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A NEW APPROACH TO BONE CONSERVATION: PHYSICALLY BALANCED DEHYDRATION

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Introduction

In this study dehydration, or drying, processes of bone material were studied in order to find an alternative to consolidation of subfossil bone material and to find the interval of relative humidities, where bone material should be dehydrated and stored to prevent physical damage of the type evidenced by cracking, splitting, flaking and eventual fracturing. Dehydration is defined here as loss of water until equilibration with the relative humidity of the surroundings.

Traditionally consolidants have been used for subfossil bone materials (e.g. Koob, 1984; Bunn, 1987; Shelton and Johnson, 1995; Kres and Lovell, 1995). Almost all of these consolidants preserve only the morphological structure of the bone, preventing scientific analyses, except for the recording of measurements and the study of traces in the bone surface, such as cut marks, wear and some types of pathological evidence. Even these analyses are often compromised by the presence of the consolidants which obscure the surface details.

Uncontrolled dehydration was first studied in order to see how water evaporates under normal conditions. Physically balanced, or protected, dehydration was also studied to find a method to prevent damage during the dehydration process. The minimum level of humidity for bone dehydration and storage is estimated. Dehydration was monitored as weight loss by the bones. Possible macroscopic changes of the bone material, such as cracking and splitting, were also documented. Both modern and ancient bone was studied.

Material

The modern bone material consisted of the skulls of juvenile and adult pigs, obtained from a bacon factory. The juvenile material was of six months old animals and the adult of more than one year. The skulls were macerated at Zoological Museum, Copenhagen. Maceration of the material was done in water at 34-39°C. Soft tissue was removed after maceration. Only mandibles and maxillas were used in the study.

The subfossil bone material consisted of eight Mesolithic, sub-marine bone artifacts (Møllegab LMR 12123) and of two human Viking Age skeletons

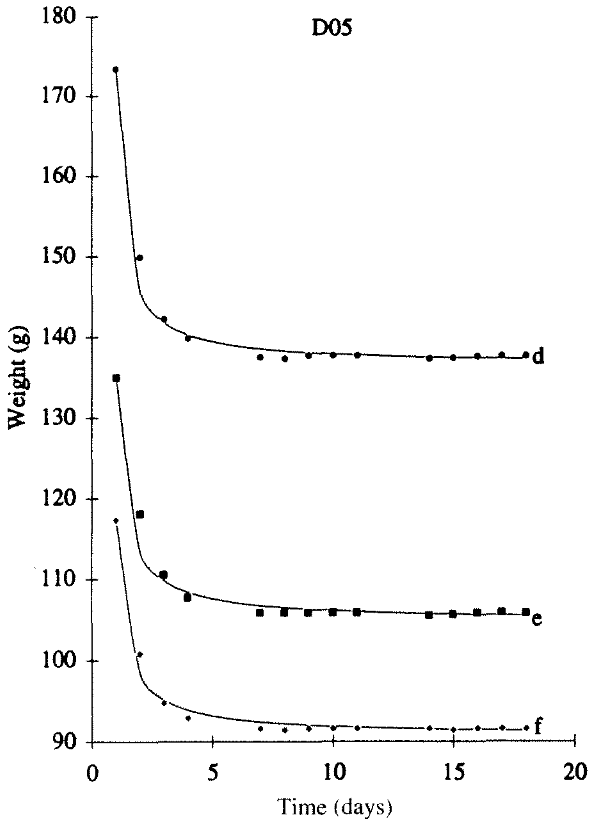

Fig. 1. - In DO5 weight loss of three wet juvenile mandibles (d-f) at 55±5% RH is recorded for 18 days.

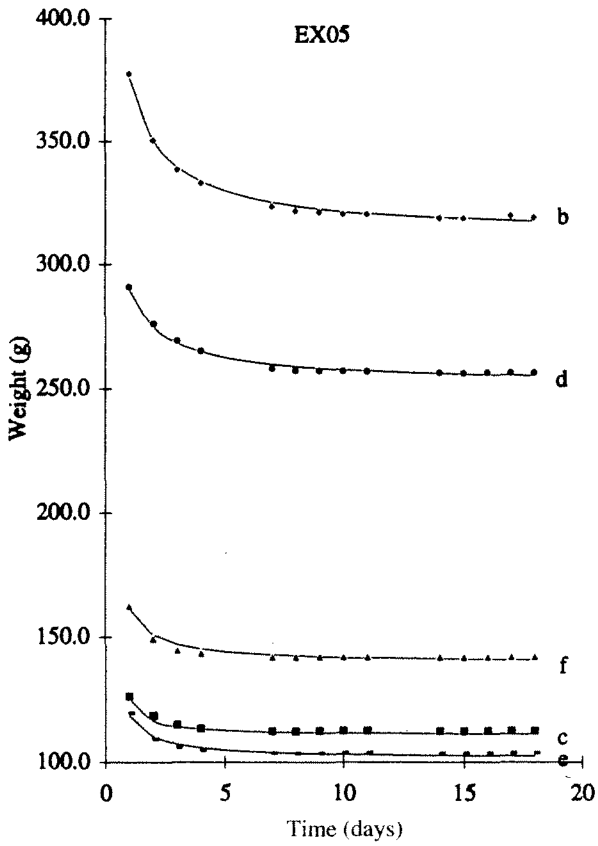

Fig. 2. - In EXO5 weight loss of five adult mandibles (b-f) at 55±5% RH is recorded for 18 days.

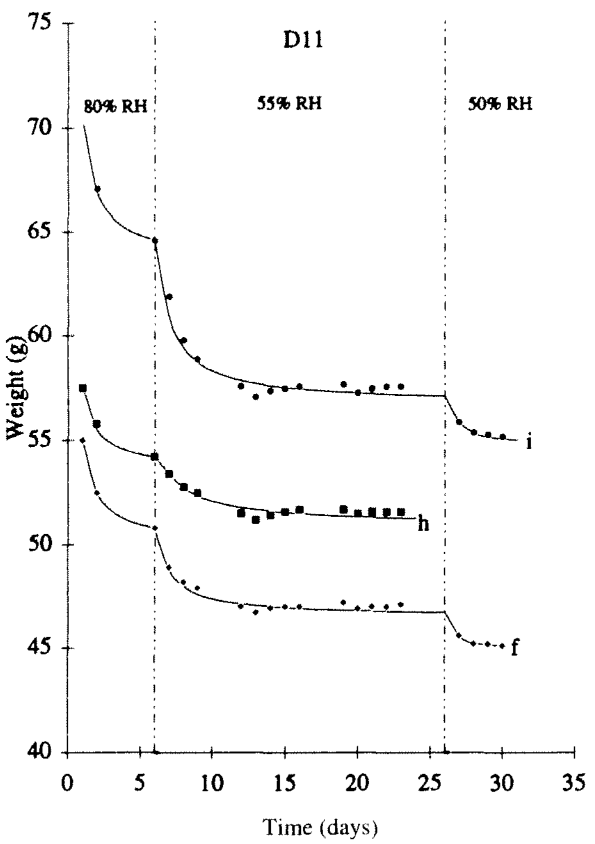

Fig. 3. - In D11 weight loss of three wet juvenile maxillas (f-i) is recorded. The bones were kept at 80% RH for five days, followed by 55% RH for 17 days. i and f were subsequently placed at 50% RH.

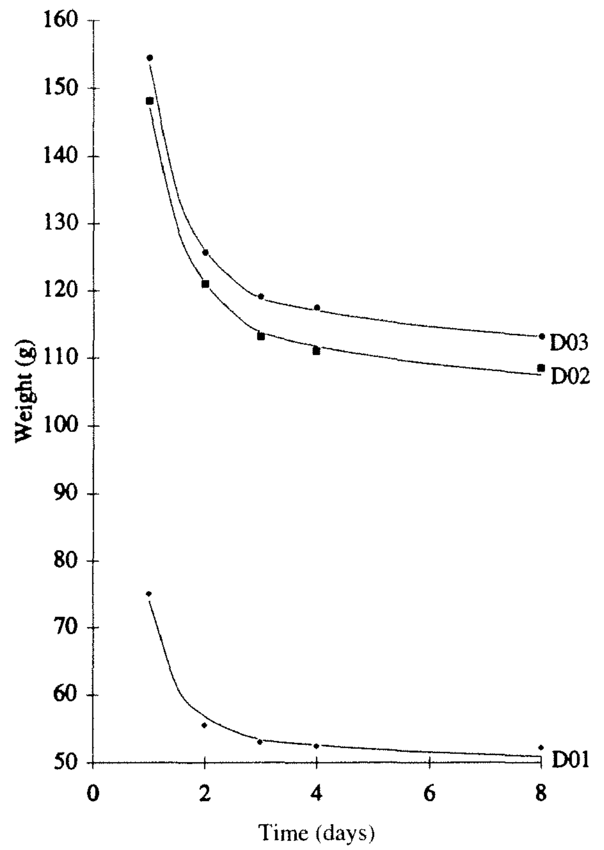

Fig. 4. - Weight loss is recorded of DO1 which is one wet juvenile maxilla and DO2 and DO3 which are two wet juvenile mandibles. Dehydration took place at 35% RH.

(Bogøvej LMR 12077, grave S and T). During excavation and transport the material was kept at the same humidity as in the sediment body. Generally, bones found wet should be kept wet, bones fund humid kept humid and and bones found in dry circumstances should be kept dry. The material was well preserved, stage 0, according to Behrensmeyer (1978). Organic as well as inorganic fractions are preserved, to which extent was not determined.

Method

Dehydration of bones was studied at different levels of humidity. Dehydration was documented as weight loss of the bones, using a digital balance (Satorius Industries I.P. 65). The bones were observed for cracks or other physical damage before and after treatment. Constant relative humidities were maintained in climate chambers with the use of silica gel conditioned to 80%, 45%, 40% and 35%, apart from 55±5% RH, which was the humidity of the climate controlled lab. Relative humidity was measured by means of a Testo 6300/6400.

1. Uncontrolled dehydration of bone material was studied in three series of juvenile mandibles of pig (DO5, D11) and in one adult mandible (EXO5).
   In DO5 three wet mandibles (d-f) and in EXO5 five wet mandibles (b-f) were placed on a poly-ester mesh at 55±5% RH and approximately 20°C. The bones were weighed once a day (Figs. 1 and 2).
   In D11, three wet juvenile maxillas (f-i) were kept at a constant humidity of 80% RH for five days followed by 55% RH for 17 days. Subsequently D11f and D11i were dehydrated at 50% RH, 20°C (Fig. 3).
2. One wet juvenile maxilla (DO1) and two wet juvenile mandibles (DO2 and DO3) were dehydrated at 35% RH and weighed once a day on days 1, 2, 3, 4 and 7 (Fig. 4).
   Two wet juvenile mandibles (BO1 and BO2) and one wet juvenile maxilla (BO3) were placed at 35% RH. Local areas of the bone surfaces that were observed to dehydrate faster than the surrounding bone material, were covered with pieces of damp cotton rag. The bone elements were turned once a day and weighed on days 1, 2, 3, 4 and 7 (Fig. 5).
3. Twelve wet juvenile mandibles were dehydrated at 45% RH, protected with pieces of damp cotton rag to cover those local areas of the bone surface that dehydrated faster than the surrounding bone material (A13 a-l). The bones were turned once a day. Subsequently the bones were placed in a climate chamber at 45% RH. The humidity was slowly decreased from 45% to 40% RH over a period of 10 weeks.
4. The subfossil wet bone artifacts from a sub-marine, Mesolithic settlement were soaked in tap water to remove salts and kept wet. The two human skeletons of Viking Age were washed in tap water

to remove soil and kept wet. The subfossil bone material was placed on a polyester mesh at 55±5% RH, 20°C. Local areas of the bone surface that dehydrated faster than the surrounding bone material, were covered with pieces of damp cotton rag. The bones were turned once a day.

Results

At any constant level of humidity the loss of water follows an approximately hyperbolic curve except that the weights level off and run flat relatively early (Figs. 1-5). In DO5 and EXO5 at 55% RH and D11 at 80% RH, followed by 55% RH, no physical damage was observed after dehydration. DO1, DO2 and DO3 were dehydrated at 35% RH. In DO1 warping of the anterior part of the bone element and substantial cracks were observed. In DO2 and DO3 obvious cracks developed. BO1, BO2 and BO3 were also dehydrated at 35% RH, but faster dehydrating areas were protected, and the bone elements were turned. In BO1, BO2 and BO3 small cracks were observed around the tooth sockets. In A13 a to l no physical damage was observed during dehydration until the 45% RH level. During dehydration from 45% to 40% RH, cracks were observed in g, j, k and l. Following the dehydration procedure, the modern bone material was stored at 55±5% RH for five years. No physical damage was observed during this period. No physical damage was observed in the subfossil bone material, which was also stored at 55±5% RH.

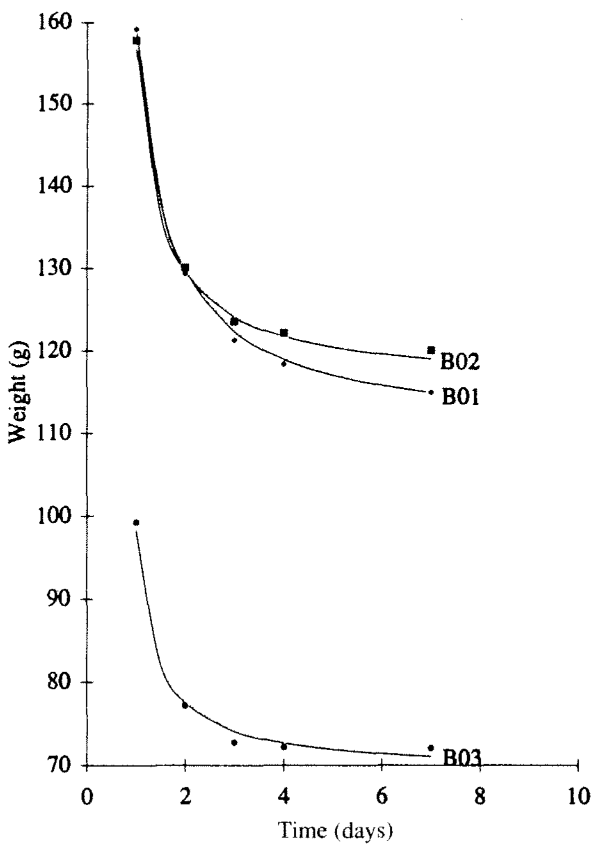

Fig. 5. - Weight loss of physically balanced dehydration of two wet juvenile mandibles (BO1 and BO2) and one wet juvenile maxilla (BO3) at 35% RH.

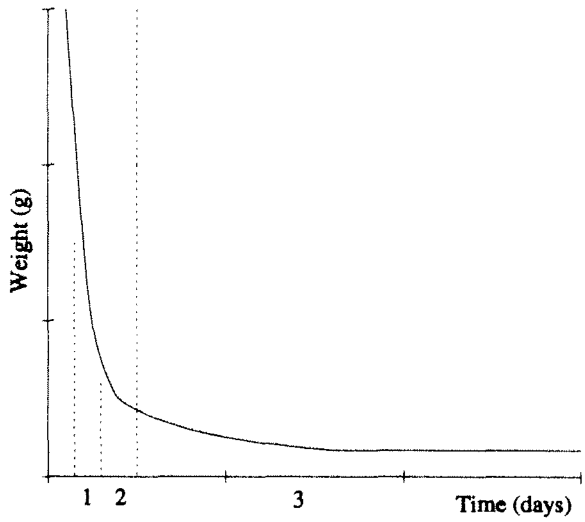

Fig. 6. - A hypothetic standard curve showing the three stages of dehydration. Stage 1 represents drainage from cavities and larger pores; stage 2, desorbtion from surfaces; stage 3, final equilibration to the surrounding relative humidity.

Discussion

According to Figs. 1-6 bones dehydrate in three stages at a given level of humidity. The actual level of humidity seems not to influence the three- stage dehydration. The first stage takes one or two days and results in the most significant loss of water. This probably represents draining of water that fills the cavities and larger pores of the bones. The second stage (Fig. 6) takes three or four days, and could be due to dehydration of water which is physically adsorbed to the bone surface. During the third stage, the bones adjust to the relative humidity of their surroundings.

At 35% RH cracks and warping became evident. However, protection of local areas of the bone surface and turning of the bone elements once a day, minimized the damage. The protection and turning of the bones seems to have prevented local stresses in areas that tend to dehydrate faster than the surrounding areas. A relative humidity of 35% seems in any case to be below the minimum level of humidity where physical damage appears in the bones.

In order to estimate the minimum level of humidity for bones to be dehydrated and stored at, the sample series A13 a to l were dehydrated, protected and turned. No damage occured until the level of 45% RH was reached. Thereafter cracks appeared between 45% and 40% RH. As a result of this, we suggest that the minimum level of humidity, where bones can be dehydrated and stored, is 45% RH.

There does not seem to be any maximum level of humidity for dehydration and storage, concerning physical damage. However, above 65% RH fungal growth appears (Atlas, 1984). Therefore, the interval in which bones ought to be dehydrated and stored, is between 45% and 65% RH.

Protection of local surfaces dehydrating faster than the surrounding bone, e.g. spongious tissue, together with turning of the whole bone element, results in a more homogenous dehydration of the element. In the modern material, however, visible effects of this treatment were only observed at low humidity levels, below 45% RH.

In subfossil bone material only protected dehydration has been performed. The dehydration of subfossil bone material seems to follow the same three stages, as the modern bone material, although dehydration seems to be faster, probably depending on the state of preservation. According to Bunn´s initial experiments with three samples of subfossil bone, equilibrium was reached within five days (Bunn,1987). Generally, the subfossil material is more porous than the modern, which may lead to a higher initial pore-water content, compared to modern material and make collagen may be more accessible to water vapour (Bunn, 1987).

Using protected, or physically balanced dehydration, on subfossil bone material, physical damage cannot be observed, even after 5 years, provided that the material is stored at a constant humidity at a level between 45% and 65% RH. In these experiments the subfossil bone material had, however, been kept humid, as excavated, until rinsing and dehydration were performed. It is our experience that serious deterioration occurs from the moment of excavation, unless the bones are kept at the same humidity as in the sediment body.

Conclusions

Physically balanced dehydration of bones can be performed at any level above 45% RH with no observations of subsequent physical damage. If subfossil bone material is kept at the same humidity as in the sediment body during excavation and transport and thereafter subjected to physically balanced dehydration, followed by storage at a constant humidity level between 45% and 65% RH, use of consolidants can be avoided.

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