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Estimation of otitis media in ancient populations: A study of past and present Greenlandic Inuit

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Abstract

Examination of disease patterns in the past has often been difficult due to lack of morphological evidence. This study presents a new unbiased method for estimation of occurrence of infectious middle ear disease (IMED) in childhood. The method is based on the relation between IMED in childhood and small or asymmetric pneumatized cell areas in the temporal bones as seen on standardised X-rays.

A polychotomous logistic regression model was applied on 434 pneumatized cell areas in temporal bones from 34 adult living Greenlandic Inuit, 56 adult crania from the 18th to the 19th century A.D. and 127 adult Inuit crania from the pre-European colonization period (before A.D. 1721) of Greenland. The occurrence of IMED as designated by the model was eight out of 34 (23.5 per cent) in living Inuit, 10 out of 56 (17.9 per cent) in crania from the 18th to 19th century and six out of 127 (4.7 per cent) in crania from the pre-colonization period. These frequencies differed significantly ($p<0.002$). The mean area size also differed significantly, thus indicating a change in occurrence of IMED and a decrease in area sizes from past to present in Greenland.

Key words: Otitis media; Temporal bone; Anthropology, physical; Epidemiology; Eskimos

Introduction

Clinical studies and animal experiments have shown a significant relationship between small or highly asymmetrical pneumatized cell areas in the temporal bones and infectious middle ear disease (IMED) in childhood, i.e. chronic otitis media, chronic tubal dysfunction and recurrent acute otitis media (Diamant, 1957; Palva and Palva, 1966; Tos and Stangerup, 1984; Hörmann, 1986; Stangerup and Tos, 1986; Ikarashi *et al.*, 1994). This relationship has enabled an epidemiological examination of IMED frequency in Greenlandic Inuit spanning almost 600 years.

IMED is very common in the modern Greenlandic Inuit population and also in the Inuit living in Canada and Alaska (Reed and Dunn, 1970; Baxter, 1982; Pedersen and Zachau-Christiansen, 1988). The reasons for this are still unknown but it has been proposed that the elevated frequency is a result of the increased western cultural influence on the Inuit living in the Arctic after the 1940's (Reed and Dunn, 1970; Baxter, 1982).

Common modern diseases such as upper and lower respiratory tract infectious diseases are difficult to trace in ancient populations due to lack of morphological evidence in skeletal remains. IMED is widely recognized as a complication to upper respiratory tract infections (URI) (Branefors-Helander *et al.*, 1975; Henderson *et al.*, 1982). Also, IMED is associated with poor social and living conditions (Christensen, 1956; Bastos, 1994). Thus, IMED may present a unique, reproducible and objective means for research in health status and social welfare in past societies.

The present study is a compilation of four studies: 1) a pilot study; 2) a validation study using CT-scanning; 3) development of a model estimating IMED and 4) application of the model on ancient Inuit skeletal material (Homøe and Lynnerup, 1991; Homøe *et al*, 1992, 1994, 1995).

Material and methods

The material consists of two skeletal samples of Greenlandic Inuit, one recent and one ancient, and a sample of living Greenlandic Inuit. The skeletal samples are part of the Greenlandic collections at the Laboratory of Biological Anthropology, University of Copenhagen.

The recent anthropological sample

This sample was used in the pilot study and comprised 56 Inuit adult crania (32 females, 24 males) (Homøe and Lynnerup, 1991). The material

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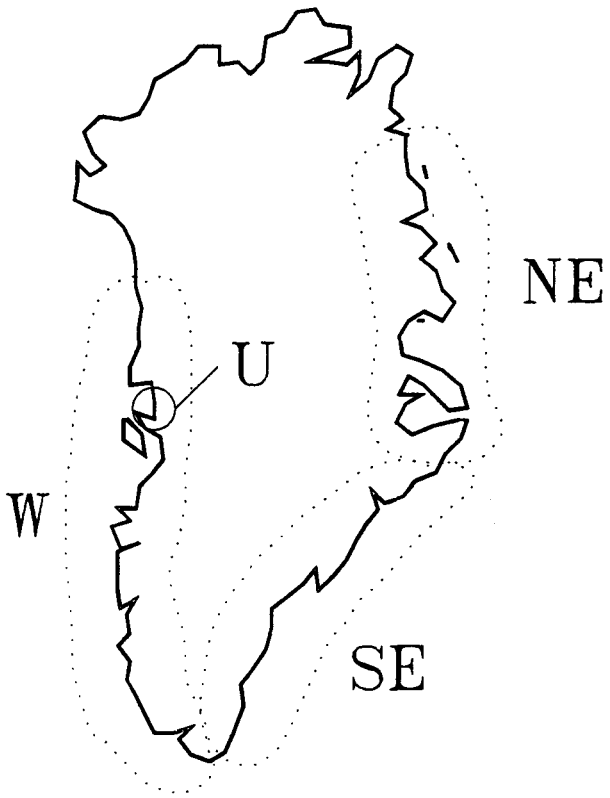
derives from the geographically localized Uummannaq district on the West Coast of Greenland (see Figure 1). The skeletal remains are believed to be from approximately A.D. 1800–1900 (Frøhlich, 1979). The extent of genetic heterogeneity of this material is uncertain but the genetic influence from Europeans is believed to have been of minor importance. However, the cultural influence is believed to have been of significant importance since e.g. smallpox epidemics have been reported from this period (Meldorf, 1907; Frøhlich, 1979).

The ancient anthropological sample

This sample consisted of 127 adult Inuit crania (54 males, 73 females). Fixty-six were from the west coast (W) of Greenland, 42 were from the southeast coast (SE) and 29 were from the northeast coast (NE) (see Figure 1) (Homøe *et al.*, 1995). The crania are archaeologically dated to be from the pre-European colonization period of Greenland (West coast: before A.D. 1721; East coast before A.D. 1884) (Jørgensen, 1953; Frøhlich, 1979). Thus, this sample is without European genetic or cultural influence.

The crania in both samples were evaluated for sex and age. Only adult crania presenting two well preserved temporal bones were included. The crania were X-rayed using the Runström II lateral projection with a 10° angle in the frontal plane (Runström, 1933). The magnification factor was 6.8 per cent. All X-rays were taken with the same apparatus and by the same radiologist. The pneumatized areas as seen on the X-rays were delineated and planimetrically measured in blind trials by computer (see Figures 2a and b) (Lynnerup *et al.*, 1992). Following previous studies, the antrum, the epitympanon and the cavum tympani were not included (Diamant, 1957; Palva and Palva, 1966; Tos and Stangerup, 1984; Stangerup and Tos, 1986). Also, we performed an otoscopic examination.



U = Ummannaq district, W = west coast of Greenland, SE = southeast coast of Greenland and NE = northeast coast of Greenland.

FIG. 1

Map of Greenland. The geographical distribution of the skeletal material is shown.

The living sample

This sample consisted of 34 Greenlandic Inuit, all born in Greenland (Homøe *et al.*, 1994). Eighteen were females and 16 were males. The agespan was 14–65 years (median = 37.5 years, interquartile range = 27–47 years). The participants were randomly selected from Greenlandic Inuit patients referred to various departments at Rigshospitalet, Denmark.

The 34 participants completed a questionnaire concerning episodes of IMED in childhood. The questionnaires and medical records served as gold-standard for classification into IMED in childhood. All were subjected to X-ray examination of the temporal bones using the Runström II lateral projection (Runström, 1933). A different X-ray apparatus was used and the magnification factor was 3.45 per cent. The X-rays were measured in analogy with the anthropologic sample. An otologic examination using conventional and pneumatic otoscopy was performed in order to estimate the severity of disease.

Statistics

The Chi-square test was used for difference between frequencies. One-way analysis of variance (ANOVA) test as implemented by the Systat MLGH ANOVA module was used to examine differences between groups of continuous data (Wilkinson, 1990). The null hypothesis was rejected when the probability $p<0.05$.

In order to estimate the frequency of IMED based on the bilateral pneumatized areas, we applied a polychotomous logistic regression model (Rosner, 1984; Homøe *et al.*, 1994). This model is well suited for analysis of data from paired organs such as ears and eyes. The model incorporates an individual effect and includes the information from unilateral IMED carried by asymmetric areas. The model specifies four probabilities for each individual, according to the four subgroups: ++, −+, +−, −− (where ++ represents bilateral IMED; −+ IMED on left side; etc.). Based on actual observations of IMED in the living sample, these probabilities can be estimated for any combination of area sizes. The classification is performed by allocating an individual to the group with the highest estimated probability.

Since this model was developed for the living sample with a somewhat different area scale than in

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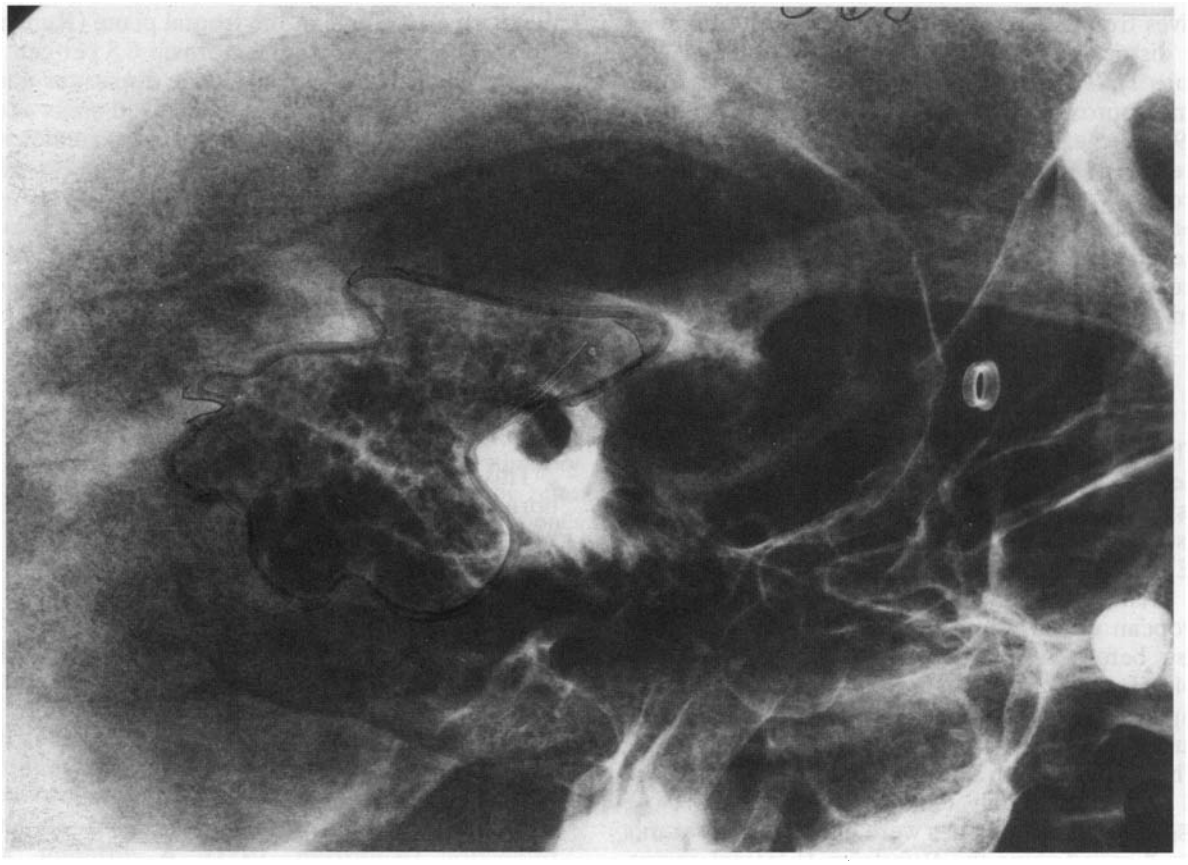
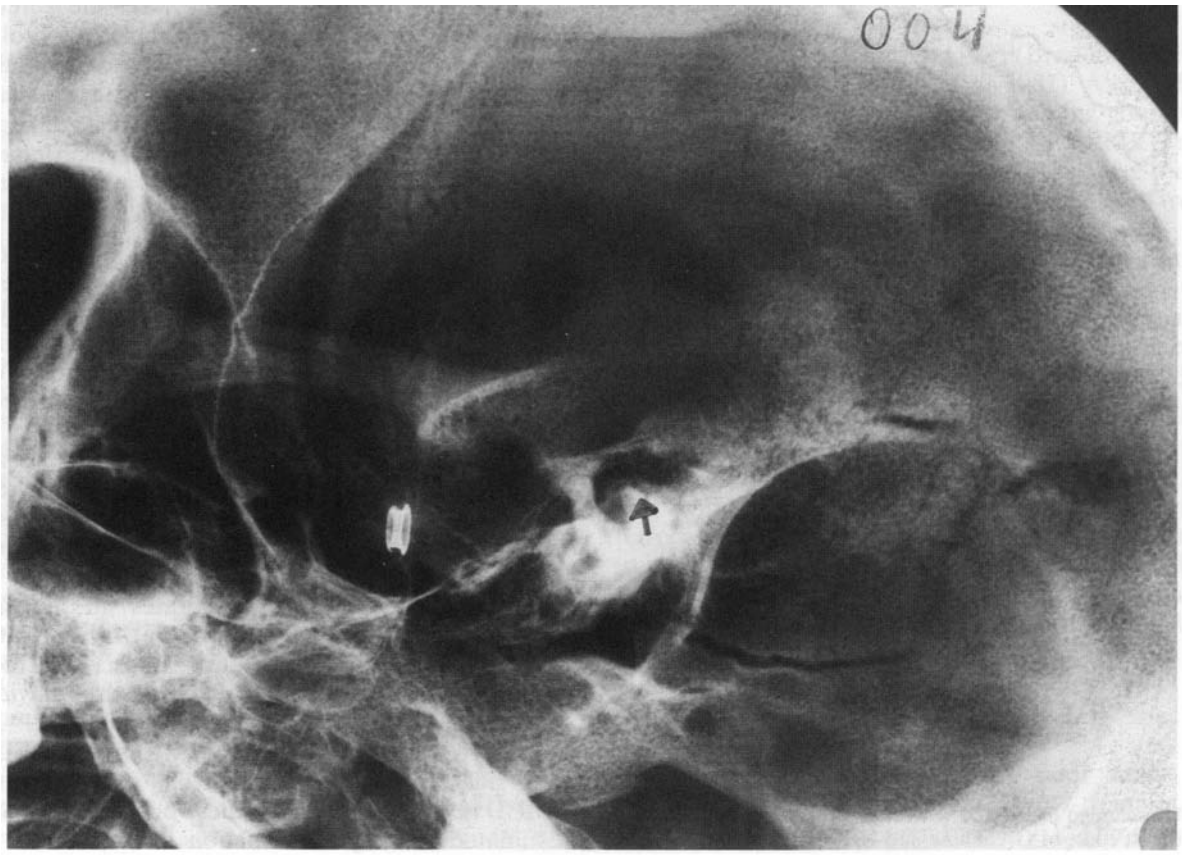


(a)



(b)

FIG. 2

a. Outline of a normally pneumatized cell system.
b. Example of a hypopneumatized cell system. Only the cavum tympani and the antrum can be seen (arrow).

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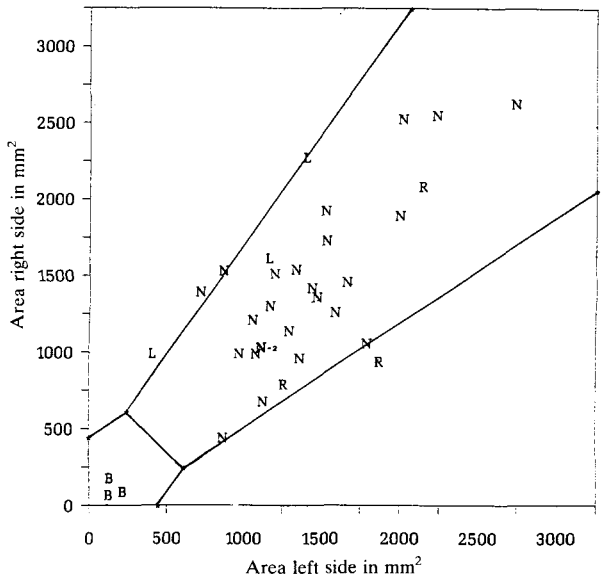
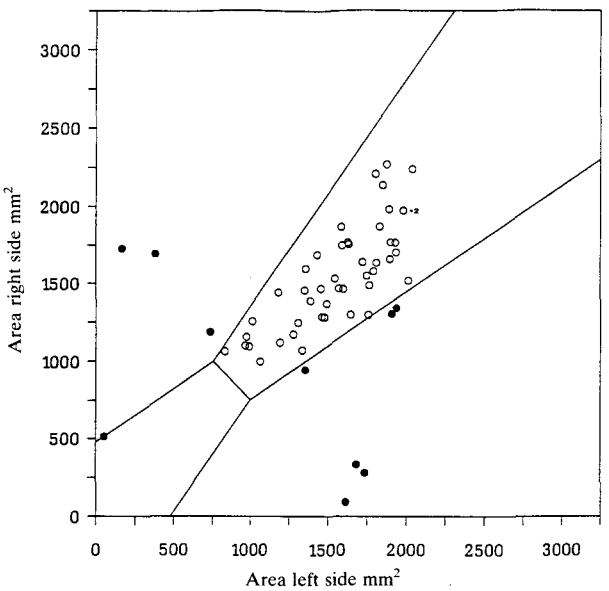


B: history of bilateral IMED, L: history of left side IMED, R: history of right side IMED and N: no history of IMED. The solid lines represent the model classification limits.

FIG. 3

Distribution of pneumatized cell areas in 34 living Greenlandic Inuit.

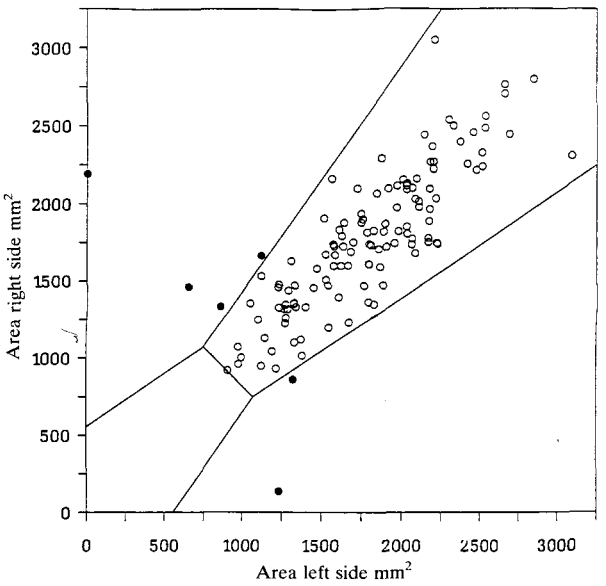
the skeletal samples the data for all samples were transformed to Z-scores before application of the model. This transformation was performed from the bilateral mean value of non-IMED persons in the living material and from the non-IMED crania after the first iteration in each of the skeletal samples. The Z-scores denote the distance from the mean of the



The solid lines represent the model classification limits. The limits are calculated on basis of Z-scores in non-IMED persons and in crania after the 1 iteration. The solid circles indicate crania with predicted IMED.

FIG. 4

Distribution of pneumatized cell areas in 56 crania from 100–200 year old Greenlandic Inuit.



The solid lines represent the model classification limits. The limits are calculated on basis of Z-scores in non-IMED persons and in crania after the 1 iteration. The solid circles indicate crania with predicted IMED.

FIG. 5

Distribution of pneumatized cell areas in crania from 127 pre-colonization Greenlandic Inuit.

samples in units of standard deviations and provide a comparable value between the samples.

Results

The pneumatized cell area distributions of the three samples are shown in Figures 3, 4 and 5 which also show the model classification limits for IMED. Additionally, Figure 3 shows six of nine with a history of IMED in childhood are correctly classified while two without IMED are incorrectly classified as having had IMED. Also, the two with a history of IMED are incorrectly classified as being healthy. The predicted IMED frequencies in the samples as calculated by the model are shown in Table I. There was a statistically significant difference in IMED frequency between the samples ($X^2 = 13.19$; $p<0.002$ (two-tailed)).

The descriptive statistics of the area distributions of non-IMED persons are listed in Table II together with the differences in area size between the samples.

The results indicate that IMED frequency has increased significantly from past to present and area size has decreased significantly from past to present.

TABLE I

FREQUENCY OF IMED IN THE THREE SAMPLES AS DENOTED BY THE POLYCHOTOMOUS LOGISTIC REGRESSION MODEL WITH CONFIDENCE INTERVALS (CI)

Sample	N	IMED frequency	95% binomial CI
Ancient (before colonization)	127	6 (4.7%)	1.8–10.0%
Recent (100–200 years old)	56	10 (17.9%)	8.9–30.4%
Living persons	34	8 (23.5%)	10.8–41.2%

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TABLE II
DESCRIPTIVE STATISTICS OF RIGHT AND LEFT SIDE PNEUMATIZED CELL AREAS IN THE THREE SAMPLES OF NON-IMED CRANIA OR PERSONS

	Right side areas				Left side areas			
Sample	Mean	SD	Max.	Min.	Mean	SD	Max.	Min.
Ancient	1779.6	450.4	3050.0	920.0	1801.9	449.7	3093.0	907.0
Recent	1554.0	330.8	2270.0	999.5	1560.2	330.2	2038.5	732.0
Living	1449.5	569.6	2647.0	464.0	1470.5	449.8	2738.0	863.0

All values in mm^2. One-way ANOVA test for difference between the three area distributions; Right side: $F = 8.420$, $df = 2$, $p<0.001$; Left side: $F = 9.785$, $df = 2$, $p<0.001$.

Discussion

Pneumatization of the temporal bones varies considerably between individuals. According to Schuknecht and others, the pneumatized cell system in the temporal bone can be divided into five regions; the middle ear region, the mastoid region, the perilabyrinthine region, the petrous apex region and the accessory regions (Schuknecht and Gulya, 1986). The development of the pneumatized cell system starts during gestation as a hollowing out process from the tympanic cavity and results in communicating air cells. At birth the pneumatized cell system is preformed but only poorly developed. The cell system enlarges during growth and achieves the final size at 12 to 14 years of age (Rubensohn, 1965).

Whether IMED in infancy and childhood inhibits growth of the pneumatized cell system (the environmental theory) or small pneumatized cell systems predispose for IMED (the hereditary theory) is a matter of controversy (Diamant, 1957; Tos and Stangerup, 1984). However, supporters of either of the theories recognize the relation between IMED and small pneumatized cell areas irrespective of causal relationship. This study does not aim at exploring any of these theories.

The ability of the model to classify the crania correctly is crucial in this study as formerly discussed (Homøe *et al.*, 1994). The living sample served as a gold standard due to information of IMED in childhood. As can be calculated from Figure 3, the sensitivity was 67 per cent, the specificity was 92 per cent and the positive predictive value was 75 per cent which is acceptable in an anthropological context. The confidence intervals were rather wide mainly due to the small sample size. However, modern ethical standards did not allow for a larger sample.

Evaluation of IMED by the method presented in this study has several advantages in a paleopathological and a paleoepidemiological context. Firstly, the method is based on unbiased evaluation of IMED in anthropological material from the pneumatized cell areas. This is in contrast to former biased methods based on gross inspection, examination of ossicles and subjective classification of the cell system into sclerotic, diplöic, mixed, atypical and normal pneumatization (Gregg and Steele, 1982; Bruintjes, 1990). Secondly, the method has an advantage compared to other methods evaluating past health based on skeletal remains, in that the temporal bones are often well preserved and abundant. Thirdly, the method is based on modern medical research of a disease which occurs worldwide with largely equivalent clinical manifestations.

In anthropological research, however, the problems of selection and unknown demography of the populations are always prevalent (Brothwell and Sandison, 1967; Wood *et al.*, 1992). In the present material the method only records occurrence of IMED in childhood in individuals who survive to adulthood. Therefore, differences in age-specific mortality rates due to IMED-related infectious diseases between the samples (selective mortality) will influence the observed frequency of IMED (Wood *et al.*, 1992).

Our results indicate an increasing secular frequency of IMED in Greenlandic Inuit and thereby also an increasing frequency of URI. Since lower infant and childhood mortality may be assumed for living samples compared to skeletal samples, the results may reflect a more substantial increase in IMED frequency after the colonization of Greenland in A.D. 1721 than actually observed, possibly even with a minor decrease in modern Greenland. This corresponds with medical reports from the 17th and 18th centuries and archaeological reports of a generally social decline of Inuit societies in the same period (Meldorf, 1907; McGhee, 1994).

The observed significant secular decrease in cell area size may either be ascribed to an increased frequency of IMED and URI, or to increased genetic admixture with Europeans in the present Greenlandic Inuit population. However, in our study of crania from different parts of Greenland, variation in cranial morphology, also a genetic marker, could not explain the large variability in cell areas (Homøe *et al.*, 1995). Also, in this study the median area size was found to be lowest in the region with the highest frequency of IMED. The anthropological samples display more distinct area distributions either having a smaller cell area size or larger cell area size than the living Inuit sample (see Figures). This latter finding may reflect the effect of modern antimicrobial treatment of IMED as has also been indicated in a former study (Gregg and Steele, 1982). Our observations are thus in accordance with the conception that IMED causes a decrease in cell area size.

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References

Bastos, I. (1994) Otitis media and hearing loss among children in developing countries. (Thesis). University of Lund, Sweden.

Baxter, J. D. (1982) Observations on the evolution of chronic otitis media in the Inuit of the Baffin Zone, N.W.T. *Journal of Otolaryngology* **11:** 161–166.

Branefors-Helander, P., Dahlberg, T., Nylén, O. (1975) Acute otitis media. A clinical, bacteriological and serological study of children with frequent episodes of acute otitis media. *Acta Otolaryngologica (Stockholm)* **80:** 399–409.

Brothwell, D. R., Sandison, A. T. (1967) *Diseases in Antiquity: A Survey of the Diseases, Injuries, and Surgery of Early Populations.* CC Thomas, Springfield, U.S.A., pp 378–404.

Bruintjes, T. D. (1990) The auditory ossicles in human skeletal remains from a leper cemetery in Chichester, England. *Journal of Archaeological Science* **17:** 627–633.

Christensen, V. (1956) *Housing and Childhood Morbidity.* (In Danish). (Thesis). University of Copenhagen, Munksgaard, Copenhagen.

Diamant, M. (1957) Anatomical etiological factors in chronic middle ear discharge. *Annals of Otology, Rhinology and Laryngology* **66:** 380–389.

Frøhlich, B. (1979) The Aleut-Eskimo mandible. (Dissertation). The University of Connecticut: 18–44.

Gregg, J. B., Steele, J. P. (1982) Mastoid development in ancient and modern populations. *Journal of the American Medical Association* **248:** 459–464.

Henderson, F. W., Collier, A. M., Sanyal, M. A., Watkins, J. M., Fairclough, D. L., Clyde, W. A., Denny, F. W. (1982) A longitudinal study of respiratory viruses and bacteria in the etiology of acute otitis media with effusion. *New England Journal of Medicine* **306:** 1377–1383.

Homøe, P., Lynnerup, N. (1991) Pneumatization of the temporal bones in Greenlandic Inuit anthropological material. *Acta Otolaryngologica (Stockholm)* **111:** 1109–1116.

Homøe, P., Lynnerup, N., Videbrek, H. (1992) CT-scanning of ancient Greenlandic Inuit temporal bones. *Acta Otolaryngologica (Stockholm)* **112:** 674–679.

Homøe, P., Lynnerup, N., Rasmussen, N., Skovgaard, L. T. (1994) A statistical model estimating the occurrence of otitis media from temporal bone pneumatization. *Annals of Otology, Rhinology and Laryngology* **103:** 469–473.

Homøe, P., Lynnerup, N., Skovgaard, L. T. (1995) Pneumatization and otitis media in Greenlandic Inuit before European colonization. *Journal of Otolaryngology* **24:** 330–335.

Hörmann, K. (1986) Der einfluss der tubenfunktion auf die knöchernen strukturen des felsensbeins. *Hals-Nasen-Ohrenheilkunde* **34:** 202–207.

Ikarashi, H., Nakano, Y., Okura, T. (1994) The relationship between the degree of chronic middle ear inflammation and tympanic bulla pneumatization in pig as animal model. *European Archives of Otorhinolaryngology* **251:** 100–104.

Jørgensen, J. B. (1953) The Eskimo skeleton. *Meddelelser om Grønland* **146 (II):** 141.

Lynnerup, N., Lynnerup, O., Homøe, P. (1992) A computer program for planimetric analysis of digitized images. *Computers in Biology and Medicine* **3:** 207–217.

Meldorf, G. (1907) Epidemiske sygdomme i Grønland: Influenza og epidemiske catarrhalske affektioner af luftvejs-slimhinderne. (In Danish) *Meddelelser om Grønland* **33:** 129–305.

McGhee, R. (1994) Disease and the development of Inuit culture. *Current Anthropology* **35:** 565–594.

Palva, T., Palva, A. (1966) Size of the human mastoid air cell system. *Acta Otolaryngologica* **62:** 237–251.

Pedersen, C. B., Zachau-Christiansen, B. (1988) Chronic otitis media and sequelae in the population of Greenland. *Scandinavian Journal of Social Medicine* **16:** 15–19.

Reed, D., Dunn, W. (1970) Epidemiologic studies of otitis media among Eskimo children. *Public Health Reports* **85:** 699–706.

Rosner, B. (1984) Multivariate methods in Ophthalmology with application to other paired-data situations. *Biometrics* **40:** 1025–1035.

Rubensohn, G. (1965) Mastoid pneumatization in children at various ages. *Acta Otolaryngologica* **60:** 11–14.

Runström, G. (1933) A roentgenological study of acute and chronic otitis media. *Acta Radiologica* **(Suppl) 17:** 1–88.

Schuknecht, H. F., Gulya, A. J. (1986) *Anatomy of the Temporal Bone with Surgical Implications.* Lea and Febiger, Philadelphia, Pennsylvania, U.S.A., pp 111–128.

Stangerup, S. E., Tos, M. (1986) Treatment of secretory otitis and pneumatization. *Laryngoscope* **96:** 680–684.

Tos, M., Stangerup, S. (1984) Mastoid pneumatization. *Archives of Otolaryngology* **110:** 502–507.

Wilkinson, L. (1990) SYSTAT: The System for Statistics. SYSTAT Inc., Evanston, Illinois, pp 190–318.

Wood, J. W., Milner, G. R., Harpending, H. C., Weiss, K. M. (1992) The osteological paradox. *Current Anthropology* **4:** 343–370.

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