

Chronic Maxillary Sinusitis in Ancient Populations: X-Ray Computed Microtomography Data



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Abstract A case of chronic maxillary sinusitis (CMS) found in a burial site of a Late Bronze Age settlement in Bai-Kiyat I was studied by X-ray computed microtomography. The aim was to diagnose CMS, analyze the factors in the development of the disease, study its etiopathogenesis, and determine the potential contribution of odontogenic pathology to the overall incidence of CMS in ancient populations. Pathological changes in the left maxillary sinus characteristic of chronic maxillary sinusitis were recorded on a 3D model created using X-ray computed microtomography. The presence of chronic periodontal disease and apical periodontitis of the maxillary molars on the left, which had triggered the development of CMS, was established. The obtained and previously published data confirm the significant contribution of odontogenic pathology to CMS development. The dietary and hygienic behavioral patterns are clearly underestimated in the analysis of the incidence and prevalence of chronic inflammatory diseases of the maxillofacial region among ancient populations. X-ray computed tomography removes most of the limitations in bioarchaeological studies, allowing reliable diagnosis of odontogenic CMS forms.

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1 Introduction

Research into the epidemiology of infectious diseases is of particular importance for the analysis of adaptive models used by ancient populations and the reconstruction of critical biosocial factors in their survival. Infectious diseases that cause high mortality among populations (plague, cholera, etc.) conventionally attract much research attention. However, the spread of chronic diseases that are not characterized by increased mortality is of greater importance for elucidating the adaptation dynamics of human populations. Such diseases not only affect the biological profile of the population, but also require social mechanisms to provide the necessary treatment and care for patients, and, as a result, to mitigate disability-related consequences.

Such diseases include chronic sinusitis—a chronic inflammatory process in one or more paranasal sinuses. Chronic maxillary sinusitis (CMS) is a persistent long-term inflammation of the maxillary sinus mucosa of an infectious, allergic, or traumatic nature (Slavin et al. 2005). At early development stages, CMS is rarely accompanied by severe symptoms that pose a direct threat to human life. CMS manifestations can cause noticeable physical discomfort and decreased performance due to difficulty in nasal breathing, pain in the projection of the paranasal sinuses, general weakness, and such exacerbations, as serous purulent discharge from the nose, increased body temperature, etc. (Arefyeva et al. 2014; Sipkin et al. 2013). However, the spread of inflammation deep into the intracranial structures can lead to bone damage and the development of osteomyelitis. Another common complication of sinusitis is meningitis, a brain abscess.

In the modern population, sinusitis affects children and adults in 5.0% and 5.0–15.0% of cases, respectively. People aged 45–75 years are most susceptible to the disease. Epidemiological studies carried out in more than 30 countries indicate a three-fold increase in the incidence of sinusitis over the past decade (Yaremenko et al. 2015). In the USA, CMS is present in 15.5% of adults. At the same time, odontogenic chronic maxillary sinusitis affects 15.0% of the inhabitants of the Russian Federation and 14.0–20.0% of the world's population (Surin and Pohodenko-Chudakova 2018).

Unlike many other human diseases, CMS is relatively easy to diagnose on ancient materials presented by skeletal remains. Since the mucous membrane of the maxillary sinus is closely connected with the periosteum, representing a whole unit, inflammatory processes may quickly pass to the bone tissue. This results in the development of chronic inflammation of the bone walls of the sinus (osteitis), with the bone tissue becoming heterogeneous and containing foci of osteosclerosis, osteoporosis, and remodeled bone tissue. All these signs can be either detected by visual examination of the maxillary sinus or reconstructed by X-ray computed tomography (Sundman and Kjellström 2013; Boocock et al. 1995; Biedlingmaier et al. 1996; Erdogan et al.

2016; Mafee et al. 2006; Georgalas et al. 2010; Momeni et al. 2007; Snidvongs et al. 2014).

Previous studies discovered a link between the incidence of CMS in different population groups and their living conditions (urban or rural areas), the degree of air pollution, the social status of the buried, the prevalence of dental pathologies, and climatic and geographical factors (Roberts 2007; Zubova et al. 2020a; Zubova et al. 2022b; Lewis et al. 1995; Panhuysen et al. 1997). In bioarchaeological practice, CMS is commonly referred to as a poverty-related disease. Thus, CMS occurred several times more often in the craniological series characterizing the population of the lower strata of European societies than in representatives of the upper classes (Schultz and Schmidt-Schultz 2014). However, due to a lack of data on the epidemiology of CMS in ancient and historical communities, no consensus has so far been reached concerning the factors affecting its incidence.

A statistical correlation showing an increase in the incidence of sinusitis from south to north was found only between CMS and climatic indicators (Zubova et al. 2022b). However, given the general statistical reliability of this correlation, the specific coefficients calculated for the globe as a whole and its individual regions are not high. Hence, the relationship between CMS and particular climate characteristics may differ in different areas. One of the reasons for the observed instability may be the presence of rhinogenic and/or odontogenic etiology in the examined series of CMS. Rhinogenic sinusitis develops with respiratory infections and certain types of allergies. Odontogenic forms develop when microorganisms of the oral cavity penetrate into the sinus cavity, through channels formed as a result of bone resorption of alveolar cells during a long course of chronic periodontal diseases, or osteomyelitis (Buskina and Gerber 2000; Abrahams and Glassberg 1996).

The spread of odontogenic inflammations is theoretically less related to climate than rhinogenic ones. In the former case, the composition of the diet and the peculiarities of oral hygiene, i.e., social factors, are of fundamental importance; in the latter case, the frequency of hypothermia and the composition of the inhaled air gain more significance. Accordingly, when studying the factors affecting the epidemiology of CMS in ancient groups, it is necessary to separate odontogenic and non-odontogenic forms of the disease and compare their incidence rates differentially. This causes some methodological difficulties, since, until recently, the diagnosis of CMS has been performed visually or using an endoscope, based on the presence of porotic changes in the maxillary sinus cavity and newly formed bone tissue in the form of spicules (Sundman and Kjellström 2013). Identification of odontogenic infection foci with this approach is possible only provided that CMS signs are simultaneously present inside the sinus and the oroantral fistula. Non-linear communication channels between the oral cavity and the sinus cavity, formed in chronic apical periodontitis, cannot be detected by visual examination. In addition, infection sources are impossible to determine when bone tissue healing begins after tooth extraction or loss.

X-ray computed microtomography presents a feasible alternative to visual examination. Although this method is yet to receive widespread acceptance in the study of CMS among ancient populations, a number of our investigations have confirmed

its advantages (Zubova et al. 2020a, 2022a). Among them are the possibility of a reliable diagnosis of odontogenic CMS and its differentiation from other pathologies. Accordingly, further tomographic studies in this area are required to elucidate the factors affecting the incidence of sinusitis. Our work extends these studies by analyzing a new case of odontogenic CMS detected in an individual of the Late Bronze Age buried at the settlement of Bai-Kiyat I.

2 Materials and Methods

2.1 Description of the Research Object

The skull of a male individual of mature age (40–60 years old), discovered during excavations in burial 2 of the Bai-Kiyat I settlement (45.6778, 32.9985) in 1990, was analyzed. The state of skull preservation was medium. The bones of the base and the bottom of the alveoli of maxillary molars on the right side were posthumously destroyed; the left zygomatic arch was damaged. Multiple postmortem losses in the dental system were also present. On the maxilla, the central right incisor, the right canine, the right first molar, the right second molar, the left second molar, the left third molar were preserved; on the mandible, the central incisors, the right canine, the first and second premolars, the first and second molars of both sides were present. The rest of the teeth were lost (Fig. 1a).

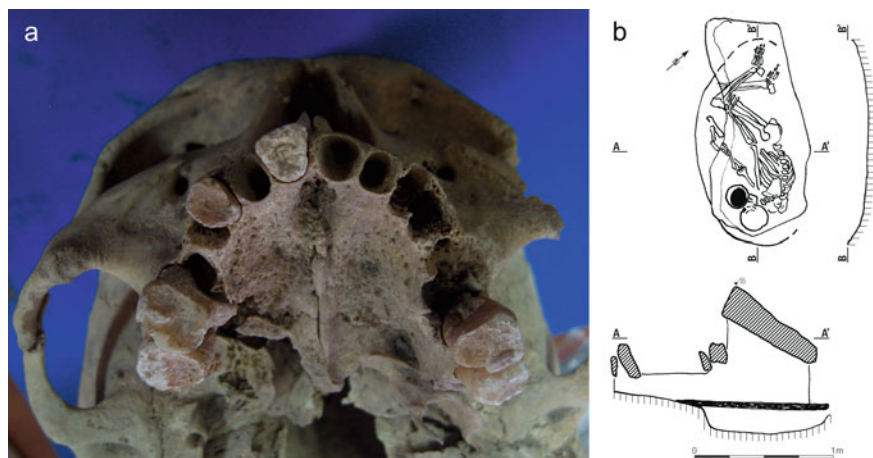


Fig. 1 **a** The skull under study, its maxilla with preserved teeth and lesions. **b** Burial 2 in the settlement of Bai-Kiyat I

2.2 *Research Methods*

The skull was subjected to X-ray computed microtomography. Scanning was performed on an MSCT-04 tomograph, according to the following protocol: the X-ray tube voltage of 140 kV, the current of 50 μ A, no filter, the slice thickness of 0.1 mm. Data reconstruction was performed using an original software package. Postprocessing analysis was performed using CTAn and CTVox (Bruker-microCT). The upper left second molar was scanned by a Skyscan-1172 X-ray microtomography scanner ($U = 82$ kV, $I = 120$ μ A, Al 0.5 filter, rotation = 0.25° , averaging by 6 frames, image pixel size = 6.92 μ m). Reconstruction and post reconstruction processing was performed by the Bruker software package (NRecon, CTAn, CTVox).

The obtained CT scans showed several pathological conditions. First, signs of osteitis in the maxillary sinus walls were recorded. According to the standard approach (Georgalas et al. 2010), we used the maximum thickness of one of the sinus walls of 3 mm and more as the threshold for diagnosing osteitis. The walls were measured at osteosclerotic foci of both left and right maxillary sinuses, avoiding corners of the sinuses.

Sources of odontogenic infections were detected using a number of markers, including the foci of chronic periodontitis and osteomyelitis and the presence of channels connecting the sinus with the alveoli.

Chemical analyses of the bone tissue were carried out by pXRF-technique with an INNOV-X Omega portative scanner.

2.3 *Description of the Archaeological Site*

The site is located on a high steep bank (cliff height of 4–5 m) and is bounded by the seashore from the north. Across the investigated area of 2100 m², about 14 rooms with stone-faced walls for various purposes were excavated. Inside were hearths, household items, and ash pits. The settlement was traced to the end of the Sabatinovka culture and the Belozerka culture, dating back to the end of the 13th–10th centuries BC (Kolotukhin 2003).

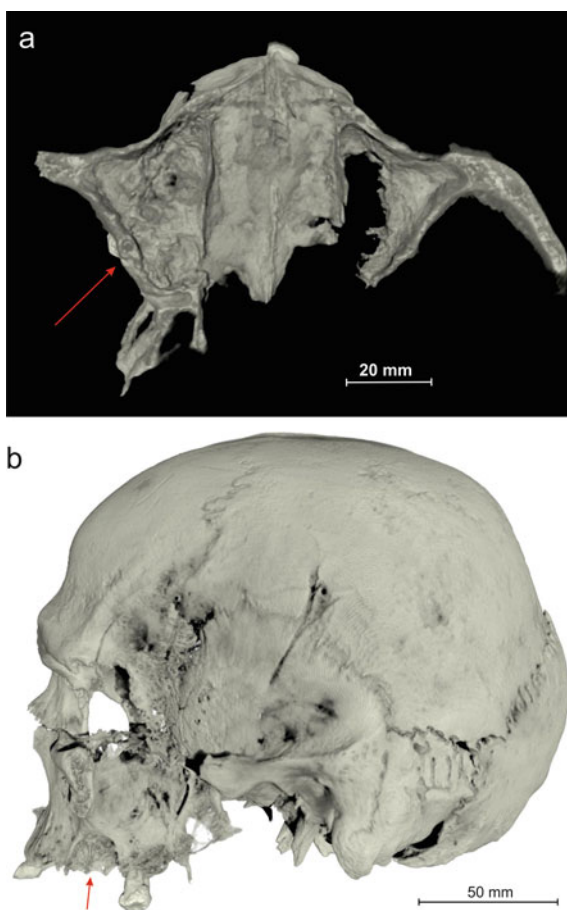
Burial 2 (Fig. 1b) was performed in a pit of an irregular oval shape (dimensions 1.50×0.95 m, depth 0.15 – 0.20 m), oriented along the northeast–southwest line. On the southern side, the remains of the overlap of flat limestone slabs were preserved; another large slab was located above the burial. The buried man was laid in a weakly crouched form on his left side, his head oriented to the southeast, the front part—to the west. The left arm was stretched out in front of the trunk, the right hand was placed along the trunk, the left hand was close to the knees. The legs were slightly bent, the right tibia rested on the left tibia, the feet were laid next to each other. In front of the face of the buried, to the west, there was a hand-formed jar-shaped vessel.

3 Results and Discussion

3.1 Results of X-ray Computed Microtomography

The data of X-ray computed microtomography for the skull from the settlement of Bai-Kiyat I showed the absence of frontal sinuses and the presence of chronic inflammation signs in the left maxillary sinus. The posterior wall of the sinus was thickened to 4.79 mm (marked by arrow, Fig. 2a), which corresponds to severe CMS, whereas the maximum thickness of the posterior wall on the right side was only 2.40 mm. At the bottom and walls of the sinus, porosis and small spicules were visually observed, whose etiology and distribution area could not be visually determined due to postmortem damage.

Fig. 2 **a** Micro CT scans of osteosclerosis foci and thickening of the posterior wall of the left maxillary sinus. **b** Micro CT scans of lesions in the area of the left upper molars



The anatomical structure of the maxillary sinuses and dental system of the buried person, accompanied by a number of pathological changes in the dental system, indicates the odontogenic nature of CMS. The bottom of the sinuses is located at the level of the lower edge of the nasal opening, with the roots of the upper premolars and molars identified in the vicinity. Postmortem destruction does not allow the thickness of the bone plate separating the sinus cavity from the alveolar cells to be measured accurately; however, its size of not less than 1.0 mm comprises a predisposing factor for the formation of infection channels from the dental system into the maxillary sinus.

On both jaws, a pronounced resorption of the alveolar margin was observed, indicating the development of chronic generalized periodontal disease of medium degree. The main causes of this disease include genetic predisposition, somatic diseases, and poor oral hygiene. The latter leads to the accumulation of pathogenic microorganisms that destroy the connective tissue and cause bone loss (Clarke and Carey 1985). Due to bone resorption, formation of periodontal pockets, and poor oral hygiene, it obviously led to exacerbations and pain. The individual may have tried to improve oral hygiene by using toothpicks. On the adjacent walls of the lower left first molar and the left second premolar, grooves from toothpicks (3.5 mm long on the premolar and 7.3 mm on the molar) were discovered. A similar groove with a length of 6.6 mm was found on the lower right first molar. The upper molars showed similar signs of damage.

On the preserved teeth of the maxilla and mandible, non-carious lesions of the teeth, having occurred after teething, in the form of increased tooth attrition and wedge-shaped defects were observed (Fig. 3). Increased attrition was typical of all preserved teeth. On the chewing surface of the teeth, the erased enamel led to dentin exposure. A possible cause of wedge-shaped defects was excessive and aggressive use of toothpicks against the background of chronic periodontitis. The increased tooth attrition may have resulted from coarse, thermally and mechanically unprocessed, food (Gerasimova et al. 2012; Pikhur et al. 2020).

The immediate trigger for the development of CMS was most likely to be chronic apical periodontitis of the upper left first and second molars, the signs of which are present on a CT scan (arrow) (Fig. 2b).

In the area of the maxillary bone located under the zygomatic process, an extensive defect of the external wall of the alveolar arch measuring 1.2×0.6 cm was discovered. It extends to two teeth—the first and second left molar of the maxilla. The first molar was lost, the second was present. The edge of the defect was sclerosed, and the area of the first molar also showed sclerotic changes in the lingual wall of the alveoli with the formation of a spongy tissue at its bottom, which indicates that the tooth had been lost during life. In modern dental practice, development of apical inflammation alike of Bai-Kiat I would lead to surgical extraction of the tooth. In some ancient samples, cases of such operations also are known (Zubova et al. 2020b; Zubova et al. in press). However, to confirm such treatment was one in this case, a special traceological analysis is required, which has not been performed for the Bai-Kiyat I skull. Thus, there is no positive evidence to assert that the molar was deliberately removed.

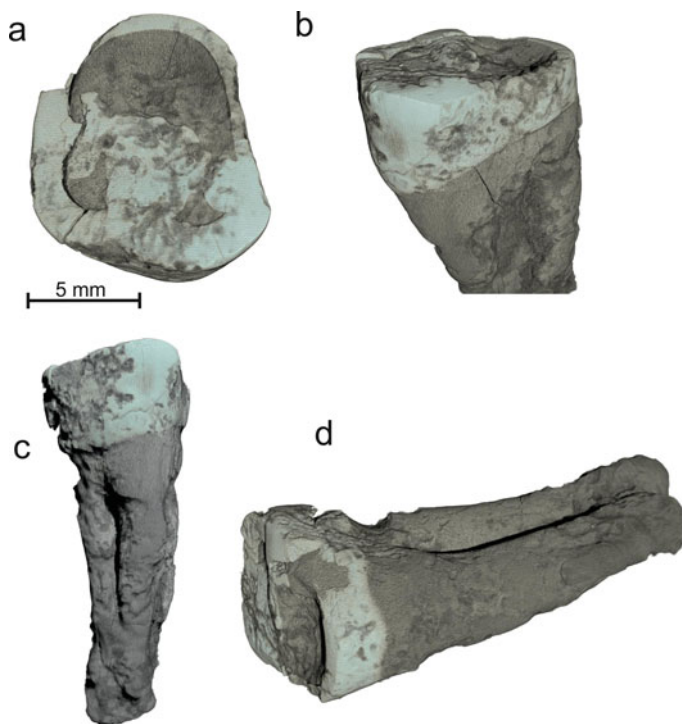


Fig. 3 Micro CT scans of the upper left second molar: **a, b**—wear facets on the chewing surface of the tooth; **c, d**—wedge-shaped defect in the cervical region of the tooth (root form)

There are no signs of healing in the area near the second molar, which indicates that recovery was not completed at the time of the individual's death. At the bottom of the alveoli of both molars, multiple holes are present. Some of them appeared due to bone destruction because of periodontitis progression. They became channels for infection to enter the sinus cavity. Thus, the analysis of the obtained X-ray computed microtomography data confirmed the penetration of an odontogenic infection into the cavity of the left maxillary sinus, demonstrating a case of odontogenic CMS.

3.2 Discussion of Maxillary Sinusitis Etiopathogenesis

Periapical inflammatory processes in the area of the roots of the teeth adjacent to the maxillary sinus comprise the main factor in the development of odontogenic lesions of the maxillary sinus.

According to literature data (Yaremenko et al. 2015; Koshel 2017), in 10.0% of cases, an inflammatory process in the maxillary sinus can develop in the presence of a focus of chronic odontogenic infection localized near the sinus.

It should be noted that, in our previous studies into the etiology of CMS using X-ray computed microtomography, odontogenic pathology in all cases occupied the leading position. According to the data published on the Pukara de Tilcara fortress in Northern Argentina, CMS was recorded in more than 20.0% of individuals (Zubova et al. 2020a). In the total number of detected cases, odontogenic forms of maxillary sinusitis caused by chronic periodontitis of maxillary teeth were diagnosed in 80.0%. A fragment of the maxillary sinus floor found at a Neanderthal site of the Middle Paleolithic period in the Chagyrskaya Cave also demonstrated the presence of chronic periodontitis of the maxillary molar, which caused the development of CMS and subsequent infection in the sinus cavity (Zubova et al. 2022a). These findings, along with the present data obtained for the skull from Bai-Kiyat I, confirm the hypothesis that the state of the dental system significantly affected the occurrence and development of CMS in ancient people.

3.3 Results of pXRF Analysis

The development of many diseases of the dental system, including those predisposing to CMS, is associated with the diet of a particular individual or population. Data on the chemical composition of the bone for the skull from Bai-Kiyat I were obtained, which allow some assumptions about the diet of the buried person (Table 1). The indicator $\lg(\text{Sr}/\text{Ca}) = -0.469$ points to the inclusion of a large amount of plant food in the individual's diet (Magee et al. 1994; Fabig and Herrmann 2002). At the same time, the Zn content (109 ppm) and the Zn/Ca ratio ($44 \cdot 10^{-4}$) characterize the inclusion of meat food in the diet as well (Benfer 1995).

The index of diagenetic bone transformations (Ca/P), which characterizes changes in the chemical composition of the bone tissue under the influence of environmental conditions, equals 2.95. This reflects the insignificant contribution of diagenetic changes and the validity of the data obtained.

Table 1 Chemical composition of the skull bone from burial 2 in the Bai-Kiyat I site (pXRF analysis)

Burial 2 in the Bai-Kiyat I site	P, wt %	Ca, wt %	Zn, ppm	Sr, ppm	$\lg(\text{Sr}/\text{Ca})$	Zn/Ca	Ca/P
n = 3	8.3	24.5	109	851	-4.469	0.00044	2.95

3.4 Discussion of the Data Obtained

The data of X-ray computed microtomography on the skull from the settlement of Bai-Kiyat I suggest that the individual from burial 2 suffered from otolaryngological and dental diseases, the development of which had been influenced by a number of factors. The inflammatory process, which probably developed as a result of chronic periodontitis of the left first and second molars of the maxilla, contributed to the spread of odontogenic infection in the paranasal sinuses, causing odontogenic CMS of the left maxillary sinus. The anatomical structure of the dental system and maxillary sinus were the factors predisposing to the development of CMS.

The probable dominance of plant food in the individual's diet significantly affected his daily life and general health. In order to prevent exacerbations of chronic generalized periodontal disease, the individual tried to improve oral hygiene using toothpicks. However, the frequent and aggressive use of toothpicks in the area of the premolars and molars of the maxilla and mandible led to mechanical trauma to the cervical region of the hard teeth tissues followed by the formation of non-carious lesions in the form of wedge-shaped dental defects. The consumption of coarse unprocessed food increased tooth abrasion, which is clearly manifested on the preserved teeth of the individual.

4 Conclusion

The data obtained by our and previous studies confirm that CMS incidence in ancient populations should be assessed not only based on climatic and geographical contexts, or the social status of the studied community, but also taking the dietary and hygienic behavioral patterns into account. These factors are clearly underestimated in the analysis of the incidence and prevalence of chronic inflammatory diseases of the maxillofacial region among ancient populations. In order to assess the contribution of climatic and environmental (degree of air pollution) factors to the development of CMS, it is necessary to exclude cases of odontogenic CMS from the analysis. This is possible only with an accurate diagnosis of diseases, which can be achieved using X-ray computed microtomography.

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