiner Tochter Dein Freund Eugen

FIGURE 1: Personal correspondence 1996 (private collection DS).

INTRODUCTION

Skeletal evidence of cancer in the past

Evidence of neoplastic disease has already been reported for pre-human fossils as well as for early hominins (e.g., Leakey 1936 and 1953, Montagu 1957, Tobias 1960, Stathopoulos 1975, Capasso 2004, Phelan *et al.* 2007, Johnson 2013, Odes *et al.* 2016, Randolph-Quinney *et al.* 2016). Besides the historically oldest and variously interpreted case of Kanam in Kenya (e.g., Leakey 1936, Tobias 1960, Phelan *et al.* 2007), two recent contributions evidenced osteogenic neoplasms in specimens belonging to the extinct human lineage: the earliest hominin cancer, an invasive benign osteoid osteoma in the spine (Vertebra U.W. 88-37), dates to approx. 1.9-million-years and was diagnosed in a juvenile skeleton of *Australopithecus sediba* form the Malapa site /South Africa (Randolph-Quinney *et al.* 2016). The great antiquity of neoplasms became subsidised by a second specimen while re-analysing a 1.8 to 1.6-million year old hominin metatarsal fragment from Swartkrans (SK7923), Cradle of Humankind (South Africa) that exhibits an osteosarcoma (Odes *et al.* 2016). Also within the Palaeolithic human fossil record of the Neandertals, a species known as being the best represented, two cases, a fibrous dysplasia in a rib recovered from the Krapina site and a possible benign alteration that concerns the parietal bone of the Stetten II specimen, have been reported (Monge *et al.* 2013, Czarnetzki 1980). Proliferative changes of benign nature were, e.g., identified in the Upper Palaeolithic findings of Mladeč as well (Teschler-Nicola *et al.* 2006). Such alterations have – in contrast to malignancies – quite often been registered in ancient human relics, but not systematically. Primary malignant bony tumours were rare in prehistoric times due to several reasons: taphonomic changes/artefact of preservation and sampling bias (Odes *et al.* 2016), low mean life expectancy among pre-modern societies, inadequate diagnosis due to the lack or limitation of soft tissue, and inefficient imaging techniques (Becket 2010), or researchers did not have a sufficient diagnostic expertise and/or were preoccupied with other research aims (Strouhal 1994). Following Odes (2016), the rare incidence of evidence of neoplastic disease "can be seen as most-likely non-representative, and should not be construed as indicating the true prevalence". It always has been a great concern of Eugen Strouhal to increase the number of published tumorous cases (e.g., Strouhal 1976, 1994) by applying state of the art methods. He not only encouraged the use of promising new techniques, but also the appropriate inclusion of homologue clinical series to gain a plausible diagnosis. New historical evidence is still forthcoming and provides a window into the expression, aetiology, and pathogenesis, herewith contributing to the understanding and evolution of the development of neoplastic diseases.

Hallstatt

Hallstatt is a small market town in Upper Austria, located approximately 300 km to the west of Vienna (Austria). It is famous for its mining of salt since prehistoric times and is also worldwide unique for an ossuary in which human remains are stored and grouped by families for generations. This Charnel House of Hallstatt is in the basement of the church of St. Michael which was erected in the 12th century AD. Since that time, crania as well as selected long bones were excavated from the small cemetery at Hallstatt and placed in the charnel house. From the 17th century onwards, it became a custom in Hallstatt (but was also a wide-spread local tradition in several regions surrounding the Alps in Austria and Germany) to decorate recovered skulls to honour ancestors, when requested by the families (Sauser 1952, Burgstaller 1961, Martinez-Abadias *et al.* 2009). Thus, special skulls were subjected to a ritual that included cleaning, bleaching, and drying for some weeks and decoration of the forehead. Today, the ossuary of Hallstatt contains ca. 1200 skulls; about 700 of them are painted. (Besides a Maltese cross on the frontal bone in most of the cases, specific garlands of flowers on females and wreaths of oak or ivy in males adorn the crania. Additionally, the grave digger painted records of names, births, deaths, and marriages of the deceased.) To date, skulls are still entombed sporadically, the latest in 1995. The long bones of the individuals are collected and stored too, but their individual associations (e.g., to a cranium) remain unclear as there are no inscriptions on them (www.hallstattaustria.net/the-painted-skulls-of-hallstatt). In the 1920s/1930s, the object under study, a calvarium, was acquired by Viktor Lebzelter (1889–1936), curator at the Department of Anthropology at the Natural History Museum Vienna, and included into the Osteological collection (inventory number of the NHM Vienna: MN 7632). It has no decoration, but it attracted our interest with its evidence of advanced osteolytic and osteosclerotic alterations.

METHODS

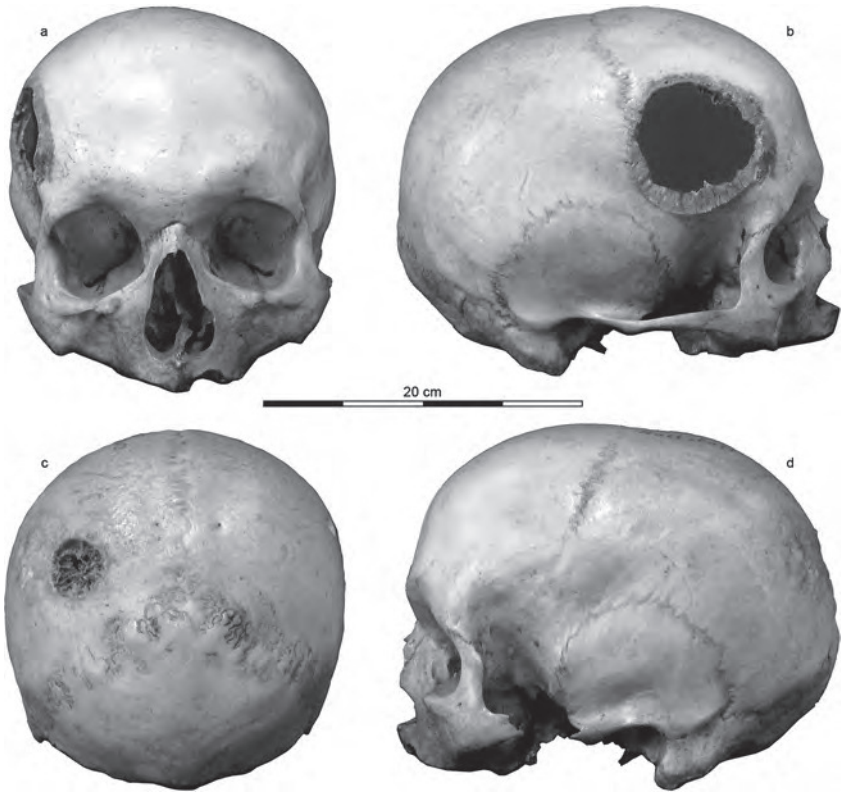
The calvarium was investigated by applying standard anthropological methods (Knußmann 1988). Age-at-death was estimated based on the obliteration status of the endo- and ectocranial sutures and the condition of the teeth, the premortal tooth loss and degree of resorption of the alveolar process. The determination of sex was carried out by inspection of the morphological standard markers, e.g., the form of the supraorbital structures, the forehead morphology, the orbital form, the form and dimension of the mastoid process and the muscle insertions at the nuchal plane. The pathological changes were first examined using non-invasive methods, including a macroscopic inspection (and the use of a magnifying lens), conventional radiography (Philips Compact Diagnost 1), and computed tomography (Philips Tomoscan SR 7.000). Thereafter, bone samples were taken and examined as non-decalcified sections in SE-mode in a SEM (Zeiss DSM 962), then embedded in polymethylmethacrylate, sectioned, polished, sputtered with carbon, and imaged in BSE-mode in the SEM by use of a four-quadrant solid state detector (Boyde *et al.* 1986).

CASE STUDY – RESULTS

Macroscopic inspection

Estimation of sex and age-at-death

The very well preserved skull without post-mortem damage most probably belongs to a mature male (aged 45–55 years): the calvarium is robust with considerably developed muscular relief (*Figure 2*); the glabella and superciliary arches are weak; the forehead slopes slightly obliquely; the frontal eminences are mildly marked; the external occipital protuberance, the mastoid process and the supra-mastoid crest are well pronounced; features of the facial skeleton are non-specific (zygomatic bones and arches are not very robust, the supraorbital margin is moderately rounded and the orbits are approximately squared).



FIGURES 2: Skull MN 7.632. Calvarium of a 45–55 year old male, in (a) frontal, (b) right lateral, (c) occipital, and (d) left lateral view.

With one exception – the left lateral incisor (tooth 22) – all teeth were lost intra vitally; endocranially, the sutures are obliterated except the bregmatic part of the sagittal suture and the lateral two thirds of the lambdoid suture; ectocranially, the lateral parts of the coronal suture are obliterated, the rear portion of the sagittal suture is in obliteration, so are the medial portions of the lambdoid suture.

Pathological alterations

Macroscopically, a minimum of 11 round to oval shaped sclerotic, porotic, or lytic changes of variable dimensions are detectable:

Defect 1 (*Figure 3*): On a macroscopic scale, a large lytic defect is apparent in the lower posterior part of the frontal bone (*Figure 3*). Its posterior edge gnaws a lateral part of the coronal suture. The predominantly lytic area has an approximately circular outline of 44 × 40 mm, with a denticulated margin. Additionally, a broad sclerosis (about 1 cm in breadth) protrudes the external and internal lamina up to 3 mm – very closely resembling a case presented by Strouhal *et al.* (1996a). This sclerosis partly exhibits zones of porous bone caused by osteoblastic reaction.

Defect 2 (*Figure 4*): This defect is located towards the occipital angle of the left parietal bone, at the height of the parietal eminence; its posterior edge is about 2 cm above the lambdoidal suture. This bony alteration is circular and sized to 23×21 mm, the margin is hallmarked by rounded to serrated notches. This lesion is bordered by a slight sclerotic tipped edge at the external lamina, especially medially, whereas such a thickening is not visible internally. Within the afflicted area, the external lamina is completely dissolved; the diploe is reduced – its bony remnants are arranged to radial spicules giving the appearance of a "sunburst"; however, the destructive process concerns the internal lamina only in parts, though, it is perforated, but not remodelled.

Defect 3 and 4: They are visible by inspection through the greater occipital foramen and concern

FIGURE 3: Skull MN 7.632. Calvarium of a 45–55 year old male with a large perforating lesion on the right side of the frontal bone.

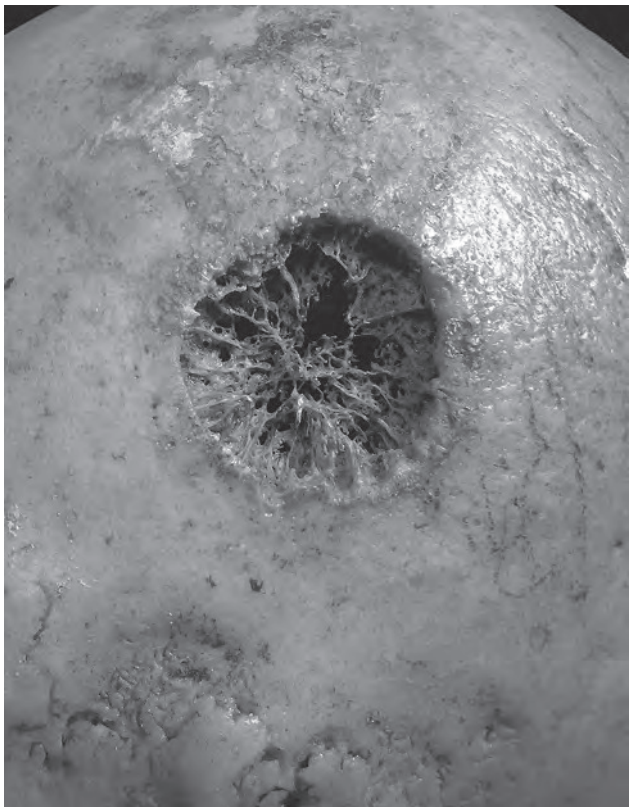


FIGURE 4: Skull MN 7.632. Lysis of the external table, radial spicules of the diploe and partial perforation of the internal table of the left parietal bone.

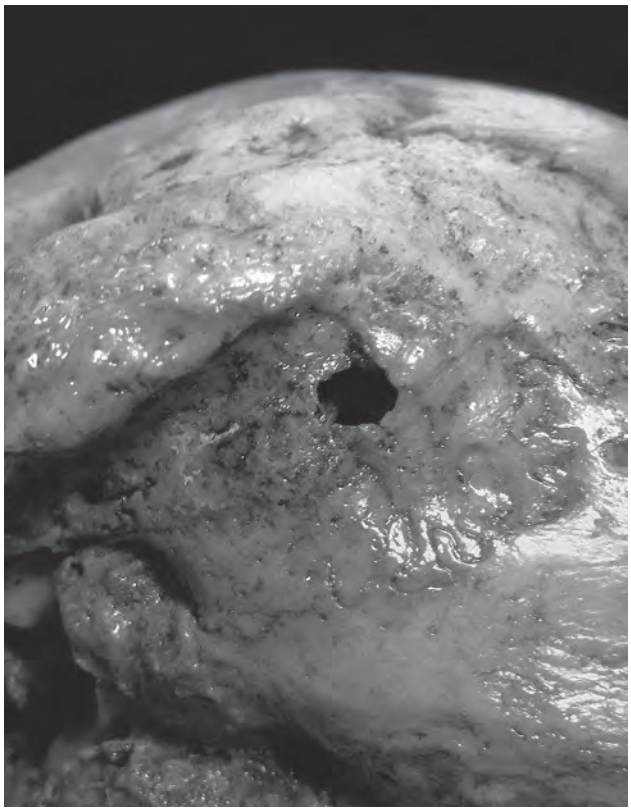


FIGURE 5: Skull MN 7.632. Lysis of the external table and partial destruction of the diploe and internal table of the temporal bone.

FIGURE 6: Skull MN 7.632. Lysis of the external table and radial spicules of the diploe of the left occipital condyle.

circled defects located on the right parietal bone. Both are hallmarked by an irregularly shaped, but distinctly limited contour pertaining the internal lamina exclusively.

Defect 5 (*Figure 5*): Beside and slightly dorsal of the left mastoid process, adjacent to the occipito-mastoid suture, another small lesion occurs. The pathological process concerns all three cranial layers: externally the defect is oval shaped (dimension 5×3.5 mm), and the outline sharply bordered. The internal layer is perforated and a few diploic structures remain as spicules.

Defect 6 (*Figure 6*): The lateral part of the left condyle shows a destruction of the external lamina and a feeble formation of diploic spiculation; the internal lamina seems to be intact.

Defect 7 (*Figure 7*): Directly adjacent on the left edge of the clivus, along the petro-occipital fissure, there is another focus visible as bony tumescence. Its surface is partly degraded. Inspection through the great occipital foramen reveals that the internal side of the clivus is affected by a largely extended lysis. Already like several other foci, the diploe shows spiculation.

Defect 8 and 9: Taking a view through the large circled defect (on the frontal bone) towards the frontal crest, we identified two more small foci beside it, approximately at the height of the frontal bosses. Externally, this process did not modify the surface.

Defect 10 (*Figure 8*): On the anterior surface of the maxilla, around the alveolar canal of the left lateral incisor, a destructive process has reduced the alveolar body of the maxilla considerably in height accompanied by bony swelling of the regular contour of the dental process and spiculation of the alveolar duct.

Defect 11 (*Figure 9*): The Hallstatt specimen shows a further conspicuous alteration concerning the area around the left middle nasal concha: it is characterised

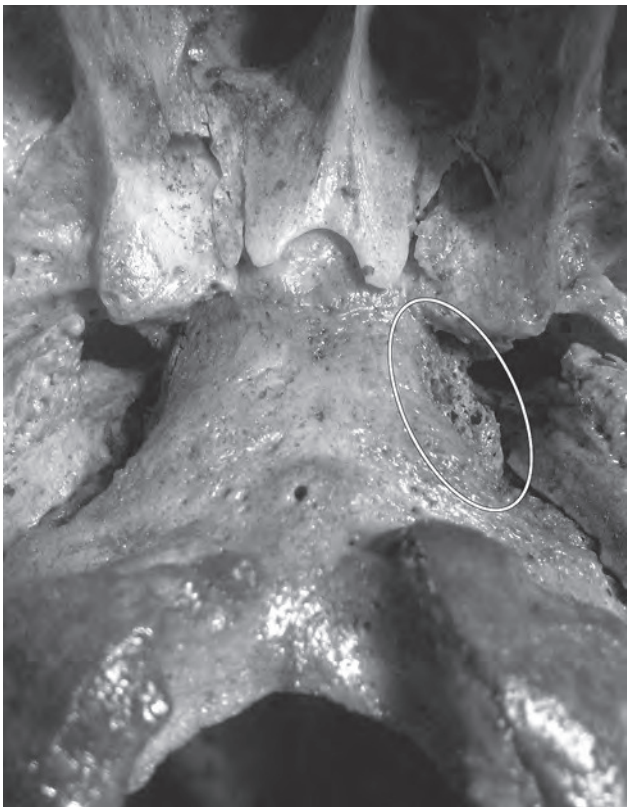


FIGURE 7: Skull MN 7.632. Tumescence and disaggregation of the *Pars basilaris* concerning the external table at the petro-occipital fissure.

FIGURE 8: Skull MN 7.632. Substance loss around the left lateral incisor, reduced height of the body of the maxilla and formation of spicules.

by a tumescence and slight formation of spicules on the lower edge of this concha and laterally adjacent to it, respectively.

Conventional radiographs

Radiography shows only some of the macroscopically observed lytic areas as radiolucent zones. In antero-posterior projection (*Figure 10*), the huge defect (HD) on the right side of the frontal bone and the overlapping of one defect (D) located on the right parietal bone are viewable. Possibly even the second circular substance loss (SL) on the right parietal bone is superimposed within this image. Impressive is another "punched-out" zone (POZ) on the left parietal bone, and small irregular defects (ID) along the internal frontal crest.

In lateral projection (*Figure 11*), seven defects become evident, three of which are clearly verifiable: the big defect on the frontal bone (D1) and the two smaller ones in the right parietal bone (D2 and D3). These defects are located directly or very close to the branches of the middle meningeal artery. The forth defect (D4), situated in the left parietal bone adjacent to the parietal foramen and well visible macroscopically as well as in antero-posterior x-ray, is difficut to identify in this projection due to the fact that it is located within the radiodense cranial bone. Furthermore, in the peripheral rim of the large frontal lytic zone we can assume distinct, less dense sectors (D5) that seem to correspond to the bony modifications observed beside the frontal crest. Lastly, the substance defficiency at the alveolar ridge (D7) is also clearely recognisable.

CT-images

The computed tomographic images reveal even more details and foci: the first transversal scan (*Figure 12*)

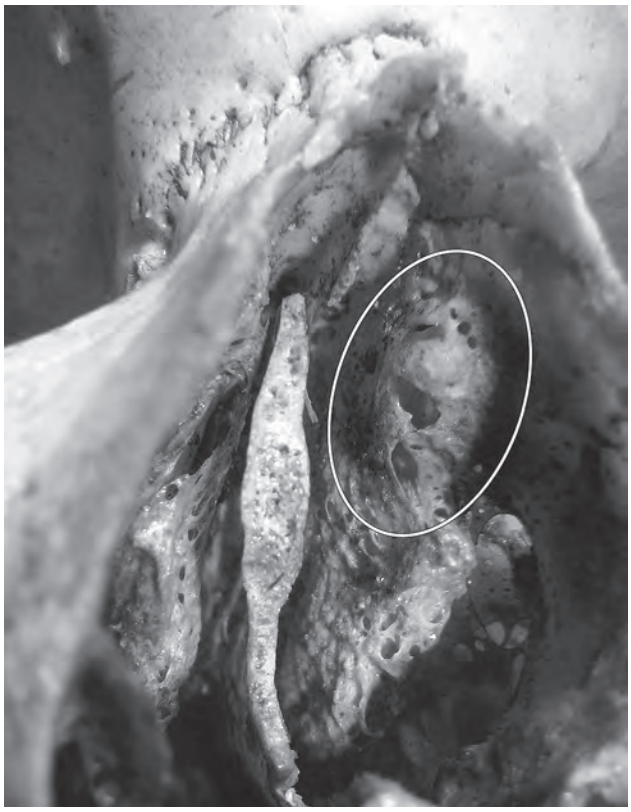


FIGURE 9: Skull MN 7.632. Close-up in the nasal cavity. Swelling, spicules, and perforation of and around the medium turbinate.

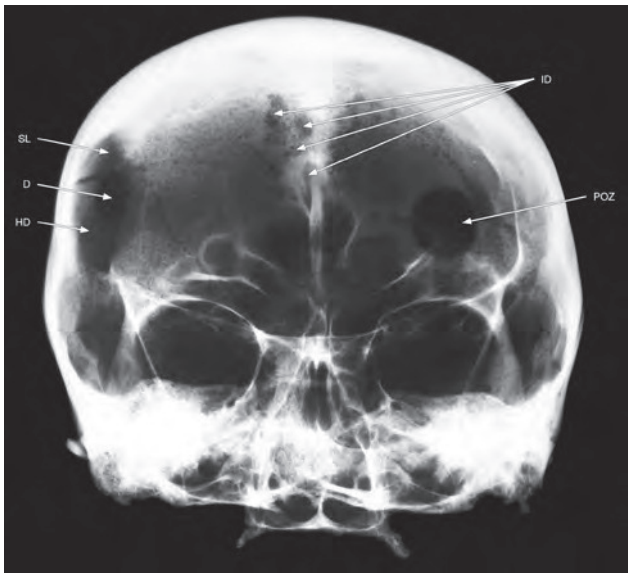


FIGURE 10: Skull MN 7.632. Radiography (antero-posterior view) shows only some of the macroscopically observed lytic areas as radiolucent zones.

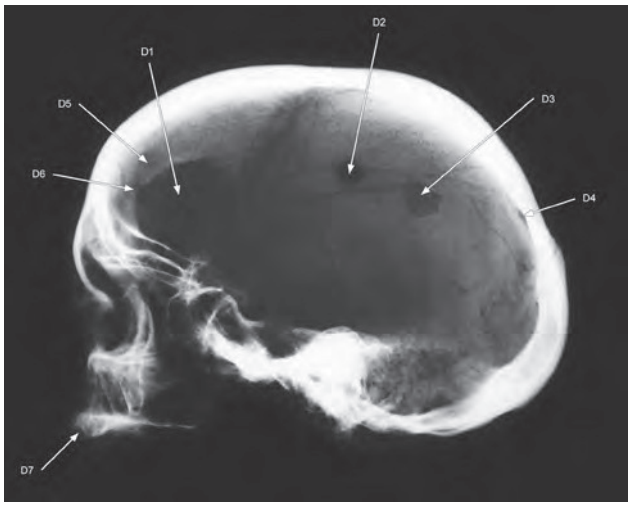


FIGURE 11: Skull MN 7.632. Radiography (lateral view) indicates several, but not all lesions.

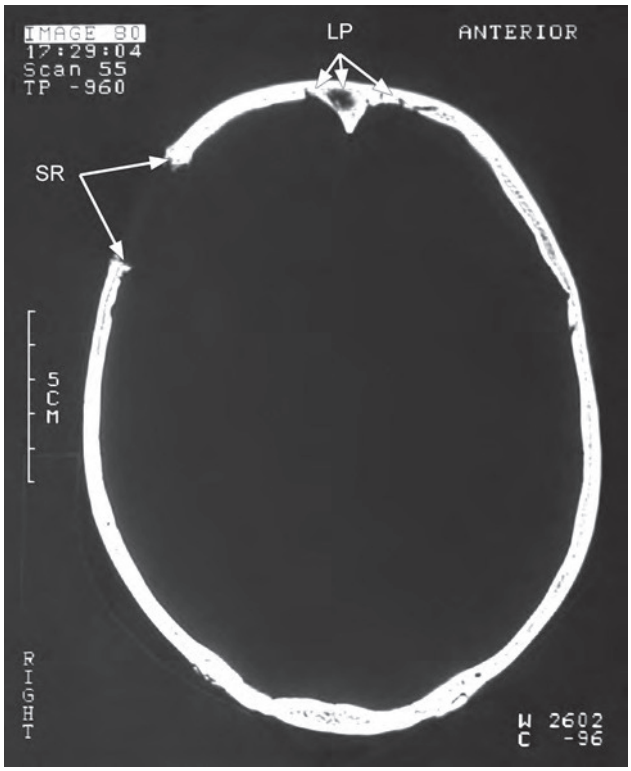


FIGURE 12: CT-scan in transversal plane demonstrates three defects at the frontal bone: lytic processes (LP) and partly sclerotic reactions (SR).

shows four lesions at the frontal bone in overview. The largest defect on the right side of the individual (left in the image) is characterised by irregularly frayed margins with sclerotic reactions (SR), which become more evident by this technique than by x-ray. Two other lytic processes (LP) are located along the internal frontal crest and erode the internal lamina, but are sparse in the external table. In addition, a lytic defect within the crest itself becomes evident when it only concerns the diploe.

The lytic effectiveness of the pathological process that resulted in complete destruction of the outer continuity is shown in detail (*Figure 13*): irregular "gnawing" concerns all three bony layers, but reactive sclerosis (SR) occurs exclusively at the external and internal laminae. There are two alterations (D1 and D2) on the internal lamina along the frontal crest (already identified by macroscopic and radiologic inspection – see *Figures 10–11* – as well as by the foregone overview depictured in *Figure 12*) that seem to represent initial stages of foci as the destruction concerns only the internal and medial layer. Additionally, the defect (D3) within the crest itself is clearly proliferated when compared to *Figure 12*. There is no sclerosis at these three lesions.

The macroscopically visible "sunburst" formation (SF) on the left parietal bone is clearly approved by

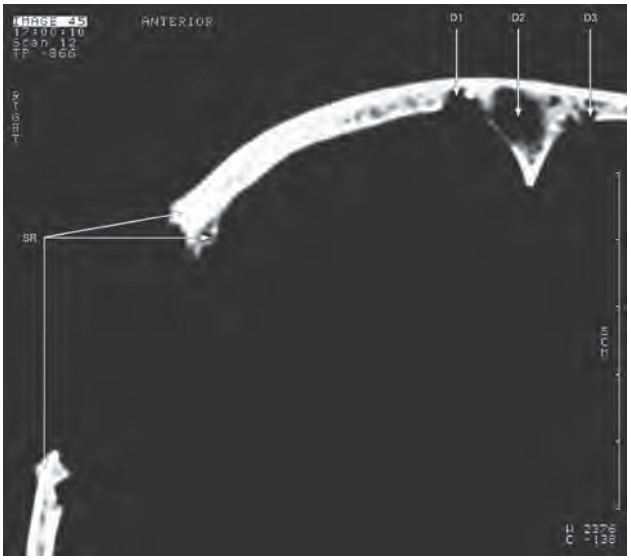


FIGURE 13: The computed tomographic transversal scan shows the largest lesion within the frontal bone with sclerotic reactions (SR) and three further defects (D1–D3) along and within the frontal crest without sclerosis.

the CT inspection. It differs only by a seemingly intact external layer (The latter is an artefact that results from the selected plane in a boundary area of the defect). The diploe is reduced leaving "crumbled" structures (*Figure 14a*). In another plane – a more central section – the details of this defect can be depicted (*Figure 14b*): the process has corroded the external table as well as the diploe; the internal table is damaged, but intact. The ogive-like arranged spicules (see *Figure 4*) are not pictured in this plane. However, on the right parietal bone, two further defects (FD) occur that penetrate all three bony layers (*Figure 14a*). This finding does not correspond to the macroscopic observation that did not face any defects there. Moreover, three additional modifications on the internal lamina come to the fore: rightly adjacent to the sagittal suture is a process (P) that affects both, the internal and medial layers. There are two other potential modifications (PM) located on both parietal bones close to the coronal suture and several small decongestions within the diploe especially on the right part of the frontal bone (seen here on the left side).

In frontal plane, the CT-image reveals even more very small defects (SD) close to or at the cranial base. These are either limited to the diploe, as represented on the right lateral portion of the occipital bone (*Figure 15a*, left) or additionally include the internal lamina (*Figure 15a*, right); however, there is no sclerotic "response", nor is the external table affected.

The detailed scan in frontal plane shows sharply limited extended destructions (ED) within the diploe close-by the occipito-temporal suture (*Figure 15b*); it concerns both the occipital bone as well as the temporal bone. The inner layers of both cranial elements are markedly thinned.

Another CT-image (*Figure 16*) was taken in frontal plane from a more ventral position than *Figure 15a*. It points out a structural disaggregation (SD) within the diploe of the marginal area of the dorsal defect on the right parietal bone. Both adjacent outer cranial layers are not affected. At the cranial base, the pathological alterations (PA) – as seen in *Figures 15a–15b* – proceed.

Figure 17 is a scan in frontal plane taken more ventrally than *Figure 15a*. It depicts a rostral area of the dorsal defect (D) on the right parietal bone. The lysis has grasped the diploe and the internal lamina. Directly right of the sagittal sulcus, an initial stage of a further focus (F) is visible that concerns both inner cranial layers.

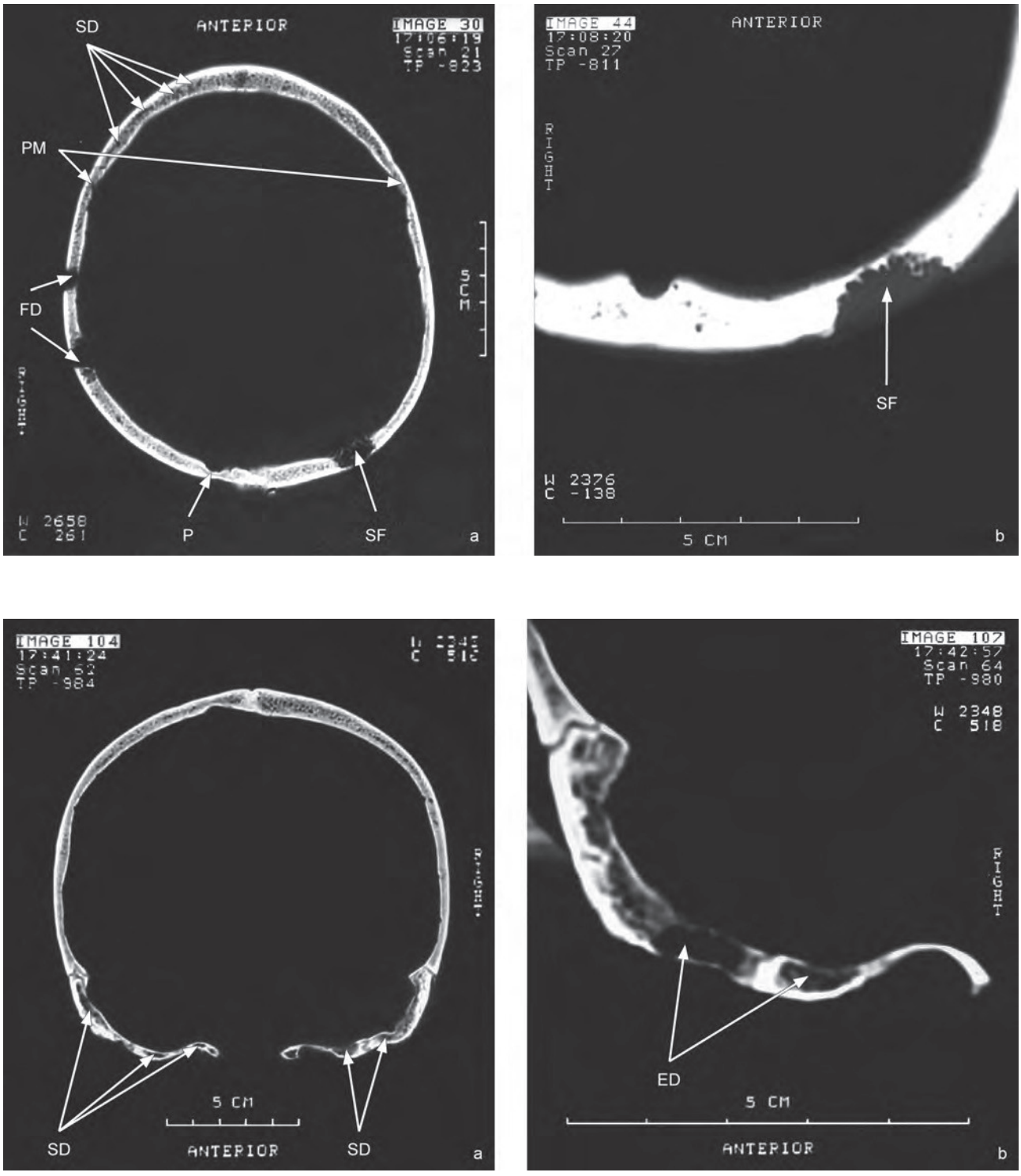


FIGURE 15a: The computed tomographic frontal scan shows a loosening of structures due to defects (SD) within the diploe and internal lamina on the lateral portions of the occipital bone.
FIGURE 15b: The computed tomographic frontal scan shows details of the right cranial base with affected areas by extended destructions (ED).

←
FIGURE 14a: The computed tomographic transversal scan shows already detected lesions by macroscopic and radiologic examination as well as further hitherto unidentified foci: small decongestions (SD) within the diploe, a dorsally situated process (P) affecting the internal and medial layer, two further defects (FD) seemingly penetrate all cranial layers, and potentially pathological modifications (PM).
FIGURE 14b: The computed tomographic transversal scan shows destruction of the external and middle layer of the cranial bone and the affected, but continuous sustained inner layer in the zone of the macroscopically visible "sunburst" formation (SF). Additionally, a slight impression rightly adjacent to the sagittal suture occurs that corresponds with the occipital alteration of *Figure 14a* and points to a further process (P).

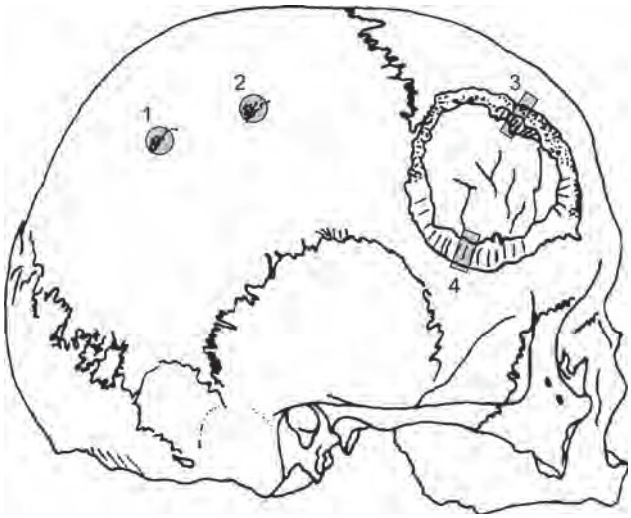


FIGURE 18: Schematic presentation of the skull MN 7.632 with the four areas (grey coloured, no. SEM 1–4) taken for SEM investigation.

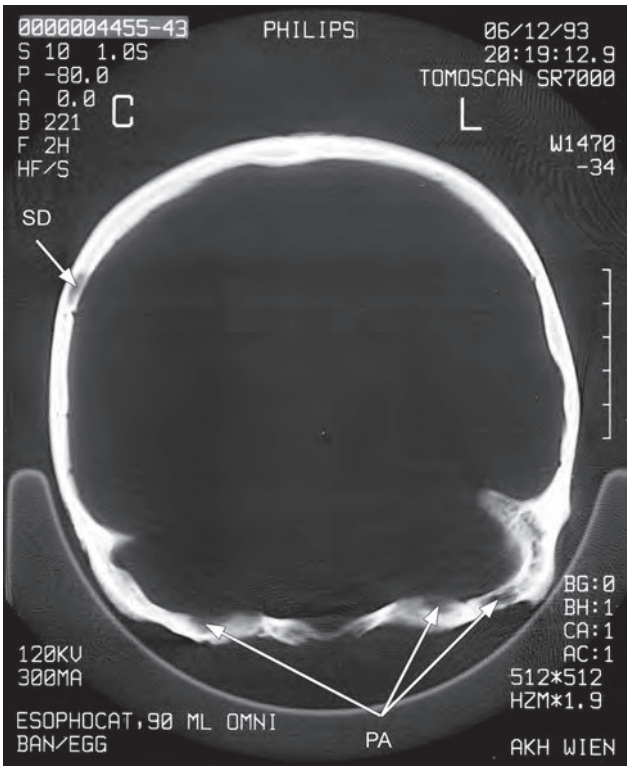


FIGURE 16: This computed tomographic frontal scan shows disaggregation of structures (SD) within the diploe on the right parietal bone and affection of the diploe and internal lamina by pathological alterations (PA) at the cranial base.

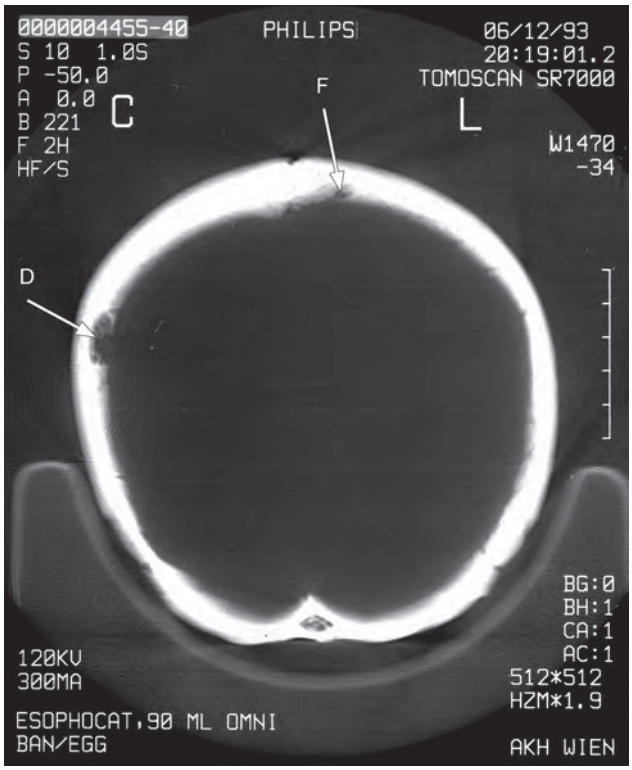


FIGURE 17: The computed tomographic frontal scan shows disaggregation of structures within the diploe and internal lamina on the parietal bones: an already recorded defect (D) and a new focus (F).

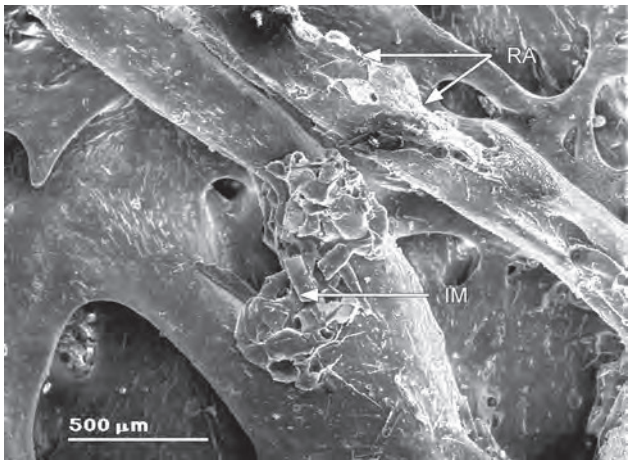


FIGURE 19: SE-mode in the SEM: resorption activities (RA) on a bony trabecula and apposition of inorganic material (IM) (× 50).

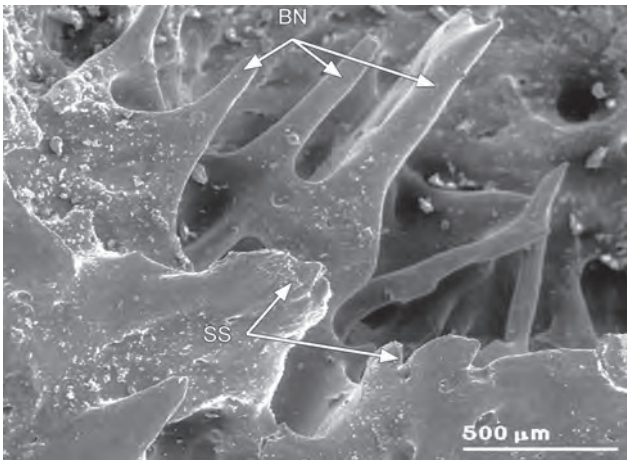


FIGURE 21: View in SE-mode in the SEM from the upper sclerotic region of the frontal bone (SEM 3): dense sclerotic structures (SS) on the periosteal side and bone needles (BN) on the endosteal side of the internal table (× 50).

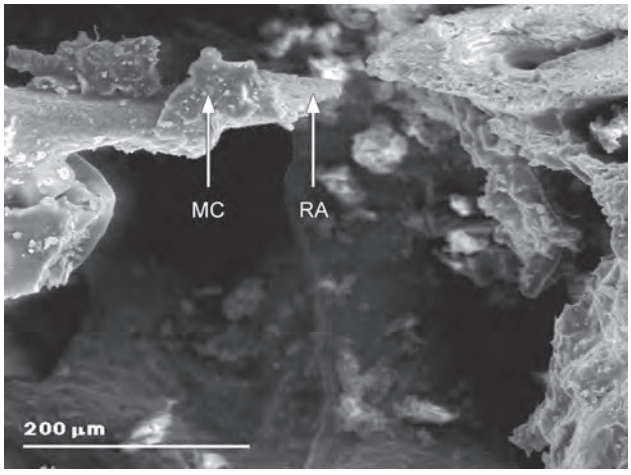


FIGURE 20: View in SE-mode in the SEM from the lower sclerotic region of the frontal bone (SEM 4) representing resorption activity (RA) resulting in the loss of the trabecula continuity and overgrowth by a micro-callus (MC) (× 200).

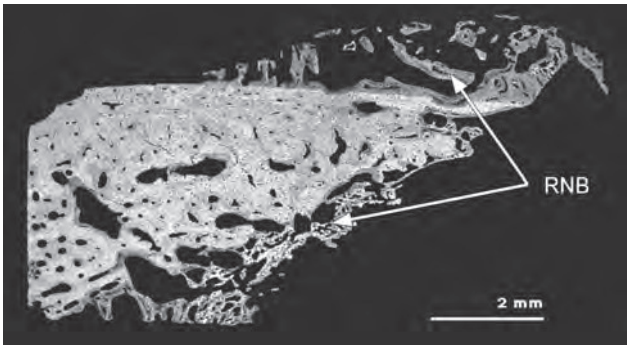
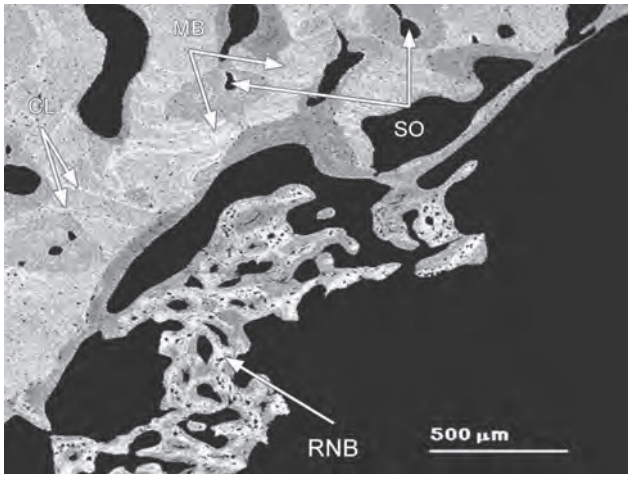


FIGURE 22: BSE-SEM image of the upper sclerotic region of the frontal bone (SEM 3): reactive new formation of bone tissue (RNB) along the destroyed former contour and the diploe (× 13).



→

FIGURE 23: Detail of *Figure 22*: BSE-SEM image shows the state of resorption and remodelling by reactive new bone formation (RNB) in the form of woven bone and new lamellar bone, mosaic bone (MB) – characterised by irregularly arranged lamellar bone structure – around secondary osteons (SO) and spongy bone (× 50).

Scanning electron microscopy

From the right parietal bone, two bone samples (SEM 1 und SEM 2) from the internally affected area were drilled out. Two additional samples (SEM 3 and SEM 4) were taken from the margin of the large lytic defect.

Secondary electron (SE)-mode in the SEM

Several microstructural changes could be identified by use of this technique: in *Figure 19*, a detailed image of SEM 2 is shown. As the internal lamina is completely dissolved by an osteolytic process, the diploe is exposed. In the right upper half of this image, a trabecula exhibits enlarged resorption activities (RA); thus the residual rod remains fragile. Below this structure, a micro-callus is probably even visible, that is covered by post mortally acquired inorganic material (IM).

Figure 20 depicts a detailed image of the lower sclerotic region of the frontal bone (SEM 4). The trabecula is disrupted; its ends are already tapered. This criterion argues against a pathological fracture. The left end of the ruptured trabecula seems to be overgrown by a micro-callus (MC) that followed a preceding fracture.

In the next SE-SEM image (*Figure 21*), further details of the upper sclerotic region of the frontal bone can be seen (SEM 3). From endocranial view, three different layers are verifiable: there are broad sclerotic structures (SS) on the periosteal side; adjacent bone needles (BN) were formed on the endosteal side; lytic reactions exposed the diploe due to increased resorption activity.

Backscattered electron (BSE)-mode in the SEM

The BSE-SEM image (*Figure 22*) is from the same bone section as *Figure 21*, but rotated 90° (SEM 3). The edge is characterised by different irregular structures concerning all three cranial layers. The reactive new bone formation (RNB) of woven bone alternates with lamellar bone and concerns all three strata. Destructive processes accompany these features on the outer and inner table as well.

Figure 23 shows a detailed image of *Figure 22*. It demonstrates the state of resorption and remodelling of this advanced lesion. Trabecular new bone is formed as a reaction to the lytic mechanism; in the area beside the reactive new bone (left side of this *Figure*: RNB) woven bone matter and higher mineralised zones are seen. Newly formed and irregularly arranged lamellar bone around secondary osteons (top and left in this *Figure*: SO) reveals the typical picture of mosaic bone. Below, cement lines (CL) of the older, regularly arranged lamellar bone are present.

Figure 24 shows a section from the former diploic area (same bone sample as before) and depicts multiple

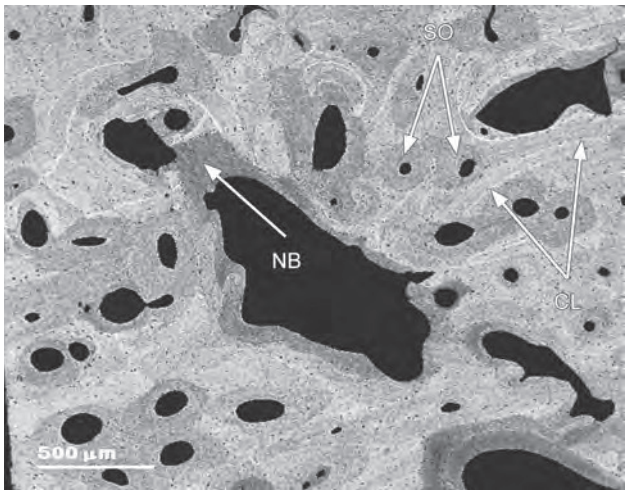


FIGURE 24: Another detailed image of *Figure 22*: BSE-SEM image of a diploic section shows cement lines (CL) of the original lamellar bone, secondary osteons (SO), and a resorptive vessel channel bordered by newly formed bone (NB) (× 42).

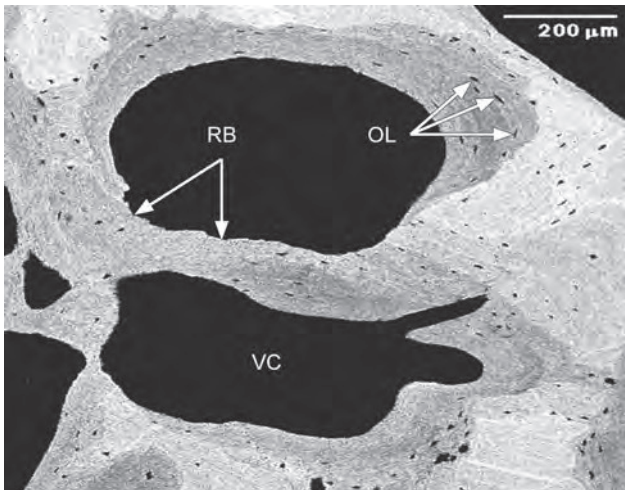


FIGURE 25: Detail from SEM 2: BSE-SEM image of a diploic section shows two vascular channels; the oval shaped channel shows details such as a resorptive border (Howship's lacunae = RB) and several osteocyte lacunae (OL); below is a diagonally cut Volkmann channel (VC) (× 100).

remodelling: the big structure in the centre of this *Figure* is a resorptive vessel channel; its borders appear dark grey, indicating recently formed new bone (NB). Furthermore, the diploe is compacted due to thickened trabeculae. New, secondary osteons (SO) were built between the cement lines (CL) of the "older" bone and, again, mosaic bone occurs.

A detailed image from the more rostrally situated defect on the right parietal bone (SEM 2) shows another oval vessel channel (top in this *Figure*) modified by extensive remodelling activities (*Figure 25*): a foregone resorption process removed bone tissue; subsequently new lamellar bone was built along the Howship's lacunae (= resorptive border: RB). It is represented by a dark grey coloured zone of new bone tissue with multitudinous osteocyte lacunae (OL) that differs clearly from the mature, light grey lamellar bone. The irregularly formed channel in this image (below in this *Figure*) can be related to a Volkmann's canal (VC) that is cut diagonally.

DIFFERENTIAL DIAGNOSIS AND DISCUSSION

The mature male individual from the ossuary of Hallstatt (inventory number of the NHM Vienna: MN 7632) shows numerous gross pathological modifications. Some of them are purely lytic in nature ("osteolytic", e.g., *Figures 5–6*); others are hallmarked by additional bone forming ("osteoblastic") suggestive of mixed osteolytic and osteoblastic osseous changes (e.g., *Figures 3, 4, 7–8*). Only defect 11 (*Figure 9*) might represent a form caused by a solely proliferative alteration, but this is questionable as the nasal septum is distorted.

Post-mortem processes

The skull is very well preserved (mandible is missing). Though the individual was buried and exposed to a geochemical environment for a certain time and the cranium probably later subjected to special reagents for bleaching before it was deposited in the ossuary, the external and internal layers are widely intact and show no erosions. Thus, the chemical effect was minimal, if any (e.g., *Figures 15a–b, 16*). Nevertheless, it is known that post-mortem destructions caused by digenetic and taphonomic effects may pretend or mimic pathologies, but in the given case we have some arguments that are indicative for an ante-mortem process: first, lesions representing an initial stage of a disease are placed within trabecular bone exclusively as has been proven radiologically. Secondly, we identified osteoblastic reactions in the form of reorganised sclerotic bone around or close to the border areas; a criterium typical for advanced stages of metastatic cancerous lesions (Ortner 2003, Lieverse *et al.* 2014; e.g., *Figures 12, 13, 22, 23*). Thirdly, along with Schultz (1997) and Lieverse *et al.* (2014), who used features observed in SEM, the presence of Howship's lacunae, irregular trabeculae, and margins of the lesion where osteoclastic activity has occurred, suggest a pathological rather than a post-mortal aetiology (e.g., *Figures 19–25*).

The alterations identified turned out to be a differential diagnostic challenge, as only the cranium is preserved. Several pathological conditions were considered:

Mycotic infection

Fungal pathogens occur worldwide and can sometimes infect bones via haematogenous pathways (Aufderheide, Rodriguez-Martin 1998). The resulting bony lesions (foci) are characterised by smooth margins. Only occasionally newly built bone structures edge such foci because of an osteoblastic reaction (Lieverse *et al.* 2014) in the form of blunt spicules (Hershkovitz *et al.* 1998). It is well known, that the geographic localisation confines the dissemination of specific species. E.g., Cryptococcosis due to *Cryptococcus neoformans* develops mainly in Europe; affection of these organisms leads to circumscribed destructions that are frequently situated on the skull (Ortner 2003, Lieverse *et al.* 2014). Typically, a circumferential periosteal formation of new bone tissue is found around, but not within the lesion (Hershkovitz *et al.* 1998). The case in question exhibits areas of osteoblastic reaction flanking some lytic defects, but also newly produced and arranged bone in the form of "mosaic bone" within the affected area. Moreover, the outer margins of the foci are jagged and irregularly formed (Lieverse *et al.* 2014).

Sporotrichosis due to *Sporotrichum schenkii* must also be considered as a diagnostic option. But this infection commonly affects the skin and soft tissues rather than bones. If so, besides several long bones, vertebrae and joints, the facial bones in particular are affected, leading to deep lytic bone abscesses and periostitis (Ortner 2003) – features that are not observable in the presented case.

Bacterial infection

Actinomycosis, mainly caused by *Actinomyces israelii*, affects the cervicofacial areas predominantly. If bone tissue is involved, lesions begin to develop on the periosteal surface and mostly remain limited there (Ortner 2003). Usually, "...there is a reactive subperiosteal bone formation [...] and a varying degree of destruction of the adjacent cancellous bone, with little or no endosteal sclerotic response" (Ortner 2003). Thus, this diagnosis can be excluded for the present case as the modifications started within the diploe and some of the defects are located there exclusively.

Tuberculosis might cause lesions on the skeleton mostly due to haematogenous dissemination of the *Mycobacterium tuberculosis*. Generally, the characteristic defects are of osteolytic and osteoblastic nature. But on the skull, destructive defects caused by tuberculosis do not show new bone formation (Resnick, Niwayama 1995, Ortner 2003, Lieverse 2014). However, as the presented case exhibits such newly formed deposits around or adjacent to most of the destructive processes, such a diagnosis is unlikely. Also, the lack of signs of hypervascularity (occurring typically in tuberculosis) and the different frequencies of abscess formation (occurring solitary in tuberculosis) argue against such an infection (Ortner 2003).

Tumorous aetiology

Langerhans-cell histiocytosis

The occurrence of this disease has been reported already since the Cro-Magnon era (Thillaud 1981). This reticuloendothelial disorder causes typically focal or diffuse lysis with defects that are frequently found on the skull (Einwögerer 2012, Lieverse *et al.* 2014). The unifocal form (= eosinophilic granuloma) affects mainly young adults and involves the bone primarily (whereas children are mostly concerned by the multifocal form). Only very rarely has it been reported in the elderly (Gerlach *et al.* 1998). Favoured locations of affection are the calvarium and the craniofacial bones (Einwögerer 2012). Symptoms include roundish destructions with bevelled, but sharply limited borders ("punched-out" defects) without diffuse radiographic perimeters (Ostendorf-Smith 2002) and only very small osteoblastic portions. Also typical is the development of sequesters (Einwögerer 2012). Although some of the lesions in the here presented case have such "punched-out" zones (e.g., *Figures 10, 14a, 14b, 15b*), others have indistinct margins (e.g., *Figures 10, 11, 14a*). There is at least one defect with an extended osteosclerotic reaction on the right side of the frontal bone (e.g., *Figures 2a, 2b, 3, 10–13*). There is no sequester formation; also, because of the advanced age of this individual and the knowledge that this disease occurs extremely rare in the elderly (Gerlach *et al.* 1998) this aetiology remains an unlikely diagnosis.

Angioma

The conspicuous lesion on the left parietal bone is characterised by radially arranged spicules of remaining trabeculae ("sunburst" formation), partial perforation of the internal lamina, and lysis of the external table. The huge lesion on the frontal bone is hallmarked by a sclerotic thickening of the margin, and sharply defined edges surrounded by bizarre structures (Adler 1983), thus, implying the diagnosis of a haemangioma. However, this diagnosis can strongly be questioned, because of two observations: the lesion on the frontal bone has a sclerosis that is far too pronounced and, profoundly, the skull has too many lesions overall.

Medullary plasmocytoma

Due to the multitude of lesions, multiple myeloma must also be diagnostically considered. Such a disease begins predominantly within the red marrow or sometimes on endosteal surfaces, spreads by haematogenous dissemination, and can finally manifest itself by numerous lesions even on the periosteal side. Foci can be scattered on any element of the skeleton. Typically, the diameters of the lesions are larger in the diploe (Strouhal 1991a). But the multiple lesions of this tumour are never that large, even if defects have merged. According to Strouhal (1991a), the size of the defects is quite uniform and the contour of the foci is circular to slightly oval with sharp, "punched-out" edges. Furthermore, they never have sclerosis at their borders (Steinbock 1976). Radiologically, affected areas are always discernible as clearly circumscribed opacities (Strouhal 1991a, Ostendorf-Smith 2002). All these attributes are not or are only partly given in the presented case, whereas most of the defects exhibit different signs.

Metastases of carcinoma

Cancerous metastases due to malignantly degenerated cells can be associated with osteolytic as

well as osteoplastic processes and may spread to many sites through haematogenous or lymphatic dissemination. According to Ortner (2003), bone metastases of carcinomas have more often been identified than primary bone tumours. After tumour-induced osteolysis, these secondary tumours grow slowly and usually give rise to an osteoblastic reaction of the adjacent bone tissue. All these aspects are discernible on the Hallstatt specimen and emphasize the diagnosis of a secondary carcinoma (metastases). Along with Strouhal (1991a), the density of the foci is less numerous in lytic metastatic carcinomas than in medullary plasmocytoma. Typically, the size of the defects varies from small to large (up to several centimetres); the contour of these lesions is more irregularly formed and bordered by a "denticulated frayed or tipped edge" (Strouhal 1996a). The surrounding bone "might be pitted with tiny apertures, which constitute a zone of potential enlargement of the central lytic lesion through gradual merging" stated Strouhal (1991a). This can be seen especially in *Figure 3* by a radiating ossification that is multiply perforated. Radiologically, observed areas of lucidity partly appear obscure, also as described by Strouhal (1991a) resulting in a diffuse radiographic perimeter of the defects (Ostendorf-Smith 2002). Lytic cancerous metastases predilect females (Ortner 2003), but there might be exceptions and it can never be relied upon that the more uncommon variant is given (Strouhal, pers. comm.).

To determine the exact source of the primary onset is difficult in dry bone, even more so here as only the skull is preserved. But some carcinomas are more likely to be taken into consideration as they do more readily metastasise to bone (Ostendorf-Smith 2002): e.g., prostatic cancer occurs most frequently in males (42.4 %) and develops osseous metastases which are mostly osteoblastic (Strouhal 1991a). Also, cancer of the thyroid glands (30.8 %) and lungs (29.8 %) are known to spread frequently and to produce mostly osteolytic metastases. Their delimitation is not possible for MN 7.632 as the examination of the long bones would be required. Breast cancer (47.2 %) that commonly causes mixed or lytic metastases are very implausible for a male, though there are single cases reported (Chau *et al.* 2016). Thus, a clear attribution to a distinct primary tumour remains unanswered.

Light microscopy of sections from archaeological bones can provide insights into the internal structures and facilitates differential diagnosis. The specimen preparation for SEM-investigation is even easier, because by this technique block preparations can be used that are much easier to produce than those of thin ground sections needed for light microscopy. The BSE-mode offers additional information about remodelling activities and the mineralisation at a much higher resolution. This is more important in archaeological remains, as there the natural cells are missing. Thus, this method seems advantageous to traditional light microscopy for palaeopathological diagnoses as imaging in BSE-mode even enables us to chart the mineral density distributions of bone.

CONCLUSIONS

The skull (inventory number MN 7.632) from the ossuary of Hallstatt (Upper Austria) shows lesions on the right and left parietal bone, on the left temporal bone, on the right frontal bone, at the base of the occipital bone, on the maxillary bone, and at the area of the left middle nasal concha. Some lesions have a sharply bordered outline, some present sclerotic thickening at their edges, and others exhibit radial spicules. The defects affect all three layers of the calvarium to a varying extent, some perforating only minimally, others to a greater extent.

The lesions of this calvarium were examined macroscopically, with conventional radiography, and with computed tomography. Then, scanning electron microscopy in the SE- and the BSE-mode was applied to illustrate the diagnostic usefulness of these methods.

The observed features and the specific osteoblastic reactions suggest a pathological origin rather than post-mortem processes (pseudopathology), and a secondary carcinoma rather than mycotic or bacterial infection, tuberculosis, Langerhans-cell histiocytosis, bone angioma, or medullary plasmocytoma.

ACKNOWLEDGEMENTS

We are highly indebted to Josef Muhsil (Department of Exhibition and Education, Natural History Museum Vienna) for the realisation of the perfect graphical works and the layout.

REFERENCES

ADLER C. P., 1983: *Knochenkrankheiten – Diagnostik makroskopischer, histologischer und radiologischer Strukturveränderungen des Skeletts*. Georg Thieme Verlag, Stuttgart.

AUFDERHEIDE A. C., RODRIGUEZ-MARTIN C., 1998: *The Cambridge encyclopaedia of human paleopathology*. Cambridge University Press, Cambridge New York.

BOYDE A., MACONNACHIE E., REID S. A., DELLING G., MUNDY G. R., 1986: Scanning electron microscopy on bone pathology: review of methods, potential and application. *Scanning electron microscopy* 4: 1537–1554.

BURGSTALLER E., 1961: Schädelbeschriftung und Bemalung in den Österreichischen Alpenländern. In: H. Koren, L. Kretzenbacher (Eds.): *Volkskunde im Ostalpenraum (Alpes Orientales II).* Pp. 71–84. Steir: Steirisches Volksmuseum.

CAPASSO L. L., 2005: Antiquity of cancer. *Int. J. Cancer* 113: 2–13. http://doi. org/10.1002/ijc.20610

CHAU A., JAFARIAN N., ROSA M., 2016: Male Breast: Clinical and imaging evaluations of benign and malignant entities with histologic correlation. *Am. J. Med*. 129: 776–791. http://doi.org/10.1016/j.amjmed.2016.01.009

CZARNETZKI A., 1980: Pathological changes in the morphology of the young Paleolithic skeletal remain from Stetten (Southwest Germany). *J. Hum. Evol*. 9: 15–17.

DUHIG C., STROUHAL E., NĚMEČKOVÁ A., 1996: Case of a secondary carcinoma of Anglo-Saxon period from Edix Hill, Barrington, Cambridgeshire, England. *J. Paleopathology* 8: 25–31.

EINWÖGERER C., 2012: *Menschliche Skelette in frühbronzezeitlichen Siedlungsobjekten der Fundstelle Ziersdorf – Ortsumfahrung, Niederösterreich. Eine archäologische und anthropologische Analyse*. Diploma thesis at the Institute for Prehistory and Early History, University of Vienna.

GERLACH B., STEIN A., FISCHER R., WOZEL G., DITTERT D., RICHTER G., 1998: Langerhanszell-Histiozytose im Alter. *Der Hautarzt* 49, 1: 23–30. http://doi.org/10.1007/s001050050696.

HERSHKOVITZ I., ROTHSCHILD B. M., DUTOUR O., GREENWALD C., 1998: Clues to the recognition of fungal origin of lytic skeletal lesions. *Am. J. Phys. Anthropol*. 106: 47–60. http://dx.doi.org/10.1002/(sici)1096-8644(199805)106:1<47::aid-ajpa4>3.0.co;2-a.

HORÁČKOVÁ L., BENEŠOVÁ L., STROUHAL E., VYHNÁNEK L., NĚMEČKOVÁ A., 1997: A case of severe metastatic carcinoma in a Late Medieval skull from Petrov, Brno (Czech Republic). *Anthropologie* (Brno) 35, 1: 57–64.

JOHNSON G., 2013: *The cancer chronicles: unlocking medicine's deepest mystery*. New York Vintage Books. doi: 10.1097/01.COT.0000444391.35879.78

LEAKEY L. S. B., 1936: Fossil human remains from Kanam and Kanjera, Kenya Colony. *Nature* 138: 643.

LEAKEY L. S. B., 1953: *Adam's ancestors*. 4th edition. Methuen, London.

LIEVERSE A. R., TEMPLE D. H., BAZALIISKII V. I., 2014: Paleopathological description and diagnosis of metastatic carcinoma in an Early Bronze Age (4588+34 cal. BP) forager from the Cis-Baikal region of Eastern Siberia. *PlosOne* 9, 12: e113919: 1–25. http://doi.org/10.1371/journal.pone.0113919

MARTÍNEZ-ABADÍAS N., ESPARZA M., SJØVOLD T., GONZÁLEZ-JOSÉ R., SANTOS M., HERNÁNDEZ M., 2009: Heritability of human cranial dimensions: comparing the evolvability of different cranial regions. *J. Anat.* 214: 19–35. doi: 10.1111/j. 1469-7580.2008.01015.x

MAYS S., STROUHAL E., VYHNÁNEK L., NĚMEČKOVÁ A., 1996: A case of metastatic carcinoma of Medieval date from Wharram Percy, England. *J. Paleopathology* 8: 33–42.

MONGE J., KRICUN M., RADOVČIĆ J., RADOVČIĆ D., MANN A., FRAYER D. W., 2013: Fibrous dysplasia in a 120,000+ year old Neandertal from Krapina, Croatia. *PlosOne* 8, 6, Art. #e64539. http://dx.doi.org/10.1371/journal. pone.0064539.

MONTAGU M. F. A., 1957: The chin of the Kanam mandible. *American Anthropologist* 59, 2: 335–338.

KNUSSMANN R. (Hrsg.), 1988: *Anthropologie – Handbuch der vergleichenden Biologie des Menschen*. Band 1, Gustav Fischer Verlag, Stuttgart – New York.

NĚMEČKOVÁ A., STROUHAL E., KOLÁŘ J., 2009: *Case of a malignant tumour from the necropolis of Isola Sacra near Rome (2nd–3rd cent. AD)*. 45th International Congress on Anatomy, 46th Lojda Symposium on Histochemistry Pilsen, Czech Republic, Program – Abstracts: 7.

NĚMEČKOVÁ A., STROUHAL E., VYHNÁNEK L., 1995: The histological picture of an osteosarcoma from the Early Medieval Age in England (Abstract). *J. Paleopathology* 7: 117.

NĚMEČKOVÁ A., STROUHAL E., VYHNÁNEK L., 1996: The histological picture of an osteosarcoma from the Early Medieval Age in England (Abstract). *Papers on Paleopathology.* 11th European Meeting of the Paleopathology Association, Maastricht, The Netherlands, Program – Abstracts: 14.

NĚMEČKOVÁ A., STROUHAL E., VYHNÁNEK L., WAKELY J., MAYS S., 1998a: Workshop on light and scanning electron microscopy of tumours. *Papers on Paleopathology.* 12th Biennial European Members Meeting Prague and Pilsen, Czech Republic, Paleopathology Association, Detroit, Michigan, Program – Abstracts: 2.

NĚMEČKOVÁ A., STROUHAL E., VYHNÁNEK L., WAKELY J., MAYS S., 1998b: Workshop on light and scanning electron microscopy of tumours. *Papers on Paleopathology*. 12th Biennial European Members Meeting Prague and Pilsen, Czech Republic, Paleopathology Association, Detroit, Michigan, Program – Abstracts: 67.

ODES E. J., RANDOLPH-QUINNEY P. S., STEYN M., THROCKMORTON Z., SMILG J. S., ZIPFEL B., AUGUSTINE T. N., DE BEER F., HOFFMAN J. W., FRANKLIN Y. D., BERGER L. R., 2016: Earliest hominin cancer: 1.7-milllion-year-old osteosarcoma from Swartkrans Cave, South Africa. *S. Afr. J. Sci.* 112, 7/8, Art. #2015-0471. http://doi.org/10.17159/sajs.2016/20150471.

ORTNER D. J., 2003: *Identification of pathological conditions in human skeletal remains.* Academic Press, 2nd edition, New York.

OSTENDORF-SMITH M., 2002: A probable case of metastatic carcinoma from the Late Prehistoric Eastern Tennessee river valley. *Int. J. Osteoarch*. 12: 235–247. http://doi.org/10.1002/oa.618.

PHELAN J. A., WEINER M. J., RICCI J. L., PLUMMER T., GAULD S., POTTS R., BROMAGE T. G., 2007: Diagnosis

of the pathology of the Kanam mandible. Oral Surg., Oral Med., Oral Pathol., Oral Radiol., Endodont. 103, 4: Art. # e20. http://doi.org/10.1016/j.tripleo.2006.12.041

RANDOLPH-QUINNEY P. S., WILLIAMS S. A., STEYN M., MEYER M. R., SMILG J. S., CHURCHILL S. E., ODES E. J., AUGUSTINE T., TAFFOREAU P., BERGER L. R., 2016: Osteogenic tumour in *Australopithecus sediba*: earliest hominin evidence for neoplastic disease. *S. Afr. J. Sci*. 112, 7/8, Art. # 2015-0470. http://doi.org/10.17159/sajs.2016/20150470

RESNICK D., NIWAYAMA G., 1995: Osteomyelitis, septic arthritis, and soft tissue infection: organisms. In: Resnick D. (Ed.): *Diagnosis of bone and joint disorders*. Pp. 2325–2418. W. B. Saunders Company, Philadelphia.

SAUSER G., 1952: Bemalte Ossuarienschädel aus Hallstatt. *Actes du VIe Congrés International des Sciences Anthropologiques et Ethnologiques Vienne:* 112–116.

SCHAMALL D., 1996: Rasterelektronenmikroskopische Differentialdiagnose von Knochengeschwülsten in paläopathologischem Skelettmaterial. Diploma thesis at the Department of Anthropology, University of Vienna.

ŠEFČÁKOVÁ A., STROUHAL E., NĚMEČKOVÁ A., THURZO M., STAŠŠÍKOVÁ-ŠTUKOVSKÁ D., 2001: Case of metastatic carcinoma from end of the 8th–early 9th century. *Am. J. Phys. Anthropol.* 116, 3: 216–229. http://doi.org/10.1002/ajpa.1117

SCHULTZ M., 1997: Microscopic Investigation of excavated skeletal remains: A contribution to paleopathology and forensic medicine. In: Haglund W. D., Sorg M. H. (Eds.): *Forensic taphonomy: the post-mortem fate of human remains*. Pp. 201–222. CRC Press, Boca Raton. http://doi.org/10.1201/9781439821923.ch14

STATHOPOULOS G., 1975: Kanam mandible's tumour. *Lancet* 1:165–167. https://doi.org/10.1016/S0140-6736(75)91462-2

STEINBOCK R. T., 1976: *Paleopathological diagnosis and interpretation – bone diseases in ancient human populations*. Charles C. Thomas, Springfield Illinois. http://doi.org/10.1002/ajpa.1330600418

STROUHAL E., 1976: Tumors in the remains of ancient Egyptians. *Am. J. Phys. Anthropol.* 45, 3: 613–620. http://doi.org/10.1002/ajpa.1330450328

STROUHAL E., 1978a: Ancient Egyptian case of carcinoma. *Bull. N. Y. Acad. Med.* 54, 3: 290–302.

STROUHAL E., 1978b: Two cases of polytopic osteolytic lesions in the Pyramid Age Egyptians. *Ossa* 3–4: 11–52.

STROUHAL E., 1980: Paleopathology of the Coption cemetary at Saqqara-North. *Proceedings of the 3rd European Meeting of the Paleopathology Association*, Caen, France: 211–217.

STROUHAL E., 1989: Paleopathology of the Christian population at Sayala (Egyptian Nubia, 5th–11th cent. A.D.). In: Capasso L. (Ed.): *Advances in Paleopathology*. Pp. 191–196. Proceedings of the 7th European meeting of the Paleopathology Association, Chieti, Italy.

STROUHAL E., 1991a: Myeloma multiplex versus osteolytic metastatic carcinoma: differential diagnosis in dry bones. *Int. J. Osteoarch.* 1: 219–224. http://doi.org/10.1002/oa.1390010314

STROUHAL E., 1991b: A case of a primary carcinoma from Christian Sayala (Egyptian Nubia). *J. Paleopathology* 3: 151–165.

STROUHAL E., 1991c: Evidence for malign tumours in ancient populations. *Plzeňský lékařský sborník*, Suppl. 64: 33–38.

STROUHAL E., 1992: Malignant tumours in the Christian population at Sayala (Egyptian Nubia). International Symposium on Paleopathology Warsaw 1990. *Int. J. of Anthropology* 7, 1: 84.

STROUHAL E., 1993: A case of metastatic carcinoma from Christian Sayala (Egyptian Nubia). *Anthrop. Anzeiger* 51: 97–115.

STROUHAL E., 1994: Malignant tumors in the Old World. *Paleopathology Newsletter* (supplement) 85: 1–6.

STROUHAL E., 1995a: Metastatic cancer in the Old World in ancient times. *Papers on Paleopathology.* 22nd Annual Meeting of the Paleopathology Association, Oakland, California, Program – Abstracts: 13.

STROUHAL E., 1995b: Metastatic cancer in Old World past. In: *Winkler's Memorial Symposium Perspectives in Anthropology of Past and Present Populations*. Xanthi, Greece: 86–87.

STROUHAL E., 1996a: Examination of malignant tumours from historical periods of England. In: *Abstrakta 3. česko-slovenského sympozia z historie medicíny*, Benešov u Prahy 1996. Praha, Ústav dějin lékařství 1. lékař. fakulty U K: 88.

STROUHAL E., 1996b: Comparative study of malignant tumours in ancient Egypt and England. *10th Congress of the European Anthropological Association*. Brussels, Belgium, Program – Abstracts: 36.

STROUHAL E., 1997: Looking forward: Malignant tumours. *Paleopathology Newsletter* 100: 21–24.

STROUHAL E., 1998a: Paleopathological evidence of jaw tumors. In: K. W. Alt, F. W. Rösing, M. Teschler-Nicola (Eds.): *Dental Anthropology. Fundamentals, Limits and Prospects*. Pp. 277–292. Springer Verlag, Wien – NewYork. http://doi.org/10.1007/978-3-7091-7496-8_15.

STROUHAL E., 1998b: Survey and analysis of malignant tumours of past populations in England and Scotland. *Papers on Paleopathology*. 12th Biennial European Members Meeting Prague and Pilsen. Paleopathology Association, Detroit, Michigan, Program – Abstracts: 21.

STROUHAL E., 1998c: *Survey and analysis of malignant tumours of past populations in England and Scotland*. 12th European Meeting of the Paleopathology Association, Prague – Pilsen, Czech Republic, Program – Abstracts: 88.

STROUHAL E., 1998d: Is it possible to reconstruct an epidemiology of malignant tumours in past population of Ancient World? (Abstract). *Homo* 49, Suppl.: 106.

STROUHAL E., 1998e: Survey and analysis of maligant tumours of past populations in England and Scotland. *J. Paleopathology* 10, 3: 99–108.

STROUHAL E., 2000: *Malignant tumours of past populations in middle Europe*. 13th European meeting of the Paleopathology Association, Chieti, Italy, Program – Abstract: 87.

STROUHAL E., 2001: Malignant tumours in past populations in Middle Europe. In: La Verghetta M., Capasso L. (Eds.): *Proceedings of the 13th European Meeting of the*

Paleopathology Association. Pp. 265–272. Edigrafical Publisher, Teramo.

STROUHAL E., 2009: History and palaeopathology of tumours. *Anthropologie* (Brno) 47, 3: 289–294.

STROUHAL E., JUNGWIRTH J., 1970: Die menschlichen Skelette aus dem Neolithischen Hornsteinbergwerk von Mauer bei Wien. *Mitteilungen der anthropologischen Gesellschaft in Wien* 100: 85–110.

STROUHAL E., JUNGWIRTH J. 1977: Ein verkalktes Myoma uteri aus der späten Römerzeit in Ägyptisch – Nubien. *Mitteilungen der anthropogischen Gesellschaft in Wien* 107: 215–221.

STROUHAL E., KOLÁŘ J., NĚMEČKOVÁ A., 2010a: *Skulls with large lytic defects and sclerotic borders*. 18th European Meeting of the Paleopathology Association, Vienna, Austria, Program – Abstracts: 229.

STROUHAL E., KOLÁŘ J., NĚMEČKOVÁ A., 2010b: Skulls with large lytic defects and sclerotic borders. (Abstract). *Pohybové ústrojí* 17, 3–4: 366.

STROUHAL E., KRITSCHER H., 1989: Paleopathological differentiation of myelomatosis and osteolytic metastases in a Neolithic skeleton. *Rivista di Antropologia* 67: 265–272. (the name of the first author was concealed by the second one, see Erratum in the same journal 71: 343, 1993).

STROUHAL E., KRITSCHER H., 1990: Neolithic case of a multiple myeloma from Mauer (Vienna, Austria). *Anthropologie* (Brno) 28: 78–87.

STROUHAL E., NĚMEČKOVÁ A., VYHNÁNEK L., 2000: Is it possible to reconstruct an epidemiology of malignant tumours in past populations of the Old World? In: M. Schultz *et al.* (Eds.): *Schnittstelle Mensch – Umwelt in Vergangenheit, Gegenwart und Zukunft*. Proceedings. 3rd Kongress der Gesellschaft für Anthropologie Göttingen 1998. Göttingen, Deutschland, Cuvillier.

STROUHAL E., NĚMEČKOVÁ A., 2004: Paleopathological find of a sacral neurilemmoma from ancient Egypt. *Am. J. Phys. Anthropol.* 125, 4: 320–328. http://doi.org/10.1002/ajpa.10404

STROUHAL E., NĚMEČKOVÁ A., 2008: *Big lytic defects in cranial vault*. 17th European Meeting of the Paleopathology Association, Copenhagen, Denmark, Program – Abstract: 65–66.

STROUHAL E., NĚMEČKOVÁ A., KOLÁŘ J., 2009: Case of a malignant tumour from the necropolis of Isola Sacra near Rome (Abstract). *Pohybové ústrojí* 16, 3–4: 270–271.

STROUHAL E., NĚMEČKOVÁ A., KOLÁŘ J., 2010: Maligní nádor z Isola sacra (Itálie, 2.–3. stol. n. l.). *Pohybové ústrojí* 17, 1–2: 77–96.

STROUHAL E., NĚMEČKOVÁ A., VYHNÁNEK L., 1995: Examination of malignant tumours from English collections. A progress report (Abstract). *J. Paleopathology* 7: 137.

STROUHAL E., NĚMEČKOVÁ A., VYHNÁNEK L., 1996: Examination of malignant tumours from English collections. *Papers on Paleopathology*. 11th European Meeting of the Paleopathology Association, Maastricht 1996, The Netherlands, Program – Abstracts: 19.

STROUHAL E., VYHNÁNEK L., 1981: New cases of malignant tumours from Late Period cemeteries at Abusir and Saqqara. *Ossa* 8: 165–189.

STROUHAL E., VYHNÁNEK L., 1987: Nouveaux exemples de tumeurs osseuses malignes provenant de cimetières égyptiens de la Basse Époque. *Bulletins et Mémoires de la Societé d'Anthropologie de Paris.*, sér. 14, 2: 159–170. http://doi.org/10.3406/bmsap.1987.1632

STROUHAL E., VYHNÁNEK L., HORÁČKOVÁ L., BENEŠOVÁ L., NĚMEČKOVÁ A., 1995: Five newly detected medieval and Early Modern cases of cancer from Moravia (Czech Republic). In: *Papers on Paleopathology*. 22nd Annual Meeting of the Paleopathology Association, Oakland, California, Program – Abstracts: 16.

STROUHAL E., VYHNÁNEK L., HORÁČKOVÁ L., BENEŠOVÁ L., NEMEČKOVÁ A., 1996a: Malignant tumors affecting the people from the ossuary at Křtiny (Czech Republic). *J. Paleopathology* 8, 1: 5–24.

STROUHAL E., VYHNÁNEK L., HORÁČKOVÁ L., BENEŠOVÁ L., NEMEČKOVÁ A., 1996b: Two unusual benign tumours in skulls from the ossuary at Křtiny (Czech Republic). *Int. J. Osteoarch*. 6: 289–299. http://10.1002/(SICI)1099-1212(199606)6:3<289::AID-OA272>3.0.CO;2-R

STROUHAL E., VYHNÁNEK L., HORÁČKOVÁ L., BENEŠOVÁ L., NĚMEČKOVÁ A., 1997: A case of osteosarcoma in a Late Medieval – Early Modern skull from Kyjov (Czech Republic). *Int. J. Osteoarch.* 7: 82–90.

TESCHLER-NICOLA M., CZERNY C., OLIVA M., SCHAMALL D., SCHULTZ M., 2006: Pathological alterations and traumas in the human skeletal remains from Mladeč. In: M. Teschler-Nicola (Ed.): *Early Modern Humans at the Moravian Gate. The Mladeč Caves and their Remains.* Pp. 473–489. Springer Verlag, Wien – New York. http://doi.org/10.1007/978-3-211-49294-9_16

THILLAUD P., 1981: L'histiocytose X auf paléolithique (sujet no.1 de Cro-Magnon). *L'Anthropologie* 85: 219–239.

TOBIAS P. V., 1960: The Kanam jaw. *Nature*, 195: 946–947. http://doi.org/10.1038/185946a0

VYHNÁNEK L., STROUHAL E., NĚMEČKOVÁ A., 1998: "Kissing" osteochondroma: a case from ancient Egypt. *Papers on Paleopathology*. 12th Biennial European Members Meeting 1998 Prague and Pilsen. Paleopathology Association, Detroit, Michigan, Program – Abstracts: 23.

VYHNÁNEK L., STROUHAL E., NĚMEČKOVÁ A., 1999: Kissing osteochondroma: a case from Ancient Egypt. *Int. J. Osteoarch.* 9, 5: 361–368. http://doi.org/10.1002/(SICI)1099-1212(199909/10)9:5<361::AID-OA469>3.0.CO;2-A

WAKELY J., STROUHAL E., VYHNÁNEK L., NĚMEČKOVÁ A., 1998: Case of a malignant tumour from Abington, Oxfordshire, England. *J Archaeological Science* 25: 949–955. http://doi.org/10.1006/jasc.1997.0228

ZINK A., 2012: Eugen Strouhal (1931–). In: J. Buikstra, C. Roberts (Eds.): *The Global History of Paleopathology: Pioneers and Prospects.* Pp. 126–130. Oxford University Press, Oxford – New York. http://doi.org/10.1093/acprof:osobl/9780195389807.003.0016

Doris Schamall*
Maria Teschler-Nicola
Natural History Museum (NHM) Vienna
Department of Anthropology
Vienna
Austria
University of Vienna
Department of Anthropology
of Evolutionary Anthropology
Vienna
Austria
E-mail: Doris.schamall@nhm-wien.ac.at
E-mail: Maria.teschler@nhm-wien.ac.at
E-mail: Doris.schamall@univie.ac.at
E-mail: Maria.teschler@univie.ac.at
Doris Schamall
Medical University of Vienna
Center for Anatomy and Cell Biology
Department of Applied Anatomy
Vienna
Austria
E-mail: Doris.schamall@meduniwien.ac.at

*Corresponding author.