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# An innovative method to visualise mastoiditis using a hand-held X-ray system

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ABSTRACT

*Objective:* We explore the utility of using a hand-held X-ray system to diagnose mastoiditis in archaeological populations.
*Materials:* A sample (n = 56) of hunter-fisher-gatherers from the Early Neolithic (8,000–7,000/6,800 cal. BP) Cis-Baikal cemetery of Shamanka II (Russia) were examined.
*Methods:* Images were taken medio-laterally, approximately 90° to a sensor temporarily affixed to the lateral surface of the mastoid process. Digital radiographs were analysed for signs of mastoiditis occurring pre- and/or post-puberty.
*Results:* Two thirds of individuals (39/56) exhibited evidence of mastoiditis. Chronic mastoiditis and chronic sinusitis co-occurred in 61.5% (24/39) of observable individuals.
*Conclusions:* This method was found to be an effective, convenient, and versatile non-destructive alternative to sectioning and traditional radiographic imaging.
*Significance:* This is the first project to adapt a hand-held X-ray system for imaging and diagnosis of mastoiditis and this approach encourages future analyses of this infection.
*Limitations:* The cost of the imaging system is limiting and there are few comparative images taken in the same plane.
*Suggestions for further research:* Further research should create a larger catalogue of comparative radiographs and assess the diagnostic potential of imaging the mastoid process to rather than imaging the entire pneumatized portion of the temporal bone.

## 1. Introduction

Mastoiditis is a condition that often forms secondary to otitis media. In fact, mastoiditis is the leading complication of acute otitis media (Bluestone, 1998; Lewis, 2017:141) since the structures of the mastoid process are continuous. However, the infection can also enter the mastoid process via the emissary veins (Bluestone, 1998; Fleischer, 1979). The middle ears are connected structurally to the upper respiratory system via the Eustachian tubes and the vascular network creating direct pathways for the transfer of infection (Kuczkowski and Mikaszewski, 2001). Therefore, the presence of mastoiditis can suggest the presence of otitis media and can be associated with upper respiratory infection (URI).

Formation of the mastoid processes—including the pneumatisation of mastoid air cells—begins in the late prenatal period (Schaefer et al., 2009:24) and is generally complete by puberty (Cinamon, 2009). Before puberty, healthy mastoids are pneumatized (Fig. 1a), but inflammation of the mucus membrane associated with chronic (3+ weeks) mastoiditis can halt pneumatization (Chien et al., 2012), leaving the structures hypocellular (Fig. 1b) or un-evenly (partially) pneumatized (Fig. 1c) (Robinson et al., 1993; Tos and Stangerup, 1984). This can increase susceptibility to otitis media that is more difficult to treat (Aoki et al., 1989; Tos and Stangerup, 1984). Chronic mastoiditis after puberty can cause other internal structural changes, namely osteolytic lesions and sclerotic sub-endosteal proliferation (Fleischer, 1979; Titche et al., 1981). This phenomenon is discussed less frequently in the clinical literature, as the soft tissues in the mastoid process generally obscure the changes in radiographs (Schultz, 1979). Many of these features/lesions are also invisible on skeletal remains if the mastoid processes are intact, limiting the diagnosis of mastoiditis from

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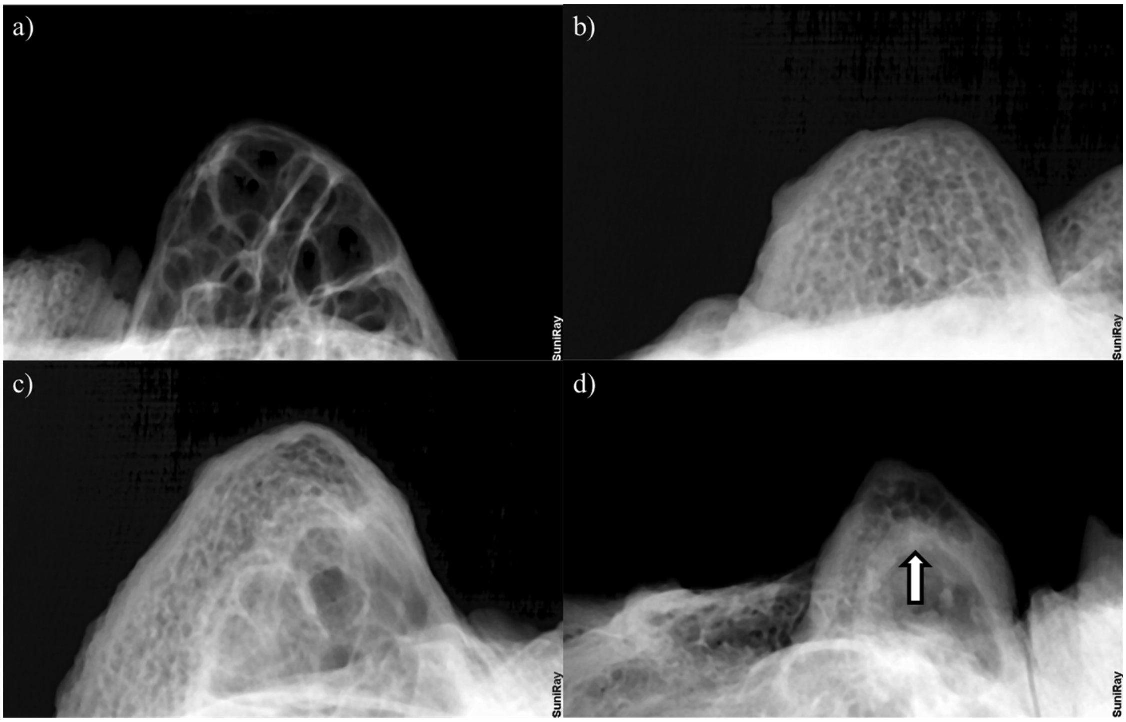


**Fig. 1.** Radiographs of a) a healthy, fully pneumatized mastoid process, b) a hypocellular mastoid process, c) a partially pneumatized mastoid process, and d) a mastoid process with an abnormally large void and sclerotic sub-endosteal bone growth (indicated by arrow) (Hodgson, 1938; Radiopaedia, 2019a,b).

macroscopic methods alone.

Before the advent of antibiotics, more children were hospitalized for acute mastoiditis than for anything else (Bluestone, 1998), yet mastoiditis is under-represented in the paleopathological literature (Flohr et al., 2009). In fact, research into pre-/historic population levels of URI has only been undertaken since the mid-1990s (Boocock et al., 1995; Lewis et al., 1995), largely because upper respiratory structures are difficult to examine non-destructively (Roberts, 2007). Sinusitis, especially maxillary sinusitis, is most often studied, as sinuses are often visible macroscopically or with an endoscope (e.g., Boocock et al., 1995). Recently, medical imaging systems have been used in archaeological studies of URI, allowing non-destructive observation of relevant structures. For example, studies of otitis and mastoiditis have used radiography (Flohr et al., 2009; Gregg et al., 1965; Oxenham et al., 2005; Titche et al., 1981; Krenz-Niedbała and Łukasik, 2016), SEM (Flohr et al., 2009), and CT (Collins and Jónsson, 2010).

Radiography and CT are at the forefront of the clinical mastoiditis diagnosis (Aoki et al., 1989; Beckett and Conlogue, 2009; Bluestone, 1998; Park et al., 2000). Until recently, radiography has been limited to fixed technology. The advent of portable X-ray systems has made radiography more accessible and versatile, reducing the need to transport archaeological material by allowing “in house” imaging. There are also fewer structural constraints when working with archaeological remains: there are no obscuring soft tissues and disarticulated skeletal elements allow for innovative imaging planes. While CT scans provide finer detail (Park et al., 2000), the portability and versatility of portable X-ray systems reduce barriers to non-destructive imaging and have the potential to transform paleopathological analyses. Here, an innovative method of mastoid process imaging was tested using a hand-held X-ray system.

## 2. Materials and methods

The NOMAD Pro Hand-Held X-ray System and the Dr. Suni Plus Intraoral Digital Light Sensor were used to image the mastoid processes of 56 individuals from Shamanka II, Russia (Early Neolithic; 8,000–7,000/6,800 cal. BP). Shamanka II (n = 153), a hunter-fisher-gatherer cemetery located in Siberia’s Cis-Baikal region (Fig. 2), was excavated between 2000 and 2008 by V.I. Bazaliiskii. It was selected due to its excellent skeletal preservation, large size, and the generally high levels of documented URI (Lieverse et al., 2019; Purchase, 2016).

A sample of 56 individuals (38 male, 18 female) with observable mastoid processes and available age-at-death data were analysed. Previously published age and sex data reflect the combined efforts of several researchers (Lieverse, 2005; Lieverse et al., 2019) and were largely based on the standards presented by Buikstra and Ubelaker (1994:16–21). For an individual to be considered observable for mastoiditis, their pneumatization development had to be complete (≥18 years at death), at least two-thirds of each mastoid process had to project inferiorly from the cranial base to be visible radiographically, and the mastoid processes had to be undamaged (e.g., fracture or post-mortem erosion affecting air cell integrity) (Montgomery et al., 1994). Typically, intact adult mastoid processes were able to be imaged in this way regardless of sex. Males were not more likely than females to be considered observable.

To image a mastoid process, the cranium was inverted on a table and the sensor (43.5 by 31.5 mm; active area of 35.2 by 26.2 mm) was affixed to the lateral surface of the mastoid process using modelling clay. The radiograph was taken medio-laterally (~90° to the sensor) with the X-ray generator positioned immediately anterior to the contralateral mastoid. Disarticulated temporal bones were imaged in the same way, but with the lateral side down, on top of the sensor. In all cases, the mastoid process was imaged without adjacent bony structures obscuring the view. The digital sensor permitted all images to be viewed immediately and saved on a computer (Fig. 3). When possible, both sides were imaged, as mastoiditis can be unilateral (e.g., Titche et al., 1981), but data were recorded at the individual level only.

Clinicians diagnose mastoiditis by examining the tympanic membrane for indications of exudate buildup within the middle ear and by assessing X-ray or CT images of the mastoid air cell system for signs of infection: hypocellularity, opacity, osteolytic lesions, and sclerotic sub-endosteal bone proliferation (Bluestone, 1998). The volume of the air

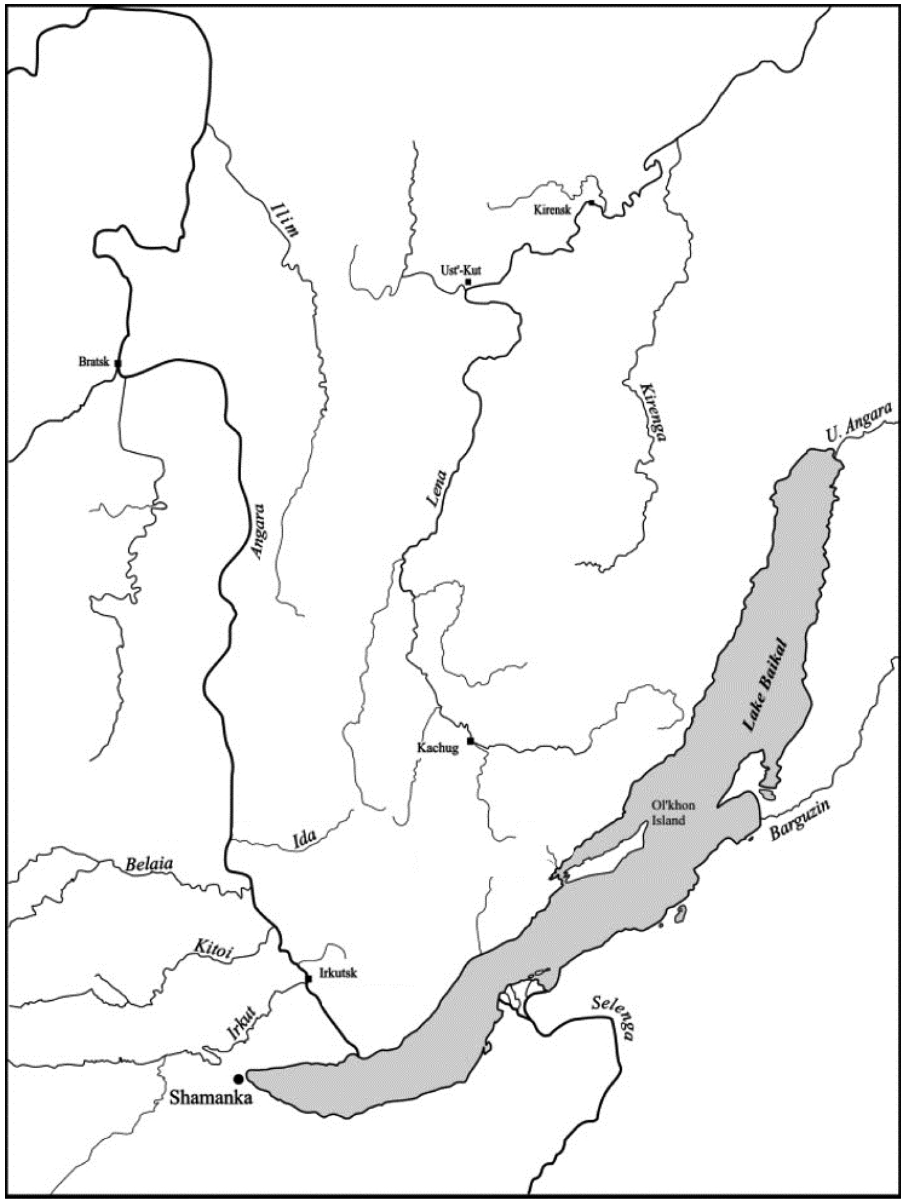


**Fig. 2.** Location of the Shamanka II cemetery in the Cis-Baikal region, Siberia, Russian Federation (Baikal Archaeology Project).

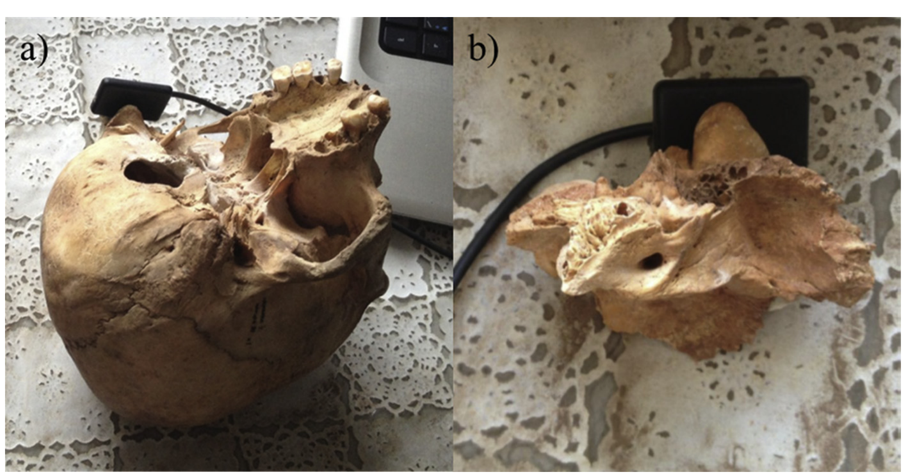


**Fig. 3.** The sensor temporarily affixed to the lateral surface of the mastoid processes using modelling clay a) with the cranium inverted on the table for imaging and b) with the disarticulated temporal bone lateral-surface-down on the table for imaging.

cell system (calculated from the radiographs or CT scans) can also be compared to an established healthy range (which varies based on the atmospheric air pressure of the region in which the individual developed) (Park et al., 2000; Tos and Stangerup, 1984). While exudate cannot be observed on archaeological samples, the osseous lesions it produces can be. As such, and consistent with clinical diagnostic criteria, radiographs from Shamanka II were assessed for hypocellularity, osteolysis, and sclerotic bone formation. Mastoid air cell volume was not calculated because the entire system was not imaged.

The appearance of partial (Fig. 1c) or complete (Fig. 1a) hypocellularity in a single mastoid process was considered diagnostic of chronic childhood mastoiditis (Krenz-Niedbała and Łukasik, 2016). Chronic adult mastoiditis was diagnosed by the presence of osteolysis and sclerotic sub-endosteal bone growth (Collins and Jónsson, 2010; Flohr et al., 2009; Oxenham et al., 2005; Titche et al., 1981). Sclerotic bone formation was distinguishable from hypocellularity due to its dense and amorphous radiographic appearance (Fig. 1d) (Hodgson, 1938; Radiopaedia, 2019a, b). An incompletely pneumatized mastoid process with osteolysis and sclerotic bone proliferation was diagnostic of both chronic childhood and adult mastoiditis. The location of lytic or sclerotic bone within the mastoid was not recorded.

For all individuals, the presence or absence of chronic sinusitis was recorded for each sinus (maxillary, frontal, ethmoidal, and sphenoidal). One third of a sinus, and one sinus in the case of paired structures, had to be present and unobscured macroscopically or endoscopically for that structure to be considered. Sinusitis diagnosis followed Boocock et al. (1995) and data were pooled at the individual level.

## 3. Results and discussion

Of the 56 individuals examined for mastoiditis, 39 showed signs of chronic infection, usually appearing bilaterally. For 27 individuals, at least one mastoid was completely or partially hypocellular, indicative of chronic childhood mastoiditis. The remaining 12 had fully or partially pneumatized mastoid processes with signs sclerotic bone growth, indicative of chronic adult mastoiditis. No osteolytic lesions were observed in this sample.

Of the individuals diagnosed with mastoiditis, 61.5% (24/39) also had sinusitis (Purchase, 2016). This co-occurrence demonstrates the interrelated nature of infection in the mastoid processes and (via the middle ears) the upper respiratory system, and suggests similar risk factors for both. However, it is important to note that this relationship and the etiology of these infections are complex. For example, allergies (Chang et al., 2018), certain congenital conditions (e.g., Ishikawa and Amitani, 1994; Turner et al., 1981), other infections (e.g., leprosy and tuberculosis) (Srinivasan et al., 1998; Upadhyay et al., 2014), pregnancy (Goldstein and Govindaraj, 2012), advanced age (Balzano et al., 2007; Jordan and Mabry, 1998), and other conditions causing immunodeficiency (Schwitzguébel et al., 2015) can cause, predispose, and/or aggravate URI. Furthermore, maxillary sinusitis can be of dental origin (Hoskison et al., 2012), and the mastoid processes can be infected secondarily via hematopoietic transfer from a primary site (Graham-Hodgson, 1950). This may explain some cases of mastoiditis or sinusitis in the sample, but their high frequency and co-occurrence suggest that broader risk factors, such as shared environmental conditions (see Dahal et al., 2009; Li et al., 2018), predisposed many individuals to both infections (Boocock et al., 1995; Lewis et al., 1995; Roberts, 2007; Schultz et al., 2007).

This method of mastoid imaging proved to be highly effective. It produced high-fidelity radiographs depicting the extent of mastoid pneumatization and sclerotic sub-endosteal bone proliferation (Fig. 1). By affixing the sensor to the lateral surface of the mastoid process and shooting medio-laterally, no other bones obscured the image. This is an improvement over previous methods (e.g., Schuller's view; Rai, 2014), which obscure structures by imaging latero-medially. The use of portable technology and a small sensor made it possible to target the mastoid processes and produce clear diagnostic radiographs. This method does not address the rest of the mastoid air cell system extending superiorly within the temporal bone. Further research should focus on imaging the rest of the bone, as the software allows radiographs to be digitally merged.

## 4. Conclusions

This novel method of using portable X-ray technology opens the door for future researchers to study mastoiditis and other pathological conditions non-destructively within field or laboratory settings and removes many of the barriers previously innate to the study of URI. It is hoped that further research refines this method and that this technology becomes more accessible.

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## References

Aoki, K., Esaki, S., Shimizu, S., Honda, Y., 1989. Suppressing the process of pneumatization in chronic middle ear disease. In: Tos, M. (Ed.), Cholesteatoma and Mastoid Surgery. Kugler and Ghedim Publications, Amsterdam, pp. 239–244.
Balzano, G., Fuschillo, S., De Angelis, E., Gaudiosi, C., Mancini, A., Caputi, M., 2007. Persistent airway inflammation and high exacerbation rate in asthma that starts at menopause. Monaldi Arch. Chest Dis. 67 (3), 135–141.
Beckett, R.G., Conlogue, G.J., 2009. Paleoimaging: Field Applications for Cultural Remains and Artifacts. CRC Press, Boca Raton, FL.
Bluestone, C.D., 1998. Acute and chronic mastoiditis and chronic suppurative otitis media. Sem. Ped. Inf. Dis. 9 (1), 12–26.
Boocock, P., Roberts, C.A., Manchester, K.M., 1995. Maxillary sinusitis in medieval Chichester, England. Am. J. Phys. Anthropol. 98, 483–495.
Buikstra, J.E., Ubelaker, D.H. (Eds.), 1994. Standards for Data Collection from Human Skeletal Remains. Arkansas Archaeological Survey, Fayetteville, AR.
Chang, E.H., Stern, D.A., Willis, A.L., Guerra, S., Wright, A.L., Martinez, F.D., 2018. Early life risk factors for chronic sinusitis: a longitudinal birth cohort study. J. Allergy Clin. Immunol. 141 (4), 1291–1297.
Chien, J.-H., Chen, Y.-S., Hung, I.-F., Hsieh, K.-S., Wu, K.-S., Cheng, M.-F., 2012. Mastoiditis diagnoses by clinical symptoms and imaging studies in children: disease spectrum and evolving diagnostic challenges. Indian J. Comp. Microbiol. Immunol. Infect. Dis. 45, 377–381.
Cinamon, U., 2009. The growth rated and size of the mastoid air cell system and mastoid bone: a review and reference. Eur. Arch. Oto. Rhino-Laryngo 266 (6), 781–786.
Collins, C., Jónsson, Á., 2010. Evidence for otitis media and mastoiditis in a medieval Icelandic monastic hospital. Poster 7 for the 18th European Meeting of the Paleopathology Association.
Dahal, G.P., Johnson, F.A., Padmadas, S.S., 2009. Maternal smoking and acute respiratory infection symptoms among young children in Nepal: multilevel analysis. J. Biosoc. Sci. 41, 747–761.
Fleischer, K., 1979. Akute Mittelohrentzündung, Mastoiditis, Petrositis. In: Berendes, J., Link, R., Zöllner, F. (Eds.), Hals-Nasen-Ohren-Heilkunde in Klinik und Praxis in 6 Binden. 2, neu bearbeitete und erweiterte Aufl., Bd. 5: Ohr I. Thieme, Stuttgart pp. 25.1–25.43.
Flohr, S., Kierdorf, U., Schultz, M., 2009. Differential diagnosis of mastoid hypocellularity in human skeletal remains. Am. J. Phys. Anthropol. 140, 442–453.
Goldstein, G., Govindaraj, S., 2012. Rhinologic issues in pregnancy. Allergy Rhinol. 3 (1), 13–15.
Graham-Hodgson, H., 1950. Radiology of the infected temporal bone. Proc. R. Soc. Med. 43, 989–998.
Gregg, J.B., Steele, J.P., Holzhueter, A., 1965. Roentgenographic evaluation of temporal bones from South Dakota Indian burials. Am. J. Phys. Anthropol. 23, 51–62.
Hodgson, G., 1938. Radiology of the mastoid process. Proc. R. Soc. Med. 32 (2), 126–132.
Hoskison, E., Daniel, M., Rowson, J.E., Jones, N.S., 2012. Evidence of an increase in the incidence of odontogenic sinusitis over the last decade in the UK. J. Laryngol. Otol. Suppl. 126, 43–46.
Ishikawa, Y., Amitani, R., 1994. Nasal and paranasal sinus disease in patients with congenital velopharyngeal insufficiency. Arch. Otolargynol. Head Neck Surg. 120, 861–865.
Jordan, J.A., Mabry, R.L., 1998. Geriatric rhinitis: what it is and how to treat it. Geriatrics 53 (6), 81–84 76.

Krenz-Niedbała, M., Łukasik, S., 2016. Skeletal evidence for otitis media in mediaeval and post-mediaeval children from Poland, Central Europe. Int. J. Osteoarchaeol. 27 (3), 375–386.
Kuczkowski, J., Mikaszewski, B., 2001. Intracranial complications of acute and chronic mastoiditis: report of two cases in children. Int. J. Ped. Otolargyngol. 60, 227–237.
Lewis, M.E., Roberts, C.A., Manchester, K., 1995. Comparative study of the prevalence of maxillary sinusitis in Later Medieval urban and rural populations in Northern England. Am. J. Phys. Anthropol. 98, 497–506.
Lewis, M.E., 2017. Paleopathology of Children: Identification of Pathological Conditions in the Human Skeletal Remains of Non-Adults. Academic Press, London.
Li, Y.R., Xiao, C.C., Li, J., Tang, J., Geng, X.Y., Cui, L.J., Zhai, J.X., 2018. Association between air pollution and upper respiratory tract infection in hospital outpatients aged 0–14 years in Hefei, China: a time series study. Pub. Health 156, 92–100.
Lieverse, A.R., 2005. Bioarchaeology of the Cis-Baikal: Biological Indicators of Mid-Holocene Hunter-Gatherer Adaptation and Cultural Change. Unpublished Ph.D. dissertation. Department of Anthropology, Cornell University, Ithaca, NY.
Lieverse, A.R., Faccia, K., Waters-Rist, A.L., Antonova, A., Vahdati, N.H., Haverkort, C., Purchase, S., Schulting, R.J., Moussa, N., Bazaliiskii, V.I., 2019. Human osteological remains. n.d. Chapter 5. In: In: Weber, A.W., Bazaliiskii, V.I., Jessup, E.L., Lieverse, A.R. (Eds.), Shamanka II, an Early Neolithic Hunter-Gatherer Cemetery on Lake Baikal, Siberia: Archaeological and Osteological Materials. Northern Hunter-Gatherers Research Series, vol. 7 CCI (Canadian Circumpolar Institute) Press, Edmonton, Alberta.
Montgomery, P.Q., Williams, H.O.L., Reading, N., Stringer, C.B., 1994. An assessment of the temporal bone lesions of the Broken Hill cranium. J. Archaeol. Sci. 21, 331–337.
Oxenham, M.F., Thuy, N.K., Cuong, N.L., 2005. Skeletal evidence for the emergence of infectios disease in Bronze and Iron age Northern Vietnam. Am. J. Phys. Anthropol. 126, 359–376.
Park, M.S., Yoo, S.H., Lee, D.H., 2000. Measurment of surface area in human mastoid air cell system. J. Laryngol. Otol. 114, 93–96.
Purchase, S.L., 2016. Infectious Disease As an Indicator of Physiological Stress in the Middle Holocene Cis-Baikal. M. A. Dissertation. Department of Archaeology and Anthropology, University of Saskatchewan, Saskatoon.
Radiopaedia, 2019a. In: Weerakkody, Y., Gaillard, F. (Eds.), Acute Mastoiditis, (Accessed 23 February 2019). https://radiopaedia.org/articles/acute-mastoiditis?lang=gb.
Radiopaedia, 2019b. In: Murphy, A., Gaillard, F. (Eds.), Periosteal Reaction, (Acessed 23 February 2019). https://radiopaedia.org/articles/periosteal-reaction?lang=us&fbclid=IwAR09zYNPlvqYt1BF9foq_qGD1oGwTNcY_McKT1OFEBEN_DZiYWlOMNR7f1k.
Rai, T., 2014. Radiological study of the temporal bone in chronic otitis media: prospective study of 50 cases. Indian J. Otol. 20 (2), 48–55.
Roberts, C.A., 2007. A bioarchaeological study of maxillary sinusitis. Am. J. Phys. Anthropol. 133, 792–807.
Robinson, P.J., Lodge, S., Goligher, J., Bowley, N., Grant, H.R., 1993. Secretary otitis media and mastoid air cell development. Int. J. Ped. Otolaryngol. 25, 13–18.
Schaefer, M., Black, S., Scheuer, L., 2009. Juvenile Osteology. A Laboratory and Field Manual. Academic Press, New York.
Schultz, M., 1979. Diseases in the ear region in early and prehistoric populations. J. Hum. Evol. 8, 575–580.
Schultz, M., Timme, U., Schmidt-Schultz, T.H., 2007. Infancy and childhood in the Pre-Columbian North American Southwest-first results of the paleopathological investigation of the skeletons from the Grasshopper Pueblo, Arizona. Int. J. Osteoarchaeol. 17, 369–379.
Schwitzguébel, A.J.-P., Jandus, P., Lacroix, J.-S., Seebach, J.D., Harr, T., 2015. Immunoglobin deficiency in patients with chronic rhinosinusitis: systemic review of the literature and meta-analysis. J. Allergy Clin. Immunol. Pract. 136 (6), 1523–1531.
Srinivasan, S., Nehru, V.I., Mann, S.B.S., Sharma, V.K., Bapuraj, J.R., Das, A., 1998. Study of ethmoid sinus involvement in multibacillary leprosy. J. Laryngol. Otol. 112, 1038–1041.
Titche, L.I., Coulthard, S.W., Wachter, R.D., Thies, A.C., Harries, L.I., 1981. Prevalence of mastoid infection in prehistoric Arizona Indians. Am. J. Phys. Anthropol. 56, 269–273.
Tos, M., Stangerup, S.-E., 1984. Mastoid pneumatization in secretory otitis: further support for the Environmental Theory. Acta Otolaryngol. 98, 110–118.
Turner, J.A.P., Corkey, C.W.B., Lee, J.Y.C., Levison, H., Sturgess, J., 1981. Clinical expressions of immotile cilia syndrome. Pediatrics 67 (6), 805–810.
Upadhyay, R., Prakash, V., Singh, A.B., Saheer, S., 2014. Maxillary sinusitis with pulmonary tuberculosis. BMJ Case Rep. https://doi.org/10.1136/bcr-2014-203952. published online (1 August).