# Estimation of Age at Death and Histomorphometric Analysis of Cortical and Trabecular Bone from Four Greenlandic Mummies

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Iliac crest and femoral bone specimens from four Greenlandic mummies were assessed. Estimated ages at death were calculated, cortical bone mass and bone histological variables from the cortical bone specimens and trabecular bone volume, surface area and diameter from the iliac crest specimens were measured. The cortical bone did not show pathological changes. The trabecular bone variables indicated that one woman was osteoporotic.

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The analysis of mummified remains provides an important link between investigations conducted in skeletal populations and investigations conducted in living populations. The use of the living-dead continuum as a research paradigm has proven valuable in discerning patterns of skeletal aging and osteoporosis among Eskimos (Thompson and Gunness-Hey 1981; Thompson *et al.* 1982). Analysis of skeletons from mummies is especially useful to fill in gaps in information between living and dead skeletal populations; information that is not otherwise obtainable from investigations of living populations or from archeological skeletal populations (Thompson and Cowen 1983). Information excluded from the analysis of archaeological populations ranges from cause of death and soft tissue pathologies to soft tissue composition. Information excluded from the analysis of living populations ranges from the inability to obtain multiple biopsies to a lack of time depth in the analysis. It can be assumed that mummified bone has undergone little post-mortem deterioration and is therefore a good approximation of the condition of the skeleton at the time of death. Additionally, the skeletons of mummies are from periods of time that are often identical with time periods from which archaeological populations are obtained.

For correct interpretation of skeletal data derived from the analysis of mummies, it is desirable to have the same data derived by the same techniques in the living population inhabiting the same geographical region and in the ancestral antecedent populations represented by the skeletons. For example, osteoporosis, a metabolic bone disease, occurs with the world's highest frequency among Eskimos of Alaska, Canada, Greenland, and the USSR (Harper *et al.* 1984; Mazess and Mather 1974, 1975; Thompson *et al.* 1982). This condition is also apparent in Eskimo skeletal populations as old as 1500 BP (Thompson and Gunness-Hey 1981). The site preferred in the diagnosis of metabolic bone diseases, including osteoporosis, is a point on the iliac crest 2 cm posterior and inferior to the anterior superior iliac spine (Merz and Schenk 1970). Age, sex, and disease standards have been established for a host of trabecular bone variables at this site (Byers 1977). Iliac crest biopsies from patients and autopsies where age, sex, etc. are known, and from mummies and archaeological skeletons permit aging and disease patterns to be analyzed across time, between ages and sexes, and between populations.

A second site that is useful in understanding aging and disease patterns and provides complementary data on both processes, utilizes cortical bone instead of trabecular bone. This site at the anterior femoral midshaft permits the analysis of bone mass, bone quality, and of histological features that can be compared with features derived from the iliac crest biopsy from the same skeleton to derive an aging and disease profile from both cortical and trabecular bone. Also derived from the analysis of the femoral bone site is the estimation of age at death determined by the quantification of histological structures following methods described by Thompson (1979).

The purpose of this paper was to assess iliac crest and femoral bone biopsies from four Greenlandic mummies. Estimated ages at death were calculated, cortical bone mass, and bone histological variables from the cortical bone biopsies and trabecular bone volume, surface area and diameter from the iliac crest biopsies were measured. Next, each of the variables is compared with the results obtained from identical analyses in other Greenlandic Eskimo skeletons, in other Eskimo mummies, and finally with living populations.

# Materials and methods

Four Greenlandic mumies identified ad I/2, I/5, II/7, II/8 were included in this study. Bone cores 0.4 cm in diameter were taken from one femur from each mummy. Also sampled was a point on the iliac crest from mummies I/2, I/5, II/7, II/8, 2 cm posterior and inferior to the anterior superior iliac spine.

# Femoral core analysis

From each intact femoral core removed, cortical thickness (mm) was measured with dental calipers. The endosteal end of the cores was ground to form a cylinder of bone. Bone weight was determined to the nearest 0.0001 gm. Cortical bone density (gm/cm$^3$) was calculated as the weight of the core divided by the core volume. Next, bone sections 90 microns in thickness were removed from the core with the aid of a low speed saw. The plane of core sectioning was transverse to the longitudinal axis of the femur. With the aid of a semi-automatic, computer-assisted image analyzer, five features were measured in each bone section from each femoral bone core. The variables were: secondary osteon area (mm$^2$), secondary osteon perimeter (mm), Haversian canal area (mm$^2$), Haversian canal perimeter (mm), and secondary osteon number per mm$^2$. Three adjacent periostally-bound fields were analysed in each section and means for each of the five variables across the three fields were computed. Age at death was estimated for each mummy with the use of a regression formula for age estimation generated by Thompson (1979). The formula is y(age)=101.9(x) + 6.7 + 6 years where x is equal to the secondary osteon area times the number of osteons per mm.

Table 1. Greenlandic Mummy Bone Mass Variables

| Mummy ID | Cortical Thickness (mm) | Core Weight (gm) | Cortical Bone Density (gm/cm$^3$) |
|---|---|---|---|
| I/2 | 1.40 | 0.0252 | 1.784 |
| I/5 | 5.00 | 0.0977 | 2.031 |
| II/7 | 4.25 | 0.0817 | 1.993 |
| II/8 | 3.60 | 0.0585 | 2.078 |

# Iliac biopsy analysis

From the iliac crest biopsies removed from the standard clinical biopsy site, sections 80 microns in thickness were taken in a coronal plane. The iliac sections were magnified 44x and using the point counting method the following variables were quantified: trabecular volume, trabecular surface length (mm) and trabecular diameter. Five fields each 4 mm$^2$ were analyzed and the means for the trabecular variables were computed.

# Results

## Femoral core analysis

Cortical thickness values and cortical bone density values derived from the analysis of the anterior femoral midshaft cores from each of the mummies are presented in Table 1. The cortical thickness value of 1.40 mm for mummy I/2 suggested a very young age. The other three cortical thickness values fell within the expected Eskimo female range (Thompson and Gunness-Hey 1981). Cortical bone density values (gm/cm$^3$) indicated no systemic pathological changes in bone composition as they are all within the range for "normal" cortical bone density values. The "normal" range for cortical bone density is 1.75 – 2.05 gm/cm$^3$ (Thompson 1979).

Table 2 contains mean values for each histological variable obtained across three periosteal fields for each

Table 2. Greenlandic Mummy Cortical Bone Histological Variables

| Mummy ID | Secondary Osteon Area (mm$^2$/mm$^2$) | Secondary Osteon Perimeter (mm) | Haversian Canal Area (mm$^2$/mm$^2$) | Haversian Canal Perimeter (mm) | Secondary Osteon Number (#/mm$^2$) |
|---|---|---|---|---|---|
| I/2 | 0.0675 | 0.9271 | 0.0130 | 0.3648 | 5.33 |
| I/5 | 0.0305 | 0.6379 | 0.0047 | 0.2374 | 14.00 |
| II/7 | 0.0543 | 0.8473 | 0.0056 | 0.2651 | 4.33 |
| II/8 | 0.0313 | 0.6521 | 0.0039 | 0.2325 | 13.00 |

Table 3. Greenlandic Mummy Iliac Crest Trabecular Bone Variables

| Mummy ID | Trabecular Bone Volume (%) | Trabecular Surface Length (mm) | Trabecular Diameter (mm) |
|---|---|---|---|
| I/2 | 13.4 | 1.998 | 0.597 |
| I/5 | 10.1 | 1.641 | 0.651 |
| II/7 | 21.3 | 2.512 | 0.472 |
| II/8 | 17.5 | 2.212 | 0.505 |

Greenlandic mummy. Mummies I/2 and II/7 revealed few but large secondary osteons, compared with mummies I/5 and II/8. This combination of histological features is indicative of very young age. Thus, these individuals must be considered less than twenty years of age. This finding is based upon analysis of individuals less than 20 years of age where the mean secondary osteon perimeter is typically greater than 0.80 mm (Thompson, unpublished results). As individuals age and maximum adult growth is attained (after 20 years of age), secondary osteon size decreases, but in a nonlinear fashion, while the number increases linearly (Thompson 1978). Estimation of age at death by histological methods in young individuals therefore often produces inaccurate results. Because age-estimating regression equations (Thompson 1979) take into consideration the linear age related increase in osteon number and the variation in osteon size, the variable remodelling rates observable in growing bone (both longitudinal and lateral) yield errant age estimate results. The growth rate of each individual less than 20 years will determine how accurately age at death can be estimated. Individuals who have undergone femoral epiphyseal closure earlier in life will undergo earlier adult remodelling of the periosteal femoral midshaft. This pattern of skeletal growth would make it possible to estimate age at death more accurately in this type of skeleton than in a skeleton that experienced growth at a slower rate.

Mean osteon number for each mummy bone section ranged from 4.33 per $mm^2$ in II/7 to 14 per mm in I/5. Haversian canal area and perimeter are similar in mummies I/5, II/7, and II/8, but considerably larger in I/2 (Table 2). The large Haversian area and perimeter and large secondary osteons in I/2 were further indications of a very young individual. Estimated ages at death for mummies I/5 and II/8 were 51 and 48 years respectively. Mummy II/7 was estimated by the use of histological methods for adults to have been 30 years old.

## Iliac biopsy histomorphometry

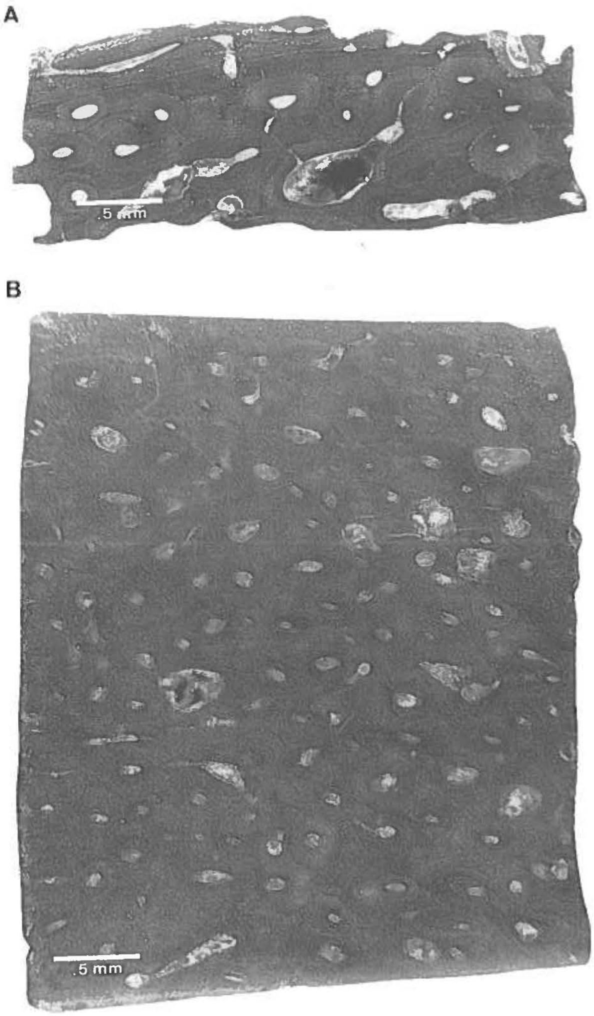
Data from the histomorphometric quantification of the iliac biopsies from mummies I/2, I/5, II/7, and II/8 are presented in Table 3. The trabecular bone values obtained from the analysis of the iliac biopsy from I/2 were expectedly low. Using 16% trabecular volume as the point of discrimination between osteoporotic and nonosteoporotic skeleton (Byers 1977), it is apparent that mummy I25 with a trabecular volume of 10% had clinically defined osteoporosis (Figure 2). Mummies II/7 and II/8 with trabecular volumes of 17.5% and 21% respectively were considered nonosteoporotic. Similarly, mummy I/5 showed the lowest trabecular surface length of the three adult mummies (1.641 mm) compared with 2.512 mm for mummy II/7 and 2.212 mm for mummy II/8.

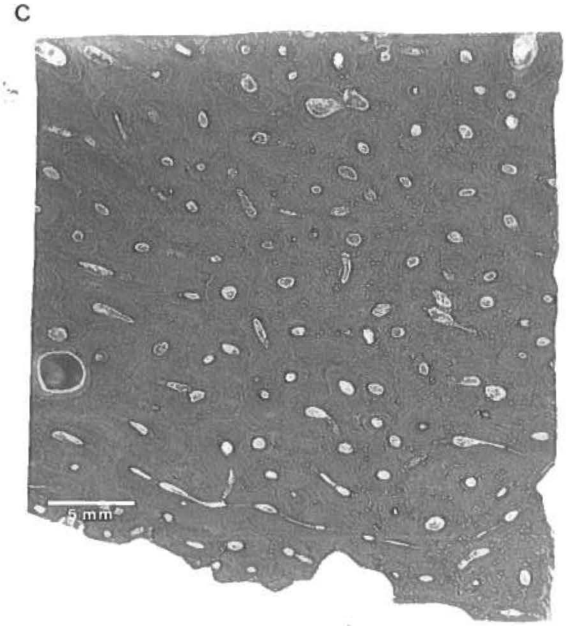
# Discussion

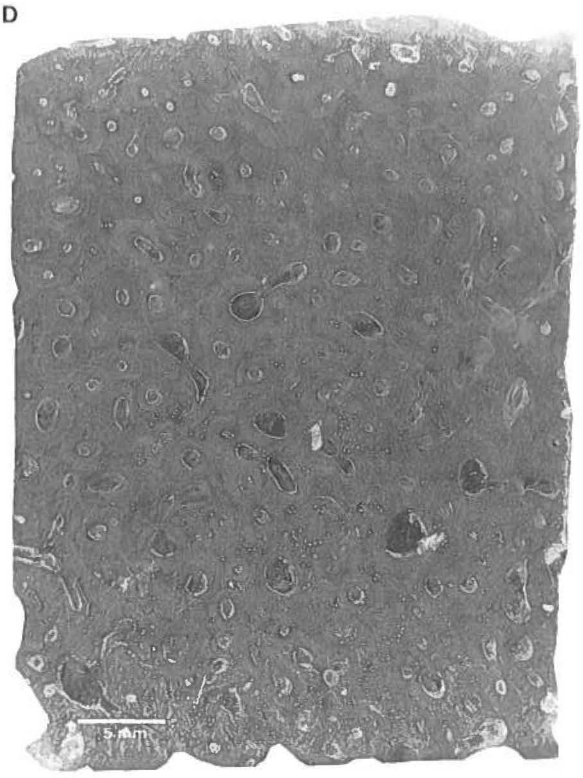
From the analysis of cortical and trabecular bone samples taken from standardized sites in four Greenlandic mummies, several important features emerged. First, the femoral cortical thickness values obtained from the analysis of the Greenlandic mummies were virtually identical to those obtained in a large series of Greenlandic Eskimo skeletons (Thompson, unpublished data) and to those obtained from Eskimo skeletons from Canada, Alaska, and the USSR (Thompson and Gunness-Hey 1981). Additionally, cortical thickness values from Eskimos were less than values obtained from US white skeletons of similar ages (Thompson *et al.* 1982). Second, cortical bone density ($gm/cm^3$) values obtained from cortical bone samples from the Greenlandic mummies were well within the normal ranges of 1.75–2.05 $gm/cm^3$. Comparable, normal cortical bone densities were obtained for other Greenlandic Eskimo skeletons, for other Eskimo mummies, for other Eskimo skeletons from Canada, Alaska, and the USSR, and for US whites and blacks (Thompson *et al.* 1982). From these data it can be concluded that only under extensive postmortem deteriorative conditions or systemic metabolic bone disease will cortical density values fall outside this range.

Histologically, the cortical bone from the Greenlandic mummies did not show any conditions suggestive of pathological bone remodelling. The areas and perimeters of the secondary osteon and Haversian canals fell within normal ranges. The age at death determination by histological quantification for mummy I/2, a sub-adult, was not performed because standards for this group do not exist. The variability in cortical bone remodelling and modelling rates during growth renders a histological technique of age determination of little use. It is only with the attainment of adult proportions and the cessation of modelling or sculpting of the skeleton that histological techniques become useful.

The quantification of trabecular bone variables in the ilium revealed the oldest mummy, I/5, to have the least amount of trabecular bone and this was considered to








be osteoporotic. The other adult mummies, II/7 and II/8, had normal trabecular volumes for their age and sex. The low trabecular bone quantity in the iliac crest of mummy I/5 did not correspond with the cortical thickness in the femur, where I/5 had the greatest thickness of the three adult mummies. Osteoporosis has been considered to have a variable expression in the human skeleton (Albright and Skinner 1979). In some osteoporotic individuals, only trabecular bone values are lower than normal and in others both cortical and trabecular bone quantities are lower than normal. In the case of I/5, it is probable that the osteoporotic condition was only apparent in trabecular bone. It may be hypothesized that the bone loss experienced by mummy I/5 at the time of her death was recent in its onset and had not yet extended to cortical bone. Several investigations have shown that with advancing age, trabecular bone is lost earlier and more rapidly than cortical bone (Albright and Skinner 1979) and the rate is most rapid

Figure 1. Anterior femoral midshaft sections (90 microns in thickness) from Greenlandic mummies: A) I/2, B) II/7 – estimated by histological methods to have been 30 years of age at death, C) II/8 – estimated by histological methods to have been 48 years of age at death, and D) I/5 – estimated by histological methods to have been 51 years of age at death.

shortly after menopause. Mummy I/5 was estimated to have been 51 years old and thus likely to have have experienced significant normal, post-menopausal, age-related trabecular bone loss which resulted in an osteoporotic skeleton. The relatively young age of mummy I/5 (51 years), yet demonstrating clear signs of osteoporosis, indicates the prevalence of the bone disorder among Eskimos, first identified in the investigation of living Eskimo populations (Mazess and Mather 1974). Also indicated is the existence of this condition in the past, as has been shown by the investigations in Eskimo skeletal populations (Thompson and Gunnes-Hey 1981) and in other Eskimo mummies (Thompson and Cowen 1983).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