# Chronic maxillary sinusitis: a comparison of osteological and CT methods of diagnosis

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# Chronic Maxillary Sinusitis: A comparison of osteological and CT methods of diagnosis

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ABSTRACT

*Objective:* To assess the differences between endoscopic and radiological methods of analysis for diagnosing chronic maxillary sinusitis (CMS) in archaeological skeletal remains.
*Materials:* 32 crania from a Dutch post-medieval rural population.
*Methods:* We assessed the presence of bone changes indicative of CMS (i.e., bone growth and bone resorption) both endoscopically and through computed tomography (CT), and then compared results.
*Results:* We observed moderate agreement between bone growth scores obtained through endoscopy and CT, and fair agreement when assessing bone resorption.
*Conclusions:* CMS prevalence rates observed through CT may be comparable to rates assessed endoscopically, although caution is needed when making direct comparisons.
*Significance:* This is the first study comparing data obtained through endoscopy and radiological methods in the study of CMS, informing paleopathologists about potential biases in data comparison.
*Limitations:* Our small sample size likely impacted results.
*Suggestions for further research:* Further research is advised to fully explore the comparability of endoscopic and radiological method of analysis in the study of sinusitis.
*Data Availability:* The datasets generated and analyzed during the current study are available upon request.

## 1. Introduction

Chronic maxillary sinusitis (CMS) is increasingly studied today in bioarcheology, as it is linked to environmental factors such as poor air quality and various genetic, oral, and infectious conditions (Hoover et al., 1997; Schwarzbach et al., 2020; Turfe et al., 2019). Analyzing historical prevalence rates of sinusitis provides valuable insights into the social dimension of respiratory disease. In fact, by observing patterns of occurrence in populations with different backgrounds (e.g., socioeconomic status, occupation, skeletal sex, and geographical location), we can gain a more comprehensive understanding of health experiences in the past (e.g., Boyd, 2020; Casna et al., 2023; Davies-barrett, 2018; Merrett and Pfeiffer, 2000; Roberts, 2007).

In bioarcheology, bone changes (e.g., spicules, pitting, and thickening of the sinus walls) within the maxillary sinuses have been generally considered indicative of chronic sinusitis (Boocock et al., 1995; Lewis et al., 1995; Merrett, 2003; Merrett and Pfeiffer, 2000). However, due to the enclosed nature of paranasal sinuses, their direct observation is often impossible. While the majority of published studies on sinusitis have focused on fragmented skulls, where sinuses were visible to the naked eye (e.g., Liebe-Harkort, 2012; Riccomi et al., 2021; Sundman and Kjellström, 2013b), an expanding trend among researchers involves incorporating complete skulls into analysis by using an endoscope to observe sinuses, either by drilling holes through the walls, or by using taphonomic alterations as access points (e.g., Boocock et al., 1995; Casna et al., 2021; Davies-Barrett et al., 2021; Merrett and Pfeiffer, 2000). However, even if endoscopy has been widely used to investigate sinusitis since the first published bioarcheological study on respiratory disease (Wells, 1977), it inherently comes with several drawbacks, such as challenges in assessing the comparability of results obtained with different endoscope models (Davies-Barrett et al., 2024) and in accessing the sinuses due to anatomical variations (Ashman et al., 2020). In this framework, computed tomography (CT) has been proposed as a valid alternative to traditional bioarcheological methods of analysis (Zubova et al., 2020). CT scans are advantageous as they offer a comprehensive examination of crania without the risk of damaging bone tissue (Chhem and Brothwell, 2008). In addition, they play an important diagnostic role in clinical practices and are usually regarded as the

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optimal modality for assessing sinusitis among living patients (Kandukuri and Phatak, 2016). Yet, despite their advantages, CT scans are rarely employed in the archaeological study of sinusitis. To date, only two studies have utilized CT to analyze sinusitis in archaeological samples, claiming that prevalence rates assessed using CT data are comparable to those obtained by endoscopy due to the clinical reliance of both methods on manifestations of osteitis (Zubova et al., 2020, 2022). However, despite these claims, no assessment has been made to verify the comparability of these data, meaning that there may be a discrepancy between data derived from macroscopic/endoscopic assessments of bone changes and datasets obtained through CTs. To explore the potential disparities between these analytical approaches, in the present study we examined a small sample of intact crania, assessing the presence of CMS through both endoscopy and CT imaging.

## 2. Materials and methods

A total of 32 adult crania (57 sinuses) from the Dutch post-medieval rural village of Middenbeemster (1829–1866 CE) were examined both endoscopically and through CT scans. Information on the skeletal population of Middenbeemster was previously published by Casna and colleagues (2021; 2023).

As clinical studies typically only distinguish between "bone growth" and "bone resorption" (e.g., Kandukuri and Phatak, 2016),we adapted the criteria for identifying CMS in archeological remains set by Boocock and colleagues (1995) as follows: spicules, remodeled spicules, white pitted bone, and thickened sinus walls were grouped in the "bone growth" category (Fig. 1-A, 1-B), while pitting was scored as "bone resorption" (Fig. 2-A, 2-B). The presence of both lesions was assessed per sinus and recorded as either "present" or "absent". In order for a sinus to be included in the sample, all walls and floor had to be observable both endoscopically and with CT scans.

Endoscopic analysis of crania was performed by Casna and colleagues (2023) with a flexible medical endoscope (Pentax, model: FNL-10RBS, ø=4 mm; view angle=30∘) inserted through pre-existing post-mortem breaks on the lower orbital wall and/or on the inferior nasal conchae (see Casna et al., 2021 for details on how the endoscope was inserted in the sinuses). CT scans were obtained with a PET-CT Philips Vereos scanner located at Leiden University Medical Center (scanning protocol: voltage on the X-ray tube 140 kV, tube current 70 μA, slice thickness 1 mm) and later analyzed in 3D Slicer for Windows (v.5.0.3). To observe any significant difference between methods of analysis, Cohen's kappa coefficient (κ) was used with a 95 % confidence interval. κ values were interpreted as follows: 0.00–0.20, "no to slight" agreement; 0.21–0.40, "fair" agreement; 0.41–0.60 "moderate" agreement; 0.61–0.80 "substantial" agreement; and >0.81 "almost perfect" agreement (McHugh, 2012).

## 3. Results

In total, 18 sinuses showed signs of sinusitis (i.e., either bone growth or resorption) when investigated endoscopically, and 31 when looking at CT scans. Cohen's kappa coefficient test revealed moderate agreement ($\kappa$=0.422, $p$<0.001) between the two diagnostic methods. Within both endoscopy and CT imaging, bone growth was found to be more frequent than bone resorption (Table 1). The analysis per lesion revealed a moderate agreement ($\kappa$=0.426, $p$<0.001) between bone growth scores obtained through endoscopy and CT, and fair agreement ($\kappa$=0.377, $p$<0.001) when assessing bone resorption.

## 4. Discussion

Although previous CT studies of CMS have yielded positive results (Zubova et al., 2020, 2022), there remains uncertainty regarding the comparability of CT data with those of other endoscopic and/or macroscopic studies. In the present study, we observed only moderate agreement between CT and endoscopic methods of analysis. While we noticed that the majority of observations were corroborated between methods, approximately 30 % of our bone growth results and 15 % of our bone resorption results were unsupported by macroscopic observations. These findings underscore significant implications for the comparability of sinusitis analysis methods, suggesting that such comparisons should be approached with caution.

Determining whether it was endoscopy underestimating the presence of bone lesions within the sinus or CT analysis overestimating their presence is, at this stage, challenging. Accurate observation of bone changes within maxillary sinuses is hindered by several methodological and practical issues that can affect both endoscopy and CT. For example, sinus preservation may play a significant role in the diagnosis of sinusitis, as sinus fragmentation may complicate the observation of pathological lesions (Sundman and Kjellström, 2013a). Further, Davies-Barrett et al. (2024) observed inconsistency amongst observers using the same method due to variations in observer experience and ambiguity in the original method descriptions. Although in the present study most of these limitations were mitigated by having the same observer collect the data within a short timeframe, it is important to recognize that numerous other factors likely influenced our results. For example, despite our selection criteria, in many cases soil debris was still present in the maxillary sinuses, making observation limited. While in endoscopic view, the presence of soil is clear and, in some cases, may prevent the observation of the sinus walls and floor, with CT imaging it can be difficult to distinguish between bone formation and soil, as they present similar density and color (Fig. 3). While it is plausible that recognizing soil may become easier with experience, its presence could have influenced our results as: 1) some lesions may have been obscured by soil, making impossible their endoscopic observation; and 2) debris

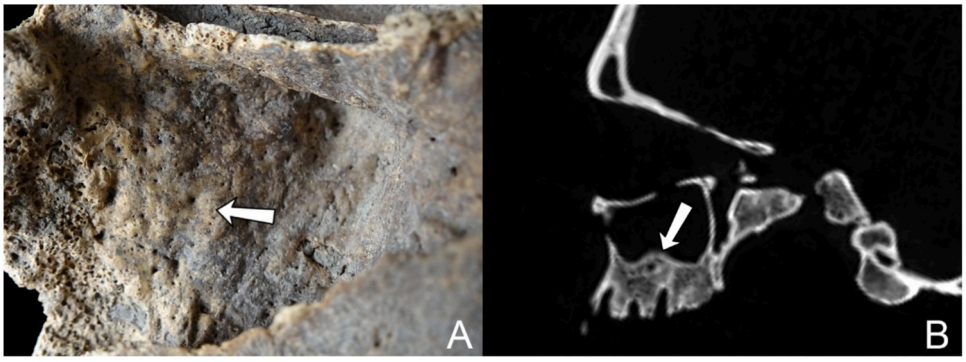


**Fig. 1.** Examples of bone growth related to chronic maxillary sinusitis adapted from Boocock and colleagues (1995). Lesions are indicated by the white arrows. A) Macroscopic view of a broken sinus: thickening of the lateral wall; B) Radiographic view of an undamaged, enclosed sinus: bone formation in the form of thickening of the sinus floor.

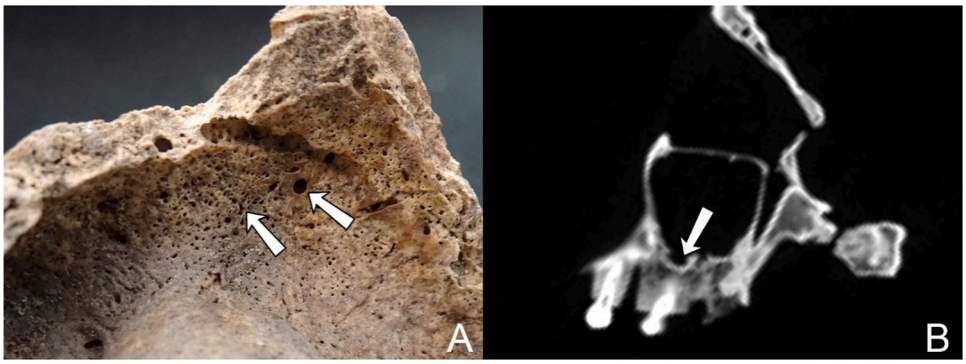


**Fig. 2.** Examples of bone resorption related to chronic maxillary sinusitis adapted from Boocock and colleagues (1995). Lesions are indicated by the white arrows. A) Macroscopic view of broken sinus: bone resorption in the form of pitting of the sinus wall; B) Radiographic view of undamaged, enclosed sinus: bone resorption on the sinus floor.

**Table 1**
Distribution of lesions linked to chronic maxillary sinusitis observed in this study.

| Bone growth | | | | Bone resorption | | | |
|---|---|---|---|---|---|---|---|
| | Presence of bone growth observed in CT scans | Absence of bone growth observed in CT scans | Total | | Presence of bone resorption observed in CT scans | Absence of bone resorption observed in CT scans | Total |
| Presence of bone growth observed endoscopically | 14 | 3 | 17 | Presence of bone resorption observed endoscopically | 3 | 0 | 3 |
| Absence of bone growth observed endoscopically | 13 | 27 | 40 | Absence of bone resorption observed endoscopically | 8 | 46 | 54 |
| Total | 27 | 30 | 57 | Total | 11 | 46 | 57 |

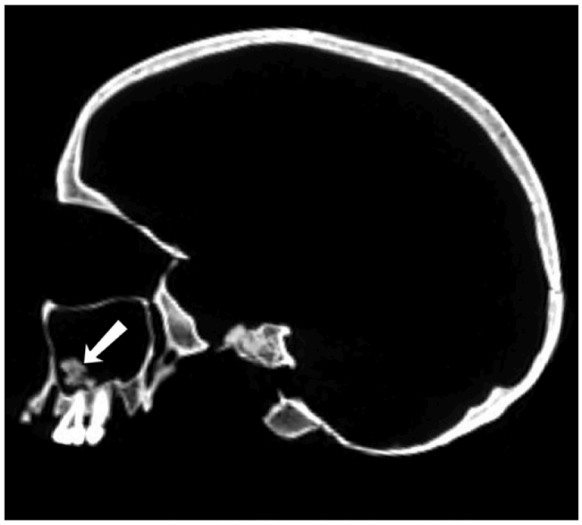

**Fig. 3.** Example of soil (indicated by the white arrow, confirmed later with visual assessment) present in the maxillary sinus of one of the individuals under study.

may have been mistaken for bone formation in individuals where there was no visible empty (i.e., black) space between the sinus floor and the soil. Surprisingly, the impact of sedimentary material in paleoradiology has garnered minimal attention to date, with a dearth of datasets available for quantifying its impact. Recently, Coutinho-Nogueira and colleagues (2022) argued that both density and compositional heterogeneity may serve as distinguishing indicators between sediment and pathological bone formations. However, despite these convincing interpretations, the existing data remains insufficient, and in our opinion highlights the necessity for further research dedicated specifically to this aspect.

Another interesting result we observed was a difference in the agreement coefficient between bone growth (moderate agreement) and bone resorption (fair agreement). We also noted a higher prevalence of bone growth compared to bone resorption in both endoscopic and radiographic assessments (Table 1). This is not surprising, as in most bioarcheological studies on sinusitis bone formation within the maxillary sinuses is usually more commonly observed than bone resorption (e.g., Casna et al., 2021; Collins, 2019; Sundman and Kjellström, 2013a). According to Davies-Barrett (2018), this may be attributed to the fact that spicules are generally easier to observe with an endoscope than other pathological lesions because they cast a shadow on the sinus wall. Given the prevalence of bone formation within the sinuses, it is plausible that the observer may have had a more finely tuned ability to detect bone growth compared to bone resorption, whose relationship to sinusitis is somewhat controversial and has been questioned by several bioarcheologists (Lee et al., 2024). In fact, while spicules and thickening of the walls/floor are largely accepted as being indicative of sinusitis, there is a consensus that bone resorption should be approached with caution, as it may be associated with dental development/disease rather than being indicative of sinus inflammation (Collins, 2019; Davies-Barrett et al., 2021; Krenz-Niedbała and Łukasik, 2016; Lewis, 2002; Merrett, 2003; Merrett and Pfeiffer, 2000; Sundman and Kjellström, 2013a). This may have led the observer to exercise greater caution when recording instances of bone resorption during endoscopic examination, as typically endoscopy does not allow to definitively ascertain the etiology of lesions due to various constraints (e.g., restricted maneuverability, limited image resolution). CT scans, on the other hand, provide a unique and straightforward opportunity to assess dental involvement, both pathological and/or developmental (Bajoria et al., 2019). It is then possible that our CT observations allowed us a better contextualization of bone resorption within the maxillary sinuses, although our data do not provide enough evidence for confirming nor

rejecting this hypothesis.

While the aim of this study was to comment on the comparability of two methodologies, several limitations may have impacted our results and statistics to some extent. Differences in image resolutions between our CT machine and endoscope likely played a significant role in our analysis, and it is possible that differences in image quality not only between endoscope and CT scans but also between different CT machines and/or different endoscopes could potentially lead to different results in future studies. As suggested by Davies-Barrett and colleagues (2024), set standards for the diagnosis of sinusitis may help improving consistency in the application of the criteria initially presented by Boocock and colleagues (1995). In addition, given the recent technological advancements in both the medical field and paleopathology, it would be beneficial for such standards to incorporate a provision regarding equipment resolution and comparability. More in general, as paleoradiology is poised to become increasingly accessible in the near future, it is crucial that standards evolve to encompass CT scans and radiographs, as well as macroscopic analysis, as varying diagnostic criteria employed in medical imaging can significantly impact the comparability of results. For instance, Zubova and colleagues (2020; 2022) employed a method reliant on measuring the maximum thickness of sinus walls to detect osteitis, in contrasti with the methodology of the present study, which does not involve quantifying bone growth observed in CT data. While this has not impacted the reliability of our results, it highlights the necessity for more comprehensive, clear standard criteria for diagnosing conditions such as sinusitis in paleopathology.

## 5. Conclusion

Despite our limitations, we argue that our results hold significance in advising researchers to exercise caution when comparing results obtained through different methods of analysis. We acknowledge that no method is flawless, and it is realistic to anticipate limitations in every strategy adopted by a paleopathologist. However, as technologies, such as CT, become increasingly accessible to archaeological research, we emphasize the importance of examining how their results compare to more traditional methods of analysis to ensure the reliability and validity of (bio)archeological data.

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## CRediT authorship contribution statement

**Sarah A. Schrader:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Maia Casna:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

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*Conflict of interest disclosure*

The authors have no conflict of interest to declare.

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