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# Health and safety issues in the Victorian workplace: an example of mandibular phosphorus necrosis from Gloucester, UK

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## Abstract

Working conditions in factories during the Industrial Era in Great Britain have been linked to numerous occupational diseases. In this paper, the authors present a case study from Victorian Gloucester, where skeletal remains of a young male recovered from the Southgate Street 3/89 excavation exhibit osteonecrosis on the left mandibular ramus, a condition known as “phossy jaw”. The case is examined in terms of macroscopic characteristics, distribution and severity of lesions and differential diagnosis.

The lesions consist of extensive bone necrosis with periosteal reaction and sub-periosteal new bone formation that affects the left side of the mandible. Conditions that may have produced similar changes were considered and include various forms of neoplasms, actinomycosis and taphonomic alterations. However, these are rejected as they are not supported by the lesion characteristics.

Additional supportive evidence for the case of phosphorus necrosis is offered by the historical context: in the 19th century, Gloucester was one of the main centres for match

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manufacture and it is well known that individuals who were directly exposed to phosphorus fumes developed a condition known as "phossy jaw".

The potential contribution of the current analysis in our understanding of working conditions in Victorian Gloucester is evaluated.

**Keywords:** Phossy jaw; Osteomyelitis; Mandible; Occupational disease; Match manufacture; History of Medicine

## 1. Introduction

The Industrial Era was marked by numerous factories producing a variety of new products in the United Kingdom, Europe and the United States. Match factories played an important role in the United Kingdom and historical sources provide detailed descriptions (insert refs),. In the 19th century the major production areas of "Strike anywhere matches" were located in London, Birmingham, Gloucester, Liverpool, Leeds and Newcastle (Gwyn-Smith, 1978).

This industry employed a large number of people, who often worked long hours in deplorable conditions. As a consequence of the working conditions, match factories are infamous for occupational diseases, including phosphorus necrosis, also known as "phossy jaw" (Harrison, 1995).

In this article, the authors present a case study from Victorian Gloucester. Skeletal remains of a young male recovered from the Southgate Street 3/89 excavation exhibit osteonecrosis on the left mandibular ramus. Subsequent to a detailed description of the affected area and a comprehensive differential diagnosis, we propose that this condition may be classified as occupationally-related osteomyelitis from industrial exposure to phosphorus.

## 2. Materials and methods

The individual is identified as Skeleton 1554 from the Southgate Street collection 3/89, currently housed at Liverpool John Moores University. The archaeological excavation in Gloucester began in 1983, and was funded by national, local, private and public sources under the supervision of the Gloucester City Museum (Atkin and Garrod, 1990).

The excavation focused on two sites: Southgate Gallery and Southgate Street, which collectively represent different occupation stages, i.e., Roman, Saxon, medieval and post-medieval periods. The skeleton discussed in this paper was recovered between the medieval St Owen's cemetery and Georgian Gloucester Infirmary Chapel Graveyard. The grave's location within the stratigraphy of the excavation, as well the archaeological data (Atkin and Garrod, 1990) indicate that the remains date to Victorian times (19th Century).

After the cleaning process was carried out at the Gloucester City Museum, the skeletal inventory, analysis and photographic documentation of the remains were undertaken at the Liverpool John Moores University osteology laboratory by the authors. Skeletal preservation is scored as “1” according to the inventory recording scheme proposed by Buikstra and Ubelaker (1994: 7), with all elements present except for the splanchnocranium, which was likely damaged and not recovered during excavation. Cortical preservation was also very good, with little erosion on only few elements and minimal fragmentation, mainly of the ribs and vertebrae. To facilitate determination of the biological profile, the remains were reassembled with reversible glue (40% B-72 Paraloid crystals solution in acetone). To increase stability of the fragmented elements, any missing portions were filled with pigmented wax (a combination of beeswax, hydrate calcium sulfate, pine resin, paraffin) following the guidelines of Borrini (2007).

In addition to the general biological profile (Brooks and Suchey, 1990; Lovejoy *et al.*, 1985; Schaefer *et al*., 2009), development of the muscle insertions (Donatelli and Scarsini, 2006) was evaluated to help understand the lifestyle and occupational stress experienced by the individual. The analysis of the enthesopathies was based on the expression degrees of forty muscles and ligaments insertions, grouped in seven muscular skeletal districts with the same functional meaning. This step is crucial for contextualizing the individual and his apparent work-related pathological condition, as was recently proposed for other archaeological cases from different periods (Baldoni et al, 2018).

## 3. Results and discussion

### *3.1 Biological Profile*

Many of the skeleton’s epiphyses are mostly or completely fused; however certain elements that are partially fusing provide evidence for the individual’s young age (Schaefer *et al*., 2009): rib heads (fusion 17-25 years), scapula inferior angle (fusion 23 years), acromion (fusion 20 years), proximal humerus (fusion 16-21 years), distal radius (fusion 16-20 years), distal ulna (fusion 17-20), iliac crest (fusion 20-23 years), proximal tibia (fusion 16-20 years) and proximal fibula (fusion 15-20 years).

Examination of the pubic symphysis (Brooks and Suchey, 1990) suggests a phase 1 (16.4-20.6 years), with obvious surface billowing and well-marked horizontal ridges with an absence of nodules. In addition, the auricular surface does not reach phase 1 (≤20-24 years) due to the very fine granularity (Lovejoy *et al.*, 1985). Together, these osteological features indicate that the individual died between 16 and 20 years of age. Although the individual may not have reached adulthood, it is still possible to assign a sex of male based on the absence of a preauricular sulcus and the morphology of the greater sciatic notch (grade 5 in the classification of Buikstra and Ubelaker, 1994). Other features that suggest male sex are the absence of a ventral arc, as well as the lack of concavity of the ischiopubic ramus (Phenice, 1969). The narrow and triangle-shaped pubic bone is also indicative of a male individual (Bass, 1995).

Muscle and ligament insertions were observed to identify any possible changes related to occupation. The upper limbs, in particular, show marked insertions (classified as moderate and strong in Donatelli and Scarsini, 2006). The greatest development is evident in the clavicle (i.e., costoclavicular ligament, deltoid muscle, conoid and trapezoid ligaments) and humerus (deltoid muscle and latissimus dorsi). These muscles are central for adduction and abduction of the arms. The pronounced deltoid insertions of this individual suggest that he regularly abducted the arms up to 90 degrees. Additional traits that may be correlated with stress on the upper limbs are the presence of an articular facet on the posterior glenoid fossa, and an accessory supraglenoid articular facet, both likely related to adduction and abduction of the arms (Capasso *et al.,* 1999).

These strongly developed muscle insertions, despite the individual's young age, indicate excessive stress on the upper limbs that, in turn, may provide an indication of his occupation. This evidence of repetitive movement (upper limb abduction) and the pathological condition (phosphorous necrosis) yet to be described would be compatible with someone employed as a 'dipper' in a match factory. The 90° arm abduction corresponds closely to the lifting of frames containing splints of wood. Additional features that may suggest the individual belonged to a lower social class, as the employee of a match factory would have been, are enamel hypoplasia (on the lower right incisors, canine and first premolar) and traces of *cribra orbitalia* in the right orbit (i.e., stage 1; Stuart-Macadam, 1985). Both lesions may result from malnutrition and/or other stress during childhood (Aufderheide *et al.*, 1998). Another finding that indicates poor life conditions for this individual is the area of ectocranial porosity found on both parietal bones. Capasso and Di Toda (1998) report that such periosteal reaction may be caused by lice infestation (*pediculosis*). Porotic hyperostosis can be ruled out, as the lesion is limited to the external surface of the outer cranial table (Stuart-Macadam, 1992).

### *3.2 Description of the pathology*

The individual exhibits extensive bone necrosis with sub-periosteal new bone formation (involucrum) that affects mainly the left side of the mandible (Figure 1) from the first premolar to the third molar, and part of the ramus. A lytic lesion affected the buccal and lingual surfaces of the left ascending ramus, measuring 15mm superior-inferior and at least 25mm anterior-posterior; the same process developed into a destructive lesion with the loss of mandibular bone from the left gonion to the alveolus of the first left premolar.

The new woven bone formations can be observed from the pogonion (inferior and posterior surface of the mental eminence) to above the genial tubercles (~30x32x6mm) and on the medial and lateral sides of both rami (Figure 2 A and B). On both sides of the rami the new bone appears to be scattered into small areas with an average thickness of ~0.5mm.

Irregular areas of new bone formation are also noticeable on the cranium (Figure 3 A and B) on the distal sides of the pterygoid plates of the sphenoid bones (left ~28x23x0.5mm; ~13x10x0.5mm), in the left jugular fossa of the temporal and on the zygomatic processes (~9x5x0.5mm). New bone formation is evident in the left mandibular fossa (~14x12x0.5mm).

In addition, the right mandibular fossa exhibits an early stage of osteoarthritis of the temporomandibular joint due to masticatory stress; there is porosity within the fossa, accompanied by flattening of the articular eminence (Aufderheide *et al*., 1998; Merbs, 1983; Rando and Waldron, 2012). In consideration of the individual's young age, as well as the unilateral development of the changes, this condition may be the result of masticatory behaviours to reduce the discomfort of the main pathological condition on the opposite side of the mandible.

The aforementioned changes are consistent with that observed in other cases (Capasso *et al*., 1999; Roberts *et al*, 2016) and can be recognized as phosphorus necrosis; the condition results from prolonged contact with white/yellow phosphorus – most likely in an industrial context. The sequestrum in the mandible, that usually originates from the necrotic process, is absent in the present case; because there are no signs of surgical intervention to remove the dead bone, the missing fragment was likely lost during archaeological recovery. It is probable that the compromised integrity of the bone brought on by the pathology, contributed to this loss.

### *3.3 Differential diagnosis*

Due to the morphology of the affected area (Figures 4 A and B), taphonomic factors such as erosion and exfoliation (Borrini et al., 2012) have been excluded as possible causes of the changes observed; upon initial inspection, one might dismiss this case as a mandible that has been heavily affected by chemical or mechanical erosion (Pokines and Baker, 2014). Under magnification however, one can observe that some bone portions that have been subjected to cortical destruction, have large areas of reactive woven bone.

The consideration of the epidemiology as well as the specific traits of the lesion, enable the exclusion of most forms of neoplastic disease such as osteoid osteoma, ossifying fibroma, osteosarcoma, chondrosarcoma. Metastatic forms of neoplasms can also be ruled out, as the edges of bone destruction are covered by woven bone, especially on the superior portion of the ascending ramus. In neoplasms, where there is a mixture of lytic and blastic metastatic lesions, the new bone that forms usually has the form of spicules, or focal woven bone formation (Ortner, 2003; Ragsdale *et al.*, 2018).

Finally, actinomycosis leads to focal destruction of the alveolar process (Ortner, 2003), while in this case we have more widespread lytic changes. Such phosphorus necrosis lesions have been described as resembling pumice stone by Marx (2008).

### *3.4 Phosphorus necrosis as a work-related disease*

Just one archaeological case of phosphorus necrosis has been comprehensively described in the literature. (Roberts *et al.,* 2016); however, it is possible to find descriptions in contemporary journals and medical reports from the 19$^{th}$ century.

According to historical literature, the disease may have manifested weeks, months or even years after the individual started working in the factory. It began with a toothache, and apparently the development of the condition was aided by the presence of caries or prior tooth extraction (Stockman, 1899; Moss, 1994). The pathology could be confined to one tooth, a circumscribed area of the mouth or, like in the present case, involve a large part of the mandible.

To better understand the development of the disease and its effects, it is useful to present a description by an actual witness of the signs and symptoms in a patient:

> "The gum becomes red, tense, and swollen, and the swelling may then resolve itself into a circumscribed phlegmon, or may form a large tumour which spreads to the neighbouring soft parts, causing a swollen appearance of the lips and cheeks, or the regions under the lower jaw. The abscess then bursts or is opened, when it discharges stinking pus, and in its place an ulcer quickly forms, which lays bare bone. […] Later the gum disappears, and exposes the alveolar arch and other part of the jaw, the bare bone having a brownish or dirty-grey colour. […] The disease, instead of healing, spreads locally, involving more bone, the patient becomes cachectic, feverish, and wasted, and ultimately dies from pulmonary phthisis, general tuberculosis, or some other tuberculous affection" (Stockman, 1899, p. 9) .

As Marx (2008) observes, the description of the pathology reported in an 1865 publication is similar to that observed in actual cases of bisphosphonate-induced osteonecrosis. The workers were subjected to $P_4O_{10}$ fumes, which passed through the alveolar membranes in the lungs and, reacting with other compounds, produced simple bisphosphonate. In combination with ammonia it could produce nitrogen-containing bisphosphonate or, with common amino acids, amino bisphosphonates. Through the circulatory system these elements were absorbed in the bony matrix; by daily exposure, this absorption resulted in chronic poisoning that negatively affected people's health (Marx, 2008; Hinshaw and Quin, 2015).

Phosphorus necrosis cases were first reported between 1839 and 1845 in Vienna, but others followed in Nuremberg, Strasbourg, Berlin, Lyon, Paris, Manchester and London (Stockman, 1899; Hughes *et al.*, 1962). The pathological condition was described among match factory workers, who were using large quantities of phosphorus. The first detailed report was written in 1858 in France, where sixty cases were identified, and half of these patients died either from the disease or by suicide induced by disfigurement and pain (Marx, 2008).

In the United Kingdom during this period numerous cases of mandibular phosphorus necrosis were reported, particularly in London after the Bryant and May factory opened. As a response to the increasing number of people affected, the founder of the Salvation Army, General William Booth, started a crusade against "phossy jaw" in 1891 (Myers and McGlothlin, 1996; Marx, 2008).

In January 1892 the newspaper *Star* published in detail a case of "phossy jaw" on Mrs Fleet, an employee of the Bryant and May match factory (Sarte, 1982). The same newspaper also reported a case mandibular changes similar to the individual in the present study, i.e., the death of 22 year-old Cornelius Lean, who was working as a "dipper" for Bryant and May for 18 months. After his death, the doctor who performed the autopsy confirmed that he suffered from two large open sores, necrosis of the mandible, and the loss and decay of several teeth (Satre, 1982). Additional cases are mentioned by Harrison (1995) from other factories in Gloucester; the last case was reported in 1907.

### *3.5 The match making industry and the related health and safety issues*

The first chemical potassium chlorate matches were invented in Vienna in 1812, but they were quickly replaced between 1830 and 1834 by white phosphorus-based Lucifer matches. These new matches, invented by French chemistry student Charles Marc Sauria (Wisniak, 2005; Roberts *et al.*, 2016), became popular because they could be lit by striking any surface. Quickly, the match making industry reached the United Kingdom and became widespread there, as well as in Europe and the United States. In 1897 Britain, 25 match factories employed a total of 4152 people, i.e., 643 men, 2015 women and 1492 adolescents between 14 and 18 years old (Harrison, 1995).

The process of match manufacturing was divided into different stages. Thousands of heat dried wood splints contained within a frame were simultaneously dipped into melted sulphur or paraffin. A second immersion into a lighting composition of 5-10% white/yellow phosphorus was then performed with a pan-like container on a hot dripping table. After this, the matches were taken to a drying room and boxed. Steam passing through a pipe into the table kept the lighting phosphorus mixture soft, generating at the same time fumes that the dippers were inhaling for many hours a day (Felton, 1982; Harrison, 1996; Roberts *et al.*, 2016).

Match factory employees worked 10-15 hours per day for low wages in a poor work environment (Marx, 2008). The *Star* reported that dippers, who of all employees had the most contact with phosphorus, spent their days in the most deplorable conditions. The dipping rooms, which were usually located under the other departments, had little or no ventilation (Satre, 1982). In many small and poorly managed factories, workers were unprotected from the fumes. As a result, their clothes were “incandescent in the dark” and white fumes came out of their mouth when breathing even in a warm environment (Felton, 1982). The *Star* reported that Bryant and May, contrary to other companies, did not provide their employees with soap or towels in the work place, where they also had to eat during their break (Satre, 1982). Yet, these companies blamed the lack of personal hygiene and individual habits as the cause of their illnesses (Harrison, 1982).

In 1855 new safety matches without white/yellow phosphorus were introduced by the Lundstrom brothers in Sweden (Satre, 1992; Myers and McGlothlin, 1996; Marx, 2008). These matches contained antimony sulphide and potassium chlorate, with red phosphorus on the side of the box as a striking surface. The new product was created in response not only to the work-related disease, but to avoid accidental spontaneous ignitions by the strike-anywhere matches (Marx, 2008). As a demonstration of the toxicity of the previous model, swallowing white phosphorus match heads was a suicide method at the time, as well as an accidental cause of death among children (Felton, 1982; Wisniak, 2005).

However, the use of white/yellow phosphorus matches was not immediately abolished; it took time even after the famous “Match Girls’ Strike” in 1888. The first country that banned the product was Finland in 1872, followed by Denmark (1874), Switzerland (1898) and the Netherlands (1901). The Berne Convention in 1906 abolished the importation of white/yellow phosphorus in all European countries. However, Britain continued to use and produce white phosphorus matches until 1910 (Myers and McGlothlin, 1996).



## 4. Conclusions

Gloucester Skeleton 1554 is a clear example of a 19th century work-related pathological condition. The examination of the phosphorus necrosis evident on the mandible of this skeleton is an important contribution to the modern scientific literature on this topic; to date, only a case from Coach Lane Quaker cemetery in North Shields has been published (Roberts *et al*., 2016).

In the 19th century, Gloucester was one of the most important centres for the production of matches, and the present case demonstrates for the first time the occurrence of “phossy jaw” in the area, as Victorian literature suggested. The skeleton represents an important case for reflection on the difficult conditions in which young individuals lived and worked in the past. Phosphorus necrosis was an occupational disease that allows us to not only understand the value of palaeopathological indicators to reconstruct historical environments, but to stress the importance of health and safety regulations in modern workplaces.

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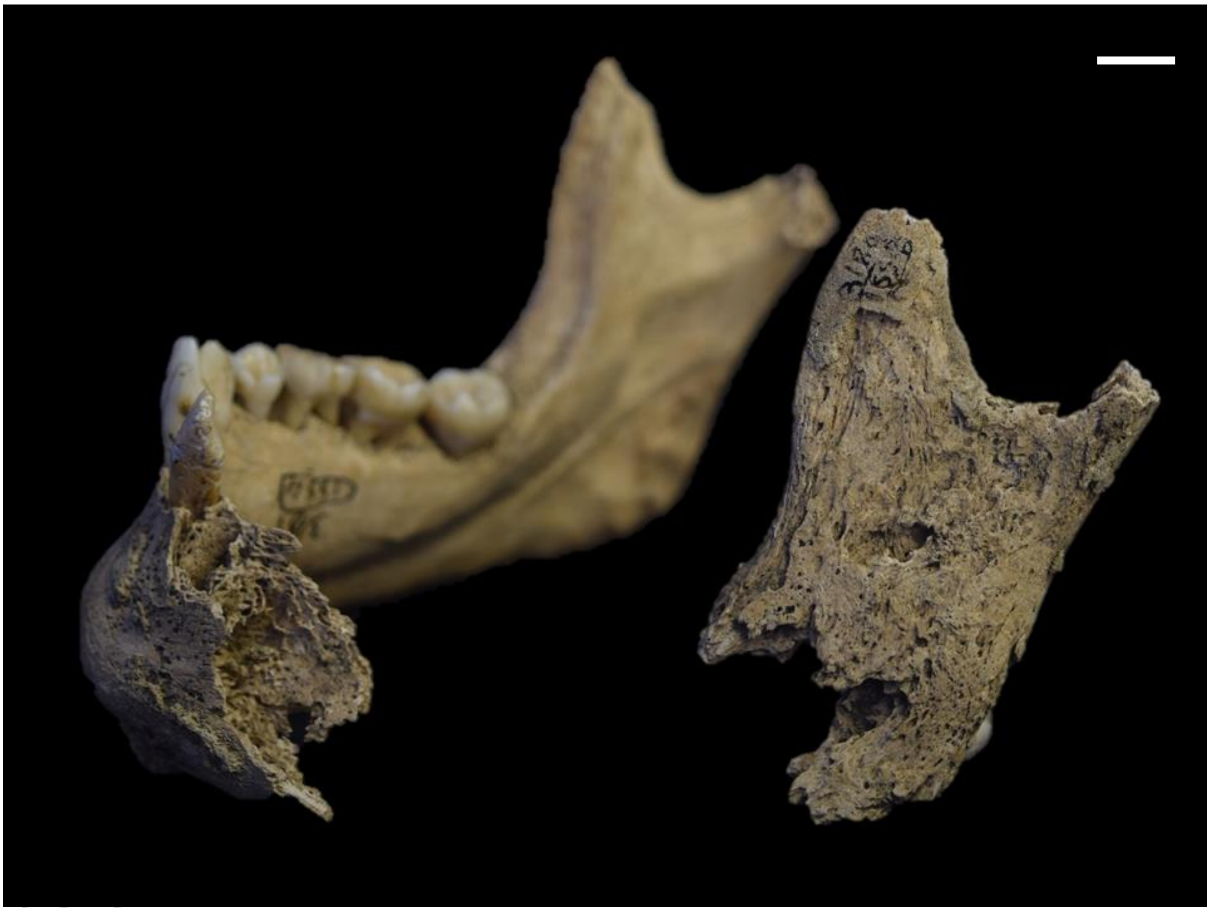

**Figure 1 The mandible shows bone necrosis with sub-periosteal new bone formation on the left body, from the first premolar to the third molar and part of the ramus.**


**Figure 2 anterior (A) and inferior (B) view of the mental eminence where the deposition of new bone formations covering the necrotic bone produced the involucrum**

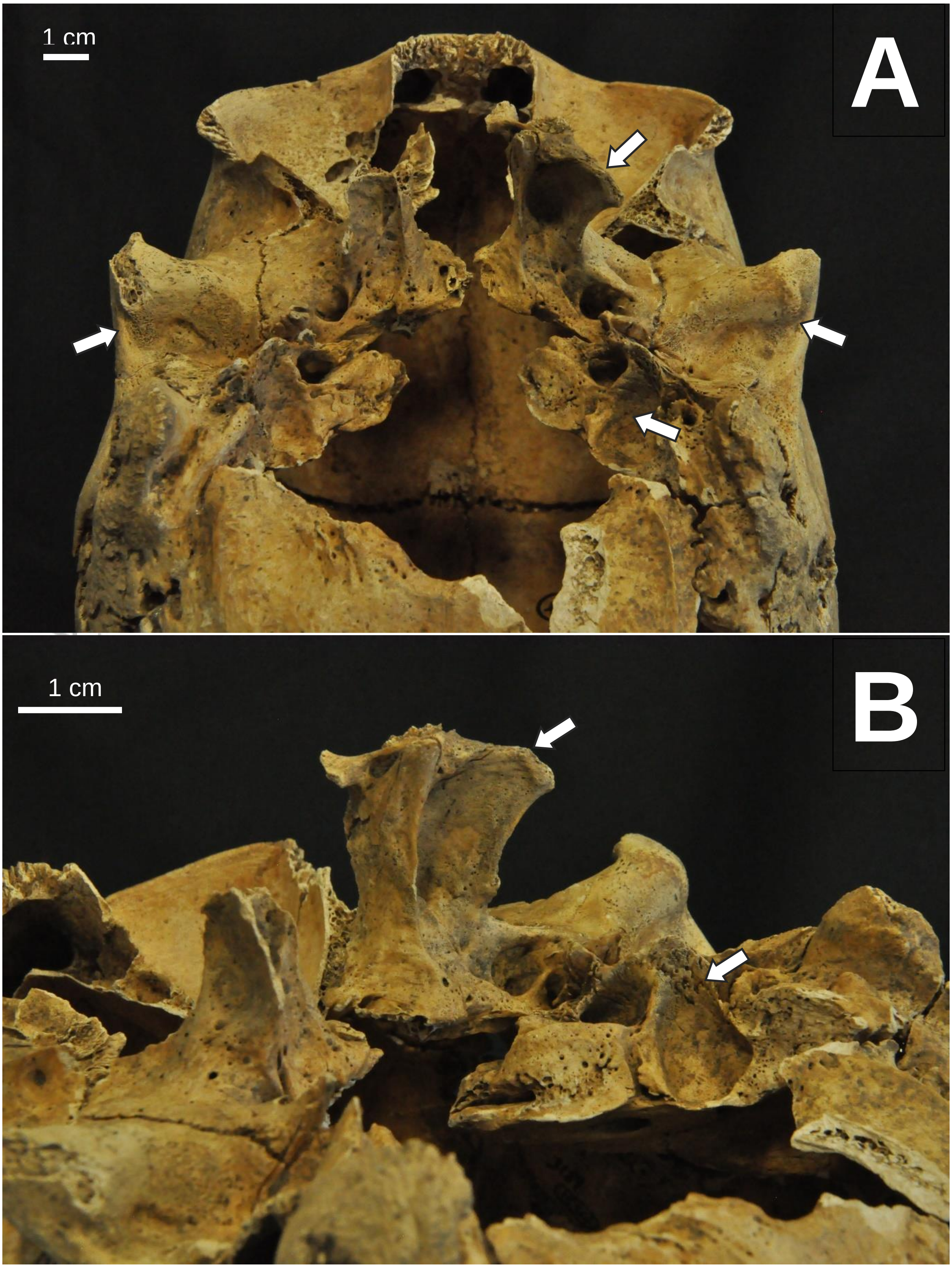


**Figure 3 New bone formation (arrows) on (A) the zygomatic processes and in the mandibular fossae and (B) the distal sides of the pterygoid plates of the sphenoid and in the jugular fossa.**

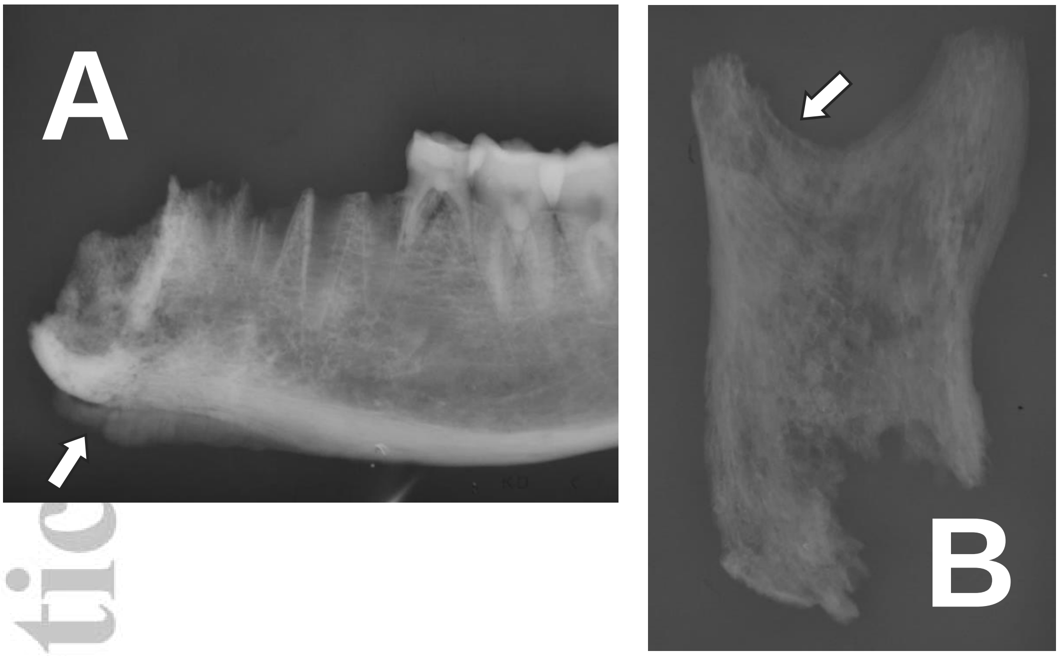


**Figure 4 Radiographic image of the mental eminence (A) that shows the involucrum (arrow), excluding a neoplastic disease. The radiographic image of the left ramus (B) displays the involucrum (arrow) and bone reaction, dismissing taphomic alterations as the cause of the changes.**