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Quantitative Effects of Skeletonizing Processes on Bone Density

Rex McDonald
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Rex McDonald entitled "Quantitative Effects of Skeletonizing Processes on Bone Density." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Alison Galloway, Major Professor

We have read this thesis and recommend its acceptance:

Lyle W. Konigsberg, Walter E. Klippel, William M. Bass

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Dr. William Bass, Ph.D.

Accepted for the Council:

Associate Vice Chancellor
and the Dean of The Graduate School

Quantitative Effects of Skeletonizing Processes on Bone Density

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Rex McDonald

August, 1991

Dedicated

To the Love of My Life,

My Wife

Kim McDonald

Acknowledgement

No project of this size can be accomplished without the help, expertise and assistance of many valued people. In the case of this project, the assistance of Dr. Alison Galloway, Ph.D. of the University of California, Santa Cruz, in the formation and general direction of this research was paramount. Dr. Galloway serves as chair of my committee and a personal inspiration as to the level of professionalism and expertise a consummate anthropologist can achieve.

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1. Introduction

The fields of physical and forensic anthropology have evolved tremendously since their inception in the late 19th century. In skeletal analysis, we are no longer confined to gross morphological and phylogenetic comparisons to document population variations. With the expanded use of high-powered light and scanning electron microscopes along with radiographic equipment, the exploration of the microanatomy and cellular variation of bone are both possible and expected. These new media provide a plethora of information on population variation in growth, remodeling, and the general physiological health of bone. Massive collections of skeletal remains have been curated for the purpose of comparative studies and many of these are undergoing extensive radiographic studies in an attempt to understand a variety of processes as diverse as osteoporosis and stature loss in living populations (Galloway *et al*, 1990) to human health in prehistory (McHenry, 1968). Many of these collections contain individuals of known health and backgrounds which are essential in modern comparative and reflexive studies.

Now that these new technologies are being applied to these collections, some basic questions as to their appropriateness as test specimens need to be addressed. In anthropology, skeletons, both human and non-human, have been collected for the purposes of identification, comparison, and

metric evaluation.

Now anthropologists are using radiographic devices for the study of skeletal biology (Anderson, 1990), archaeological (McHenry, 1968) and faunal materials (Lyman, 1984). One of these devices being introduced into anthropology is the absorptiometer. The single photon absorptiometer has been used for almost twenty years to evaluate the bone thickness in living women and men suspected of having osteoporosis (Cameron & Sorenson, 1963). The introduction of the dual photon and X-ray absorptiometers has greatly enhanced the usefulness of this technique. What must now be evaluated is the possibility that these bodies of data, in the form of our skeletal collections, have been skewed before they ever reach the researchers by the method of their procurement and processing.

The methods for skeletonizing remains are as varied as the researchers who collect them (Grayson, 1978; Hildebrand, 1968; Casteel, 1976; Russell, 1947; Friedman, 1973). These methods fall into three major categories: water bath, maceration and insect agent decomposition. The author will explore each of these techniques in an attempt to cover the widest variety of popular skeletonizing methodologies. Radiographic examination (dual X-ray absorptiometry) of the specimens after processing will provide an evaluation of the degree of alterations inflicted by the various processing techniques as compared to their expected values.

2. Background

The importance of basic research is paramount in all scientific endeavors. In physical anthropology's effort to shed its *"soft science"* skin, it has moved ever closer to the techniques and methodologies standardized in the older and better funded medical arts. In an attempt to answer upper-level, theoretically based questions, a firm foundation of well proven, falsifiable, verifiable, and replicatable experimentation must be laid to allow any further growth or resolution to a definitive answer.

With a working knowledge of bone anatomy, chemistry and physiology, the author questioned the effects of placing osseous material, composed mostly of calcium and phosphate, in water as a methodology for skeletonization. Many professionals had written on the methods of skeletonizing various types of creatures, but no one had written on the effect of this processing on the inorganic matrix or microstructure of the osseous material.

These breaches of the basic building blocks of science were easily overlooked in the early days of anthropology. The purposes for retaining skeletons have undergone vast modifications within the life span of our discipline. In the early portion of this century, the thrust of physical anthropology was to teach and explain variation in macrostructures (usually cranially) as a function of

geographic distance and genetic distinctions. These studies tended to be holistically typological. After the Second World War, the focus began to change to a more environmentally influenced biological approach. This paradigm was still based on macro-variation in cranial material with a slight interest developing in the areas of ontogeny and physiological responses to stimuli, pan-culturally.

With the influx of the 'New Archaeology' in the 1960's, the focus throughout anthropology shifted to a more techniques-oriented approach. This shift was possibly due to the proliferation of high-tech equipment originating in the medical field. With so many physical anthropologists working with physicians throughout the country, technologies quickly found new applications in physical anthropology. Until the mid - 1970's, the questions that this author is asking about microdamage to bone were not possible to investigate and probably were not conceptualized as being a question pertinent to anthropology. By the 1980's these technologies were becoming available to researchers in fields as varied as sports medicine, nutrition and biomechanics as well as anthropology. With the power to investigate microvariation on large samples for the first time in the history of the discipline, the tendency for the fundamental building blocks of science tended to get skipped. The questions that anthropologists started asking were only vaguely similar to those in medicine. The medical arts had done their basic

research on the technology and understood the limits and ramifications as they pertained to the questions being asked within the biomedical field. In this case the physical anthropologist could be viewed as a cave-man handed a Coleman lantern; while we enjoyed the light it was casting, the foundation for its function was not totally understood.

The applications differ so widely from medicine to anthropology, and the technology advanced so rapidly that it would not be unexpected that these research gaps would occur. The goal of the author is to attempt to close one of these small gaps, helping to provide the discipline a firmer foundation from which to use these incredible explorational tools. As is true with any developing discipline, who could have predicted the uses and needs being projected on skeletal collections curated for more than a hundred years? Without the foresight and wisdom of these early and modern-day pioneers, no skeletal collection would be present for current analysis. If researchers can discover the "best" method for collecting and processing osseous material, perhaps generations to follow will have the advantage of these large collections and the security of knowing any possible alteration that could have inadvertently occurred though their development.

The interests that are amassed under the discipline of physical anthropology are very diverse and creative. The cutting edge of anthropology is now firmly in the hands of

those looking into the microvariations within systems. Technologies have provided us the ability to extrapolate dietary habits through the use of Trace Element Analysis. The word taphonomy is known by all but the most sheltered professionals. Without the work of so many curators, exploration into microvariation would not be reasonable.

The author's hope is to provide some insight into the effects of skeletonizing processes on osseous material so that safe methods may be utilized. In addition, it is hoped that a method of correcting for any inadvertent alterations that may have occurred can be dealt with in a parsimonious manner.

Explanation of the Processing Techniques

The author fleshed out a myriad of methodologies were available to advise one on procedures for rendering a plethora of animals into mere skeletons of their former selves. A combination of this information with personal experience and professional communications presented a holistic view of the methods most commonly employed. We can posit these in three major categories, each with their major supporters.

Water Baths

Water bath processing techniques involve the placing of a specimen in containers of water and heating it until the

material has skeletonized. This process is similar to stewing or cooking animal meat. It is usually conducted on a flexible time schedule and the specimen is removed when the soft tissue has lost its cohesion to the bone or periosteum. The remainder of the meat is removed manually.

Water baths are the most frequently used in forensic applications when the remains discovered are not fully skeletonized by the natural processors. Forensic anthropology is a very practical and applied division of our discipline. As its name implies, forensic anthropology utilizes specific techniques to render a legal interpretation of events dealing with the death of an individual within contemporaneous surroundings. This practicality necessitates speed, precision and effectiveness. Few processes can reduce human remains as quickly as heated water. With such a straight forward objective and the extreme likelihood that the remains, if successfully identified, will be interred, the usefulness and logic of taking extreme measures to insure microstructure continuity is moot.

The point at which forensics professionals needs to take care of the histological evidence of the deceased is when the identification is not so easily obtained. A circular argument ensues. To determine identity, the forensic anthropologist employs skeletal analysis, which may require the defleshing of the remains. If however, the specimen eludes ready identification and was processed in the fastest of manners,

additional information that could provide the crucial key may have been lost before being deemed necessary. The logical course of action is to treat every case as though the entire identification relied on the evidence obtained from microstructural analysis. The value of those additional avenues of analysis will have to be weighed against the need for speed and efficiency. Fortunately, the two are not necessarily mutually exclusive. Copious records should be maintained on the processing method to allow for the discovery of any alterations that could have inadvertently occurred.

Many methods of water bath processing have developed over time with differences in processors and agendas. Some researchers will boil the remains at a vicious level to quicken the pace of skeletonization while others will simmer the remains for several days, employing what has been call the "crock pot" method. Additives, ranging from detergents to bleach are used to remove excess grease and whiten the remains. Ossian (1970) comments on the effects to osseous material through the practice of using bleach in the statement, "*Liquid, chlorine bleach, a substance known to damage bone material ...*". However, this practice is viewed by some professionals as very practical for the repeated handling and photographing of the remains. Solution rates are varied and performed usually on a "sight basis", with the concentration as potent as the researcher feels necessary.

Macerations

The second most prevalent method and certainly the most often described methodology for skeletonization is maceration. Maceration is a process wherein a specimen is placed in a fluid medium and is allowed to stand for an extended period of time. The atmospheric, water borne and species-endemic bacteria begin to consume the soft tissue of the specimen. This process continues until the specimen becomes completely skeletonized. Disarticulation occurs when the most internal ligaments are consumed and elements fall to the bottom of the container. The process ends when all consumable material has been devoured or the bacteria begins consuming itself until the colony's death.

Maceration should also be considered a process in which water-soluble minerals (e.g. Calcium and phosphates) within bone are placed in an aqueous solution. It is a common practice to allow specimens to macerate for months or even a year or more. One possible reason for such long-term processing is the death of the bacterial colony decreases the degree of olfactory distress that occurs when one recovers or "pours off" a specimen.

The solutions used display a wide range of variation and each reflects the requirements and logistics of the researcher involved. In 1967, W.R. Taylor worked out an in-depth methodology for the use of enzymes and stains for the

skeletonization of small vertebrates (Taylor, 1967). This material was published as a method to be employed by museums with the intent clearly focused on producing aesthetically pleasing specimens. Taylor wrote of the fastest and cleanest method, but no mention was made of the liability of this procedure. Ossian (1970) followed Taylor's article with a more practical guide aimed clearly at the low-budgeted research department. In this article, Ossian also writes of the speed of enzyme additives:

> *"Laundry 'pre-soakers' ... have the same basic group of chemicals: a variety of proteolytic enzymes, sodium perborate, sodium tri-polyphote and non-ionic detergent".*
>
> *"My experience, Proctor and Gambles Company's Biz gave the best results".*
>
> *"Two tablespoons per quart of water".*[1]

Taylor also writes of the favorable practice of allowing tap water to sit for a period of 24 hours to allow for de-ionization. This lead to the concept of using distilled water in the experiment's parameters. It seems clear that chlorine, originally added to drinking water to kill bacteria, would greatly inhibit the growth of endemic bacterial colonies. The author had noticed that tap water was the solution of choice among most who processed by maceration. The advantages of tap water are apparent with its ready availability, low

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[1] The metric ratio is 23.5 grams per liter.

cost and convenience. Distilled water or completely deionized water, has the dipolar values of tap water. Both proved to be excellent candidates for this research design.

Materials for containing the solutions of maceration also presented themselves as a variable worthy of exploration. The ability of *Pseudomonas*, a common bacteria present in the maceration process, to attach themselves to glass is considerably lower than to plastic containers (Fletcher, 1988). This originates in the texture of the plastic versus glass jars. Plastic, with its thousands of microscopic dents and bumps provides a greater surface area for attachment by the bacteria than glass. Because the bacteria is unable to adhere as well to glass, it attaches itself to the soft tissue and forms a self-regenerating colony at a faster rate. The percentage of bacteria in direct contact with soft tissue is greatly enhanced in glass containers. The speed of maceration is directly proportional to the percentage of bacteria that has access to the soft tissue. With a greater speed of soft tissue removal, the period of time that bone mineral is in direct contact with aqueous solution increases. This information lead to the introduction of both plastic and glass one-gallon jars to have individual femora macerated in a variety of solutions.

As far as the optimal temperature for maceration, the opinions were as varied as the researchers themselves. Below are but a small number of the variety of temperature settings

recommended:

> *"... temperatures between 50° and 70° Centigrade until the bones are free or the solution is exhausted"*, Ossian, 1970.
>
> *"Optimal maceration temperature is about 45° Centigrade"*, Hill, 1975.
>
> *"Optimal temperature for digestion is near the body temperature of the animal (being processed)"*, Taylor, 1967.

Natural Decay

Concerning "natural" processing, the literature was again bountiful. Much of the research was focused on the development and maintenance of dermestid beetle colonies (Grayson, 1978; Russell, 1947). Some work had been done on less orthodox methodologies of cleaning using marine resources. These methods ranged from the placement of material in burlap bags for sand fleas, shrimp, etc. to clean specimens (Friedman, 1973) to the use of specific isopods, *Cirolana harfordi* to render remains (Bolin, 1978).

Through the pilot study for this project (McDonald, N.D.), it was determined that there is no significant bone mineral loss in either the use of dermestid beetles or blow fly maggots when sheltered from other forces, (e.g., rain, scavengers and temperature fluctuation below 0°C). Because of this stability throughout this defleshing process. Blow

fly maggots were utilized to render the flesh from the control specimens.

The Use of Absorptiometry

Densitometry is a process where the relative density of materials is determined based on the refraction and deflection of electromagnetic radiation. X-rays have been used for years to estimate the relative thickness and density of osseous and dentin material (Garn, 1970). X-rays have not been able to tell the density of bone with metric reliability because of the variations in the settings and film sensitivities. An absorptiometer is a device that emits a stream of electromagnetically charged, alpha decaying particles (Hazen & Trefil, 1991) through a body and a counter measures the amount of those particles that pass through unscathed. This process allows for the metric evaluation of the body and is corrected for or ignores all material except those that block more radiation than the prescribed base-line level. With the ability to ignore soft tissue, this device has been used extensively in the area of osteoporosis research to evaluate the amount of bone mineral loss in critical areas most likely affected by the disease.

The use of absorptiometry was viewed as the most effective methodology to determine the effects of processing in this study. The end-goal is to be able to evaluate

material of unknown value by the use of standard, known value specimens. If this technology is to be used on archaeological remains, then these materials would be composed entirely of the inorganic matrix left after complete organic decomposition. With absorptiometry, the observer is only measuring the inorganic components of the osseous material. The water content of the bone is not important and produces no detrimental effects on the scans. While the scanner is not capable of determining which mineral it is evaluating, the relative difference in atomic weights make any overt, atomic heavy mineral deposit obvious.

Commonly used in the medical arts are three basic type of densitometers or absorptiometers. These are: 1) single photon, 2) dual photon, and the 3) dual energy X-ray. The single photon absorptiometer emits one frequency of radiation, usually power by an isotope such as I_{125}. It presents a cross-sectional portrait of the bone not dissimilar to that of an echograph. As the name implies, the unit emits only a single frequency of radiation and thus can provide only one source of information. A dual photon absorptiometer uses a series of rare earth filters to change the radiation profile to allow for a greater range of electromagnetic frequencies to be affected. The data is presented in the same basic format and, as with the single photon, is site-specific in its application.

The dual energy X-ray absorptiometer is the latest in this series of bone scanning equipment. The Norland XR-26 is one such scanning device that has the ability to examine the complete sample at one time. It portrays an image of the scanned area (p. 31) and gives specific readings on density throughout the body, and provides the possibility to isolate specific regions for evaluation. Readings of the Bone Mineral Content are divided into the areas of the specimen being scanned. Only the area in which pixals are activated by a significant change in density from the baseline are used in the area computation. The simple equation of *Density = Grams / Area* provides the Bone Mineral Density. The operator has the ability to adjust the speed of the scans as well as the size of the pixals that form the density matrix. The pixal sizes can range from 0.5^2 to 3.0^2 millimeters. The smaller the pixal size the more precise the measurement. The level of background radiation is considerably lower from the Norland XR-26 than from either the single or dual photon sources.

Since dual energy X-ray scans are becoming the standard in the medical field, the possibility to transfer data received from this source across academic barriers tends to be greater. Several studies have already been funded on living subjects using dual energy absorptiometry. Having the maximum amount of data available from one set of scans has its obvious advantages.

3. Materials and Methods

In designing a research model of this scope, certain key decisions must be made with much deliberation. In this project, the questions of paramount importance are those of the material to be used, the methods to be employed on the material and the methodology of measuring any effects or alterations.

Materials

The author chose domesticated pig femora as the material to be tested. After consultation with several colleagues and the successful completion of a pilot study on this question (McDonald, N.D.), the methods of skeletonization were chosen to be: maceration, water baths, and natural or insect processing which serves as the control procedure. The equipment to measure the results of the various techniques was the dual X-ray densitometer or absorptiometer.

The choice of *Sus scrofa* femora from a meat packing plant was premeditated more than a question of opportunity. Lay's Meat Packing Plant[2] of Knoxville, Tennessee, allowed the collection of specimens with a set of variables that are unique within populational biology. These criteria include:

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[2] Lay's Meat Packing Plant provided surplus pig femora free of charge for this research. Workers there also provided information as to the diet and lifestyle of the animals as well as logistical assistance in packaging and transportation of the specimens.

1) Dietary Consistency
2) Age Consistency
3) Limited and Universal Access to Exercise
4) Genetic Pool Known & Common
5) No need to harvest test subject.

1) The diet of the animals to be harvested was controlled in both quantity and quality. The diet consisted of a fixed ratio of protein to fat (Figure 1). The quantity was standardized and adjusted each month, regardless of growth or sex. Antibiotics were included within the diet in an attempt to control staph infection endemic to large-scale animal production. Animals that were outside a prescribed standardized growth curve were culled.

Protein	25	%	Vit. E	5	IU/lb
Fat	15	%	Vit. B_{12}	7.5	µg/lb
Fiber	3	%	Cholesterol	1100	ppm
Ash	6.2	%	Niacin	22	ppm
Calcium	0.7	%	Riboflavin	4.1	ppm
Phosphorus	0.45	%	Zinc	50	ppm
Sodium	0.35	%	Iron	50	ppm
Chloride	0.6	%	Manganese	25	ppm
Vit. A	800	IU/lb	Copper	10	ppm
Vit. D	200	IU/lb	Iodine	0.38	ppm

Figure 1. Dietary Intake

2) All animals were harvested at 120-130 days. Timing is controlled from the point of conception since the female

breeders are brought into estrus by the use of light controlled stalls. The breeding process was continued with litter production consistent throughout the collection period. The animals were brought to harvest on a calendar schedule without regard to weight variation or sex. Evaluation of age of the subadult pigs were confirmed by epiphyseal development (Hill *et al*, 1987).

3) All animals were raised entirely within holding stalls. The stalls were only slightly larger than the animal's expected harvest size. No exercise program was instituted. The animals stood on a concrete floor and no provisions were made to allow the animal to turn or walk. The only exercise during the animals' life was the 12 day period allowed for suckling and the walk to the conveyor belt to be harvested. This behavior pattern lead to an interesting collection of pathologies on the most distal portion of the femoral condyle grooves. All specimens with pathologies were admired and discarded.

4) All animals within this study shared the same genetic relationship. A small number of females and males were allowed to reach sexual maturity and breed. Of this group, females who produced a substandard number of offspring per parturition were culled as were males after reaching a predetermined age. Genetic relationships can be traced through females only. Female offspring of breeders who have shown a consistent pattern of large litters are themselves

placed in the role of breeders. The males are a much smaller genetic pool and are chosen based upon their health and personal body size.

5) It was important to this researcher to find a source of osseous material that did not cause the death of research subjects simply for the sake of this project. The animals used in this project were harvested in the process of providing meat to the general population. The research specimens would have been discarded as part of the plant's standard procedure. The use of this material is a successful example of the interaction between industry and academia and the avoidance of unnecessary animal destruction in science.

The use of *Sus scrofa* was purposeful as it provides a general eutherian mammalian model for bone anatomy and histology. The animal has a weight at harvest within the range of humans and the morphology of the upper pelvic limbs are highly correlated to a wide variety of mammals. The dietary requirements are similar to those of humans and the system of hormonal control of bone physiology shows a strong correlation to that of *Homo sapiens* (Kuznetsov *et al*, 1987). With these factors as well as those listed above, the use of *Sus scrofa* for this project became most attractive.

The use of the femur for this research provided an opportunity to examine both trabecular and compact bone regions. The diaphysis provides an extended region of dense, lamellar bone that, at this age, would be subject to

remodeling and the development of osteon and osteon fragments. The condyle region provides an opportunity to examine the effects of processing on the trabeculae. This region is highly stressed biomechanically, with both tensile and compression forces, and consistently shows the highest bone mineral density (Appendix 3). This region should, theoretically, be the most susceptible to any water action that would dissolve a water soluble mineral due to the high quantity of surface area of the trabeculae exposed to the media. With such a large quantity of both of these bone types in the same specimen, it becomes possible to explore the differential effects of the skeletonizing process on both trabecular and lamellar bone with a high degree of statistical accuracy.

The femur's biomechanical functions and stressors allow for prediction and discrimination between areas of high stress, thus greater bone strength and those of more static usage. The area of the femoral head and neck was also investigated so as to evaluate the alterations due to processing on high density, highly stressed areas.

Femora are easily amenable to metric analysis. The results of this analysis can be directly correlated to the majority of post-cranial evaluation performed in anthropology and biology. The femur is helpful in collected materials and its archaeological survivability lends the femur to large quantities of analyses.

The pigs were processed within eight hours of their harvest and shipped to the packing plant daily in a refrigerated condition. All the femora acquired for this research were obtained within two hours of their processing and were immediately refrigerated. The patellae were removed but most of the excess soft tissue was left on the specimens. The femora were then immediately either frozen or placed in a processing situation. Each femur was assigned a unique code which was used throughout the study. This code included information on the specifics of the processing techniques to which the specimen was subjected as well as its individual designation (Figure 2).

Control Specimens

A collection of 60 femora where placed in the University of Tennessee's Human Decomposition Facility in Knoxville. The specimens were positioned on a large piece of ridged sheet metal in an open air environment. Caging was secured over the specimens to prevent scavenger activity. The samples were exposed to rain and direct sunlight. The texture of the surface on which the femora were placed facilitated the rapid removal of rainwater from the specimens but still allowed water to collect 1 to 2 centimeters below the sample. The caging material provided ample access by all insects with a cross - sectional body size of less than 1 centimeter. Within

24 hours, extreme insect infestation had occurred. The specimens remained in this environment for 135 days. A notable decrease in blow fly maggot (Catts and Haskell, 1991) activity occurred 39 days after the original placement due to a decrease in ambient environmental temperature and the dehydration of the remaining soft tissue. The samples remained articulated at the epiphyseal junctions throughout the processing. Femora were collected 137 days after their introduction into the facility and were placed in sealed bags and cataloged in preparation for scanning.

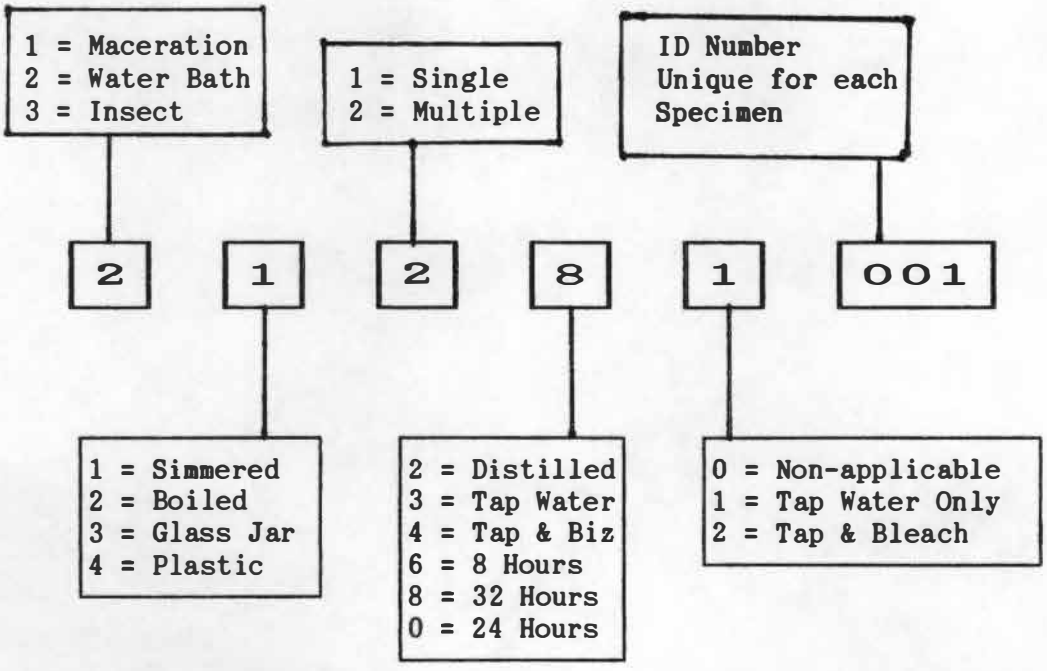

Figure 2. Coding System

Maceration Techniques

Within the subgroup of the femora processed by maceration, three further subgroups were established according to liquid medium. Those macerated in:

1) Chlorinated Drinking Water (Tap Water)
2) Chlorinated Drinking Water with Detergent Additive (Tap & Biz)
3) Distilled Water

1) The tap water specimens were examined due to the wide-spread use of this techniques. Tap water has been the standard fluid for maceration due to its extreme low cost and high availability. Researchers have recommended (Taylor, 1967) that the water be allowed to sit for a period of 24 hours before use to allow for the deionization of the water and the release of suspended chlorine particles. For this research, the water was taken directly from the faucet without the advantage of deionization. The purpose was to observe the effect of the chlorine enhanced water on the bacterial action. It was suspected that the presence of chlorine within these samples would greatly inhibit the original growth of the bacterial colonies.

2) The use of the detergent additive Biz is a common practice within the research and collection community. Biz is a commercial, enzyme activated detergent widely available in the United States. Ossian (1970) suggests the use of the enzymes in Biz for the processing of skeletons. The practice

has gained wide-spread usage in recent years for its ability to whiten bone and to increase the speed of complete skeletonization. For this project, the quantity of Biz used was kept purposely low in concentration so as not to prejudice the outcome. From personal observation and communication with other researchers, the adding of Biz is done "by sight" and without measurement. In this project, the concentration ratio of Biz to water remained constant at 23.5 grams per liter. Throughout these personal communications, no other detergent was stated as having wide-spread usage in maceration.

3) Although no research was uncovered that suggested the use of distilled water, this researcher deduced that using distilled water would achieve optimum results. Distilled water provides a medium for bacterial growth without any chemical additives to enhance or hinder development and proliferation. It has been observed that distilled water provides maximum skeletonization speed (McDonald, N.D.) and should accurately reflect the alterations that occur due to bacterial action.

An additional research category within the maceration subgroup was originally planned for this research. An attempt to use lake water from the Knoxville, Tennessee[3] region was undertaken. However, upon analysis, these samples were deemed to be too unreliable. Every sample taken from the region

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[3] Samples were taken from Lake Loudon, Knoxville, Tennessee.

exceeded the Environment Protection Agency's guidelines for chemical (heavy metals and Dioxin) and bacterial (various sewage related) contamination. The variation of pollutants within the samples was also extreme. These samples were discarded.

Within each of the above categories, each subset was then divided further into single and multiple macerating groups. This provides an opportunity to observe the differences that could occur between a relatively small ratio of water to osseous material. All solution strengths were kept at identical levels regardless of the quantity of solution. The single macerations were performed in one-gallon sealed jars of both plastic and glass and the multiple macerations were performed in five gallon plastic buckets with resealable lids. Since epiphyseal union was not complete in the age range of my sample, all specimens within the multiple samples were successfully matched after disarticulating in solution with the exception of those specimens which had deteriorated to the point of condyle destruction.

The author processed the maceration section of this project in a semi-sealed closet which preserved total darkness and a temperature of 45°C by means of a thermostat and heater. The speed in which the bacteria consumed the soft tissue was greatly accelerated. A control specimen was kept in another room maintained at approximately 27°C for comparison. The

specimens remained in the thermally excited environment until the conclusion of the experiment.

While all specimens began at room temperature, the maceration containers were placed in a confined area according to Hill's 1975 article. The speed of deterioration of the soft tissue increased dramatically while in this thermally advanced environment. Most bacterial colonies had expired before removing the samples from this environment.

The amount of time the femora were in solution also varied. This was done, in part, as a function of logistics. It also served as a method of observing diachronic alterations and made it possible to regress Bone Mineral Content (BMC) loss against time in an attempt to understand this relationship. All femora were "poured-off" at the same time regardless of the time of their introduction into solution.

The singly macerated groups were divided into sets that were processed in glass and those in plastic jars. By testing the bone mineral density of osseous material processed in both plastic and glass containers, the author hoped to correlate the action rate of soft tissue removal with the dissolution of bone minerals.

Water Bath Techniques

The water bath section of this project was divided into several subsets. First was the division between the boiled

and simmered group. The attempt here was to determine the effects of temperature and agitation on the water's ability to gain access to and affect bone minerals.

The boiling procedure was accomplished by immersing 15 separately bagged specimens into a large vat. The specimens were placed into the vat after the solution had come to a full and vigorous boil. The boiling temperature of water was calculated to be 210°F (99.6°C) at the altitude of Knoxville, Tennessee with a variant of ± .2°F. Water replenishment was necessary every three to four hours over the duration of the procedure, and care was taken to maintain temperature consistency. At the end of their respective time intervals, the specimens were removed from the vat and manually defleshed of any remaining soft tissue. Each femur was allowed to dry and individually bagged.

The simmering procedure was also completed in groups. Three femora were placed in a thermostat controlled cooking or "crock" pot. The power to the pot was controlled by timer. The temperature was established at 150°F and had a variation of ± 3.5°F. Each specimen was individually bagged and manually defleshed at the completion of its time interval.

The duration of the water baths were varied in an attempt to determine the relationship between time in aqueous solution and the effects to the bone mineral. The intervals were divided into 8 and 24 hour durations. Eight hours appears to be the minimum time that bone material of this size could be

skeletonized to the point of being manually defleshed with little difficulty. Twenty-four hours is the maximum time that the author believes the osseous material could endure boiling without massive structural and morphological destruction. The water bath groups were exposed to the same time intervals regardless of other factors to allow for a one-to-one statistical comparison between groups.

The solutions in the water baths were varied to reflect the most common approaches to this processing method. The two solutions used were tap water and tap water with a bleach additive at a ratio of 1 part bleach to 80 parts of water. Each of the four criteria discussed above were applied to these differing solutions. Explanation for the use of bleach is to degrease the bone and to whiten the specimen for display, comparison or teaching purposes. It was noted that within the groups exposed to bleach, the erosion on micro-landmarks is readily observable.

Scanning

The scanning was performed on a Norland XR-26 Dual Energy X-ray Absorptiometer under the supervision of Dr. David S. Weaver, Ph.D. of Wake Forest University's Department of Anthropology and the Bowman Gray Medical Research Center. The software package used was Norland's scan package version 2.1.

The scanner was calibrated daily with a phantom sample and results were evaluated for deviations.

Each specimen was placed in a standardized position, articulated with the anterior portion facing the source. Specimens were placed on four sheets of $\frac{1}{4}$ inch plexiglass to serve as a tissue equivalent. Any specimen that still had dehydrated soft tissue present was scanned without further processing.

The scans were performed at a speed of 80.0 millimeters per second with a pixal size of 1.5 X 1.5 square millimeters on a general body scan. Sixteen repetitive scans were performed at each scan speed and pixal size on one specimen to determine the variation within the scans and the degree of variation between scanner settings. No appreciable effects could be ascertained between either the various settings or the repetitive scans on the same settings, thus the fastest and more time - efficient setting was selected.

Areas of special interest on the femora were marked on the scanned image and Bone Mineral Content of each area was calculated separately. These areas were the 1) femoral head, 2) condyle region, 3) mid-shaft region, 4) total femur (Figure 3). The purposes for these choices are outline below.

1) The femoral head is an area of high biomechanical stress. Observation of this area would allow for determination of any preferential retention of BMC because of

the density of the cortical bone that surrounds the head and the cartilage that envelopes the structure.

2) The condyle region is both biomechanically stressed and is composed mostly of trabecular bone material. The density of the condyles is the highest of the femora due to the quantity of osseous material exposed to the scanner by measuring the thickness of the condyles in a two-dimensional image. Loss in this region disproportional to areas containing mostly lamellar bone would help support the theory of surface area vulnerability of the trabeculae.

3) The mid-shaft region serves as the bipolar agent to the condyle area. The diaphysis construction is almost entirely of compact bone and thus would provide a strong comparison for the effects that could differ between the two major bone types.

4) The total femur was also calculated to try to gain a holistic view of the effects occurring to the entire osseous system. Results affecting the bone systemically would be visible through this observation.

The area of each of these regions was calculated by the software package available with the Norland scanner and was used to calculate the Bone Mineral Density. Only the pixals activated by a reading of dense material were used for the area calculations. Standards were developed for the placement of regions upon the scanned images. Great effort was

exhibited to try and maintain as rigid control as possible over the placement of these specialized regions (Figure 3).

Each scan was printed out in the form of a data table and a visual representation of the scanned femur. The data was manually read from the printouts and entered into a dBASE III+ file. These files were, in turn, converted into a standard data file and uploaded to the Vax Cluster of the University of Tennessee.

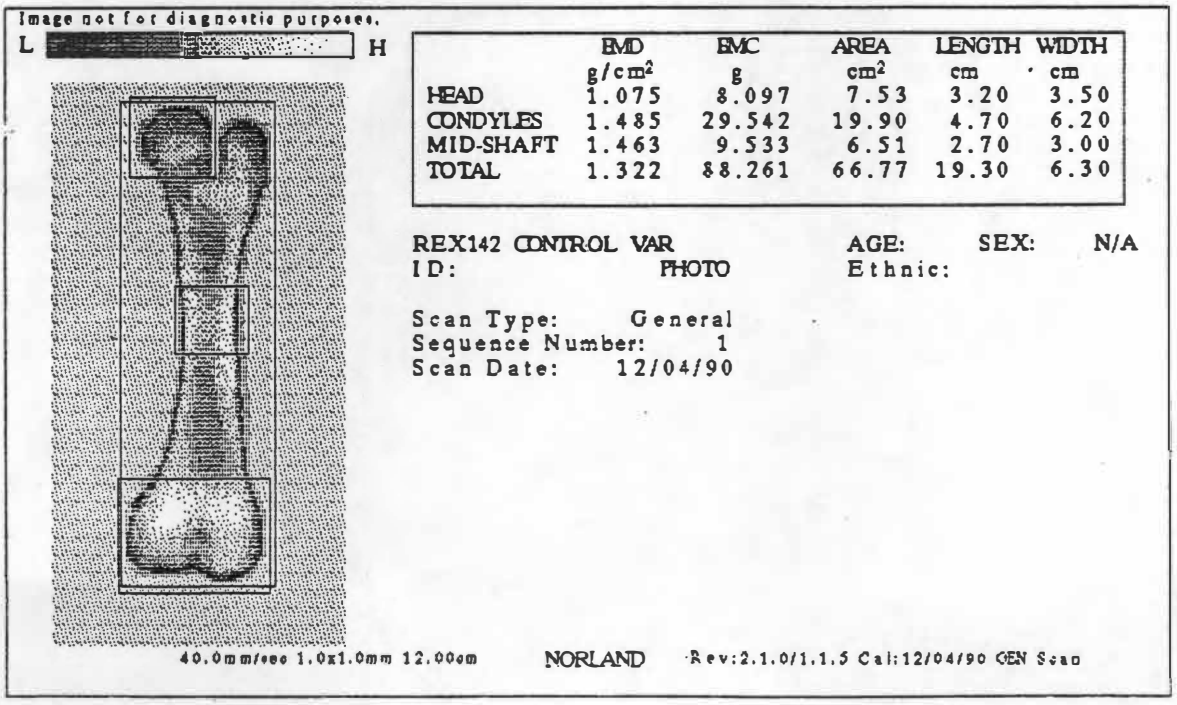


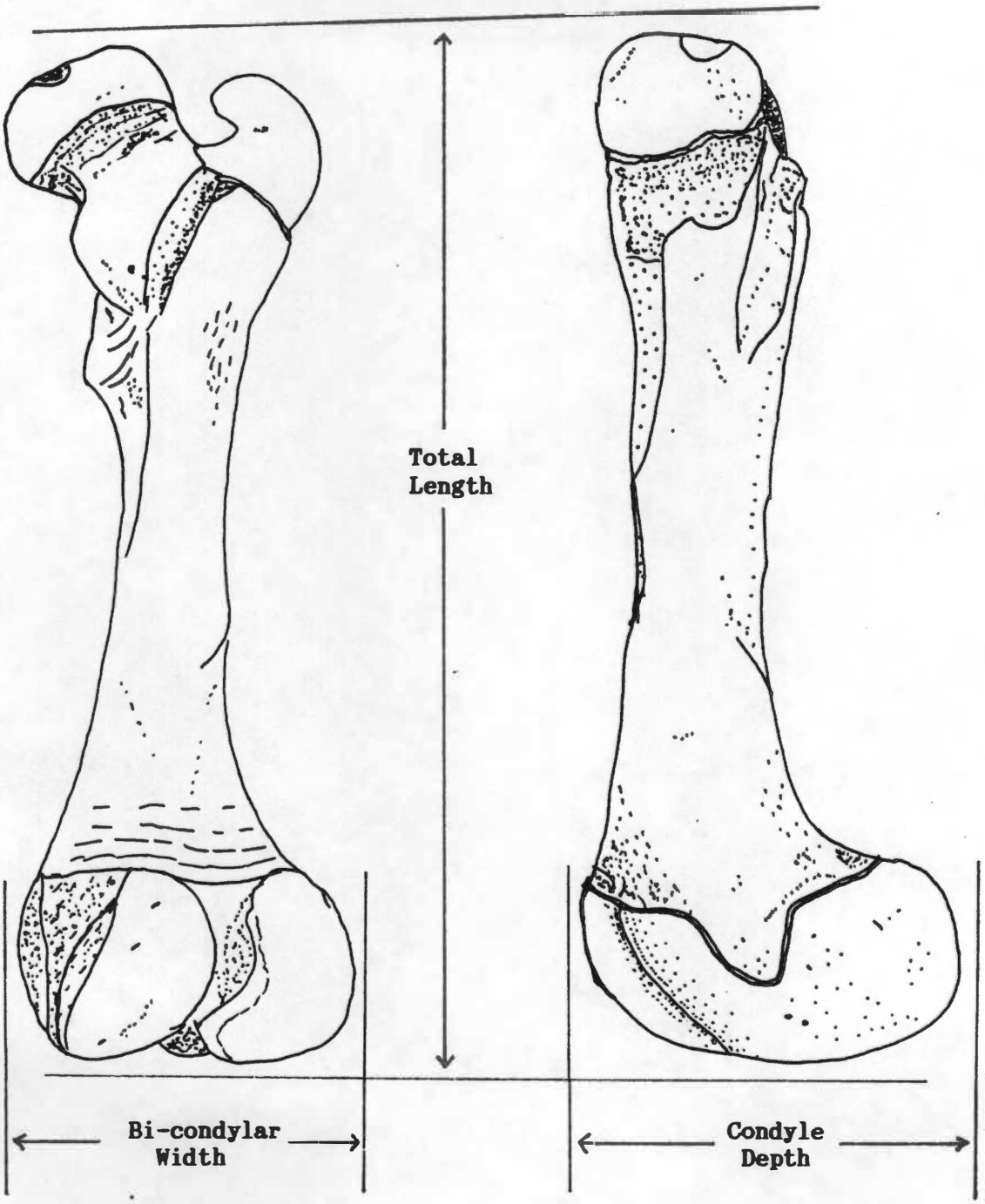
Figure 3. Scanned Image and Region Selection

Each femur was measured to obtain the maximum length, the bicondyle width and the maximum depth measure antero-posteriorly (p.34). The measurements were taken on an osteometric board to the nearest millimeter. All femora were articulated, placing the head, greater trochanter and the condyles in anatomical position, for these measurements. This information was also uploaded onto the Vax Cluster of the University of Tennessee.

4. Statistical Analysis

Once the raw measurements were entered in an S.A.S. text file, additional information regarding each specimen was also entered to allow for a complete evaluation of each process. All specimens having any inconsistencies (e.g. missing data, non-reconstructible condyles, undetected pathologies, etc.) were purged from the collection. This procedure eliminated a large number of the original sample size, reducing the count from 296 to 205 specimens.

Each specimen was measured in three planes (Figure 4). The natural logarithm of each linear measure was calculated as per Jolicoeur (1962, 1963) to reduce the distances between measurement means. Huxley's classic 1932 allometry equation $y = bx^a$ was not capable of accounting for a sufficient quantity of variation within an age-constant population, additional manipulation was necessary. A Principal Component analysis was performed to determine the relative strength and importance of each measurement (Appendix 2). The area measurement from the Norland XR-26 scanner was determined to be redundant and thus eliminated from the Principal Component analysis. The eigenvectors were used to give each measure its appropriate weight in representing the metric relevance of that sample. The proportion of the total variation that each vector represented was used to give each of the three vectors their appropriated consideration in accounting for as much



* All measurements were taken on an osteometric board to the nearest millimeter.

Figure 4. Measurement Standards

variation as possible within each specimen. The author developed the formula (3.1) to describe the robustness of each specimen. With the ability to describe size variation, predictions as to the before processed BMC could be made.

$$\text{Robustness} = \Sigma\ [\delta_1 p_i + \delta_2 p_i + \delta_3 p_i]\ \beta_i \qquad (3.1)$$

Where δ_1 = is Log of the total length

δ_2 = is Log of the bi-condylar width

δ_3 = is Log of the anteroposterior depth

p = the weight of the Eigenvectors

β = the proportion of variation in that Principal Component

$_i$ = the series within the Principal Component analysis

From the above formula, the robustness or size in the form of a single integer could be obtained for every specimen. This evaluation of robustness had a better fit in terms of the residual error (R-square value) than did the First Principal Component alone, however, the amount of variation that was described by the robustness index was less.

A regression fitting all three linear measurements against the total BMC of each specimen lent itself to the most accurate fit of all the regressions attempted (3.3). The linear measurement set versus the total femoral Bone Mineral

Content was used in a general linear regressional model performed upon the control femora to predict the expected BMC value of all the processed specimens. The graph of the relationship between size and Bone Mineral Content proved to be parabolic in nature, thus the quadratic equation shown below was used (3.2).

$$y = b_0 + b_1 x + b_2 x^2 + \epsilon \tag{3.2}$$

And

$$y = b_0 + b_n x_n \ldots + \epsilon \tag{3.3}$$

Where
- y = the total amount of Bone Mineral Content
- b_0 = the intercept of the slope and the y axis
- b_i = the slope
- b_n = the regressional correction
- x = the robustness of the sample
- x_n = the variable interacting with the regressional correction
- ϵ = the amount of error within the model

The results of these regressional formulae were re-entered into the S.A.S. program and used to find the difference between the predicted and the measured quantity of Bone Mineral Content in each processed sample.

Means of the newly sized - corrected densities were calculated and their relative positions to one another were plotted in an attempt to understand the relationship between each process and the fluctuation (both positive and negative) in the total population.

The mean of the residual between the predicted and observed BMC of each processed group was calculated and each set was evaluated to determined if the differences from the unaltered, control group were statistically significant. ANOVAs were preformed at every level, from the simplest, i.e. large groupings of processed verses control to the most complex, i.e. every subgroup and branch within the study (p.39). This allowed for the precise intergroup variation of deviations from the expected BMC to be analyzed. This procedure can be analyzed as the following provided by Zar (1974):

$$F = \frac{\dfrac{SS_t - SS_p}{(m + 1)\ (k - 1)}}{\dfrac{SS_p}{DF_p}} \qquad (3.4)$$

And:

$$DF_p = \sum_{i=1}^{k} n_i - k\,(m + 1) \qquad (3.5)$$

Where: SS_t = The Total Sum of Squares

SS_p = The Pooled Residual Sum of Squares

m = Number of Independent Variables

k = Number of Regressions

DF = Degrees of Freedom

These procedures were performed on the hierarchial levels of the project (Figure 5) to determine the minimum sample size necessary to significantly predict the amount of alteration that would likely occur within each processed group (Appendix 1). When the level of significance was determined ($\alpha = 0.05$), a general linear model was preformed to determine if the angles of the slopes themselves were significantly different. The samples that proved significant were then developed into a regressional formula using the equation stated above. These are the processing methods that not only alter osseous material, but do so in a predictable manner.

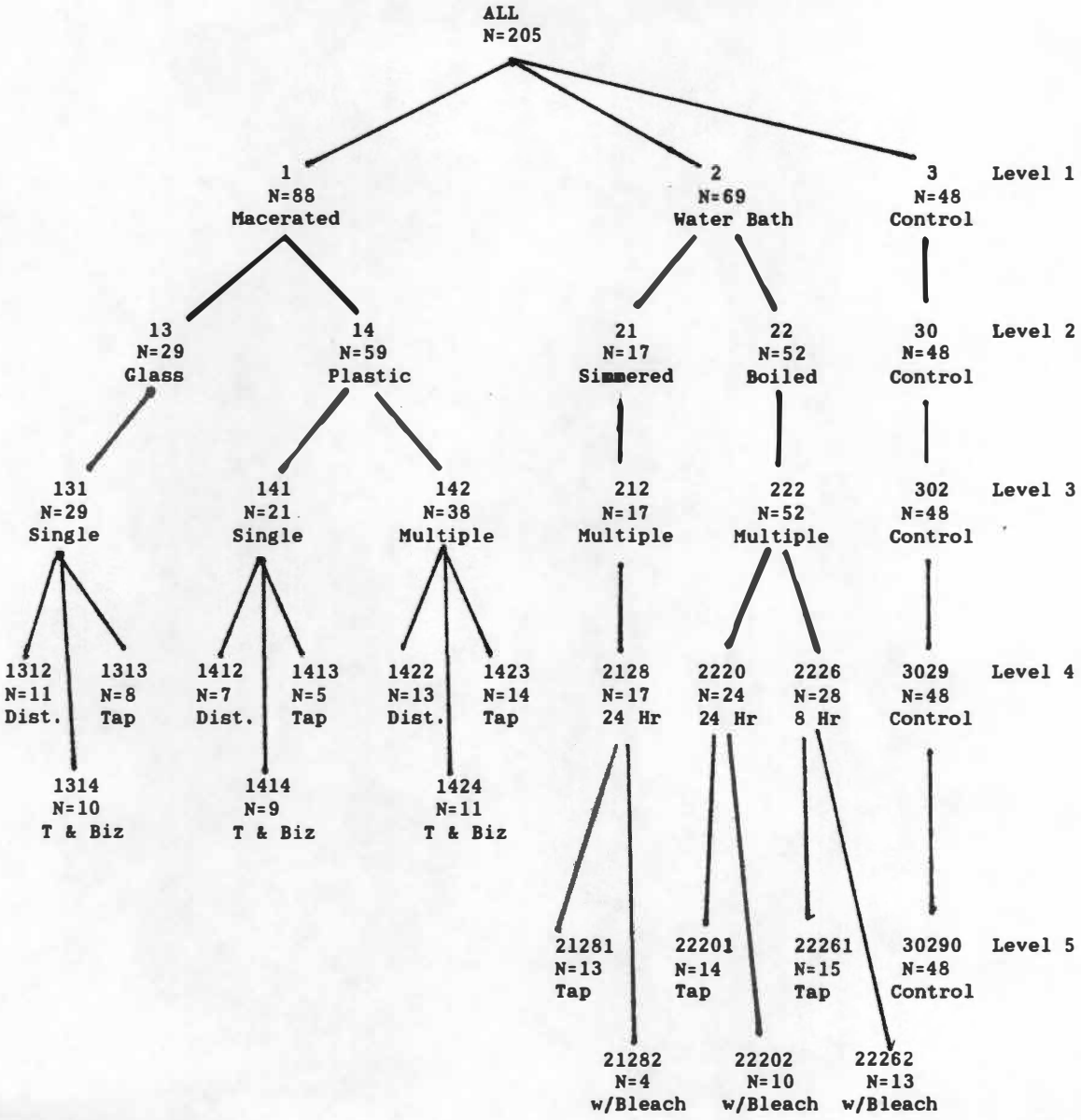


Figure 5. Hierarchial Tree of Processing Techniques

5. Results

Before any assessment of the effects a particular processing technique had on the femora in this study could be evaluated, a scale of the amount of Bone Mineral that was expected within a specimen before it was processed, had to be made. This analysis was accomplished by regressing the First Principal Component of the three linear measurements against the observed Bone Mineral Content (Appendix 2). This relationship proved to be regular and predictable, forming a parabolic interaction depicted in Figure 6.

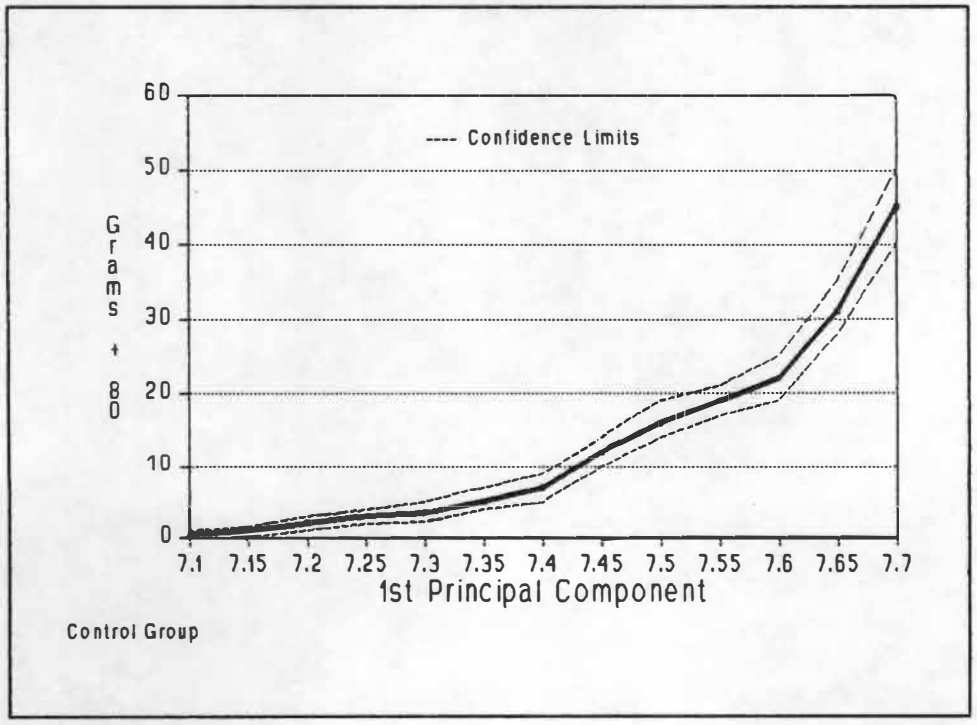


Figure 6. Relationship Between Size and BMC

With this relationship established, the evaluation of the grams of bone mineral loss was simply a process of subtracting the observed BMC from the predicted and analyzing the variation.

Maceration

First, the evaluation of the effects of multiply macerated versus singularly-macerated specimens was performed due to the condition of many of the specimens when retrieved from the multiple - processing containers. In several groups within the Tap & Biz multiply macerated subgroup, there were specimens that were no longer useable (N=15), due to the advanced degree of bone destruction. In 9 cases, the condyle had eroded to the point of consisting only of small sections of cortical bone. All of these cases were unreconstructable. Demineralization had occurred making the condyle region malleable and with the textural consistency of clay (N = 13).

What is remarkable is that when scanned, the multiply macerated group showed a lower degree of BMC loss than their singly macerated counterparts (Figure 7). These results are confounded by several factors. First, as stated above, many of the unreconstructable specimens were purged from the study, thus biasing the sample toward the more stable specimens. The loss of BMC was significant even with these clay-like subjects purged.

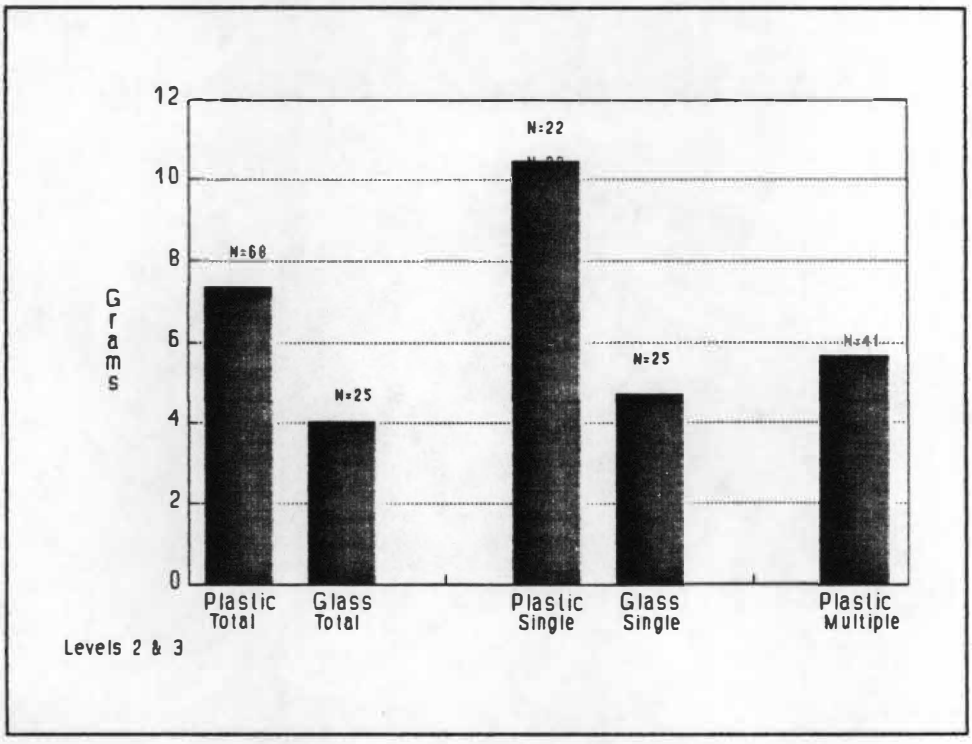


Figure 7. Variation Between Containers - BMC Loss

The second of these considerations is the containers in which the specimens were macerated. Contrary to the theoretical stance posited earlier based on Fletcher's article (1988), the author of this work found just the opposite results. The specimens macerated in plastic containers lost Bone Mineral in quantities nearly twice as high as their glass counterparts. This is especially true of the single macerations (Figure 7). When the average of all plastic to glass containers was calculated, the loss in the plastic

containers was nearly 85% higher than their glass counterparts. The author observed, conversely, the speed of maceration was notably higher in the glass than in the plastic containers.

When the speed of maceration, degree of soft tissue consumed and the time in which the specimen remained in solution were analyzed, an interesting correlation appeared. Specimens that had been in solution only until the consumption of that major portion of the soft tissue, but removed before the breach of the periosteum, had almost no Bone Mineral loss. Those that remained in solution past the completion of maceration and further, until the death of the bacterial colony or beyond, had a much larger mineral loss.

In observing the variations between solutions, the predicted results and reality of the experiment were not extremely synchronous (Figure 8).

In the samples containing distilled water, very little comparative loss in the single, glass containers (less than 2 grams), occurred, whereas in the single, plastic containers the loss was enormous (greater than 16 grams). The samples in single containers had the greatest amount of parity of any of the test subjects and yet the results are, by far, the most dipolar. The multiply macerated, distilled water group also showed the greatest amount of loss with the multiply macerated group. The quickest speed of maceration and the cleanliness of the femora was also best in the distilled water group.

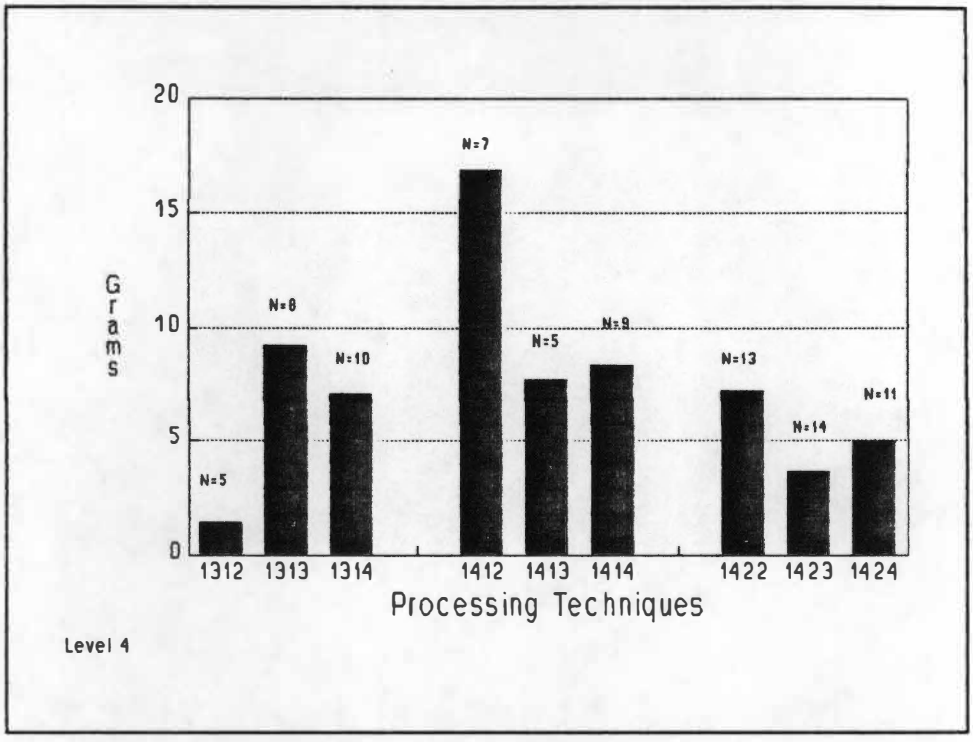


Figure 8. Maceration Loss

The tap water groups had a more uniform performance. There was little disparity between the singly macerated group and a small decline in the multiple group. This loss still follows solidly within the statistically significant range as shown with the ANOVA correlations. The tap water with the enzyme additive (Biz) also showed a more consistent and predictable loss across all macerated groups. Here again, the multiply macerated group appears to be more stable but this data is misleading due to the exclusion of a large group of unusable specimens.

Overall, the maceration techniques significantly lower the Bone Mineral Content, with one exception, of the femora below the limit and range acceptable from forming a baseline for comparison to unknown samples. The degree of loss does follow a mathematically predictable pattern, although, a great many variables must be taken into account to manage such a "correction".

Water Bath

The variation that occurred within the water bath section was much more dynamic than that of the maceration section. The reaction to the water bath treatment by the osseous material is opposite of what the author had intuitively thought. It was suspected that boiling water would be more costly to the overall bone mineral health of the femora than simmering the material. What the results of this project has shown is the simmering of the osseous material in tap water was the most detrimental to the material than any of the water bathing techniques. The author also projected that the exposure to heated water would be detrimental to the mineral content. The increased loss due to duration was borne out and is graphically demonstrated (see Figure 9). This researcher also noted that in one case, the density of the femora actually increased. This simmering group's movements were also plotted and will be discussed briefly and a theory will

be proposed concerning the interactions that could have cause this phenomenon.

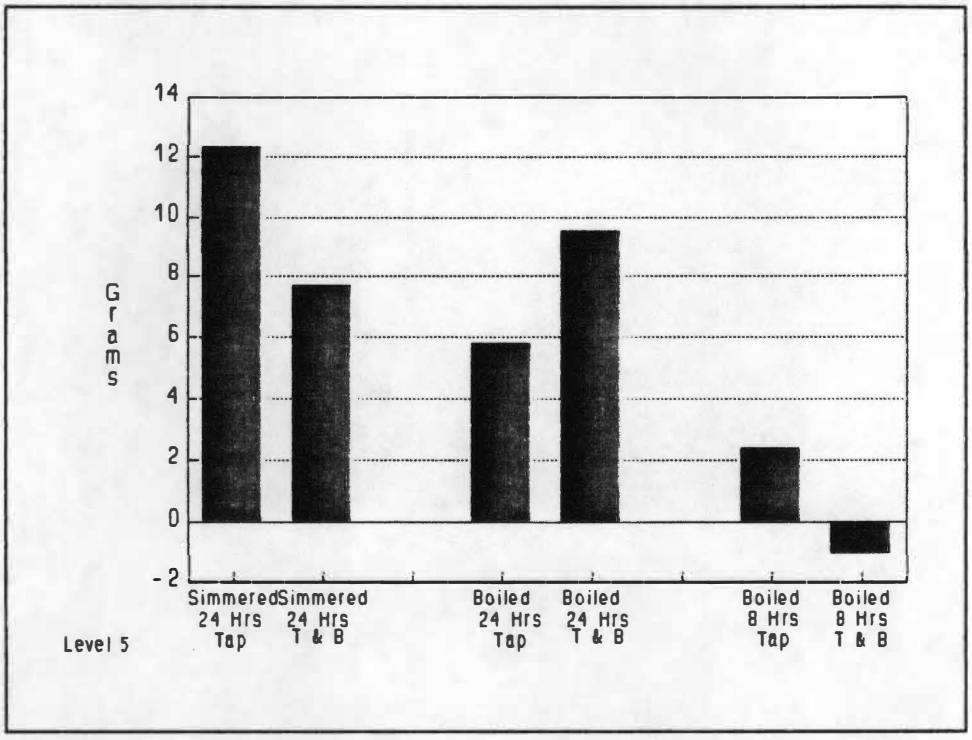


Figure 9. Water Bath Variation

A significant trend was noted showing material exposed to chlorinated bleach increased in density and mass over the predicted value. While several groups of the femora lost bone mineral, this loss was not as great as had been expected. In the case of the boiled, 8 hour samples, the density increased to obtain a mass greater than one would expect from unprocessed material. The author had expected the introduction of a strong oxidizing agent such as bleach to remove from the femora a large quantity of Bone Mineral. Only in the case of the 24 hour, boiled samples did the bleached

specimens exceed their tap water counterparts in the amount of Bone Mineral loss. The author has postulated the following theories for the possible explanation for this unexpected density trend.

In the formula below, the calcium from the osseous material has been sheared from its ionic bonds by heat and the formation of hydrochloric acid and has rebonded into a calcium salt and calcium hydroxide.

$[(Ca)_{10}\ (PO_4)_6\ (OH)_2] + NaOCl + NaCl + H_2O \xrightarrow{HEAT}$ Replacement Reaction

Where

$Ca^{++} \rightarrow Na^{+}$ or
$PO_4^{--} \rightarrow Cl^{-}$, or OCl^{-}

OR

$[(Ca)_{10}\ (PO_4)_6\ (OH)_2] + NaOCl + NaCl + H_2O \xrightarrow{HEAT}$ Precipitation Reaction

Where

$OH^{-} \rightarrow H^{+}$ or
$OH^{-} \rightarrow OCl^{-}$

When

$(Ca)_{10}\ (PO_4)_6\ (OH)_2$ Calcium Hydroxyapatite	Osseous Inorganic Matrix[4]
NaOCl Sodium Hypochloride	Bleaching Material[5] 5.25% of Bleach By Volume
NaCl Salt	Bleaching Material 4% of Bleach by Volume
H_2O Water	Bleaching Material 90.75% of Bleach by Volume

(5.1)

This interaction would do two separate actions that could increase the density of the specimen. First, it would bind calcium that would otherwise be leaving the system and, secondly, by binding into the calcium, it would reduce its quantum energy and allow a lower electron shell to be filled, thus letting the atoms physically get closer together due to this shell contraction. The above theory is conjecture and cannot be verified until mass spectrometry is performed on the sample to detect the quantity of chlorine present. This theory would support the general idea expressed by many professional that bones shrink or distort when placed in water baths.

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[4] As per Sillen, 1989

[5] Formula provided by Clorox Bleach's Customer Service office.

When one evaluates the effects of water baths versus other processes, it becomes clear that either tap water or chlorinated bleach and tap water baths cause a great deal of damage to the osseous material. What makes this particularly enlightening is that the vectors and quantity of the alterations are multidirectional. In all cases, the change in the material was significantly different from the expected Bone Mineral Content for femora of that size.

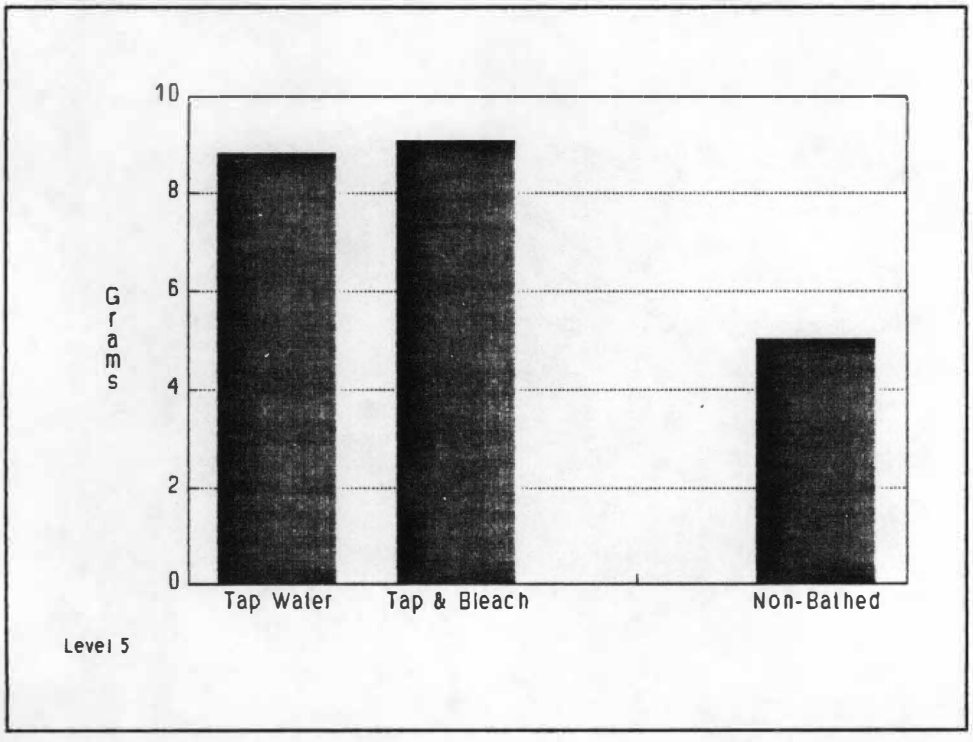

Figure 10. Variation in Water Types

Specimen	Head Density	Condyle Density	Mid-shaft Density	Total Density	Total BMC	Size
13120	1.172	1.457	1.200	1.298	103.949	7.55
13130	1.045	1.376	1.062	1.169	85.594	7.46
13140	1.077	1.407	1.149	1.235	89.159	7.48
14120	0.942	1.268	1.006	1.077	84.506	7.53
14130	1.037	1.357	1.078	1.158	83.772	7.41
14140	1.071	1.397	1.171	1.211	91.385	7.50
14220	1.078	1.381	1.146	1.207	88.054	7.47
14230	1.107	1.373	1.176	1.226	91.441	7.48
14240	1.099	1.288	1.161	1.211	86.947	7.44
21281	1.023	1.345	1.145	1.207	84.498	7.45
21282	1.106	1.435	1.200	1.222	94.024	7.53
22201	1.094	1.319	1.201	1.209	90.828	7.48
22202	1.060	1.323	1.202	1.193	85.141	7.45
22261	1.131	1.444	1.216	1.263	92.104	7.45
22262	1.170	1.520	1.325	1.319	100.469	7.49
Controls	1.131	1.453	1.267	1.277	93.806	7.46

Figure 11. Means of Level 5 Density Values

In designing this project, one of the basic tenets was to assess the effects of the processes on varies types of bone material. Above are the means of the density for all four areas examined in depth by this project (Figure 11).

As is shown above, various techniques effect various parts of the femora in different ways and to differing degrees. The percent of loss suffered by the head region in the single, plastic maceration and the simmered water bath demonstrates how similar effects can occur from widely different techniques (Figure 12).

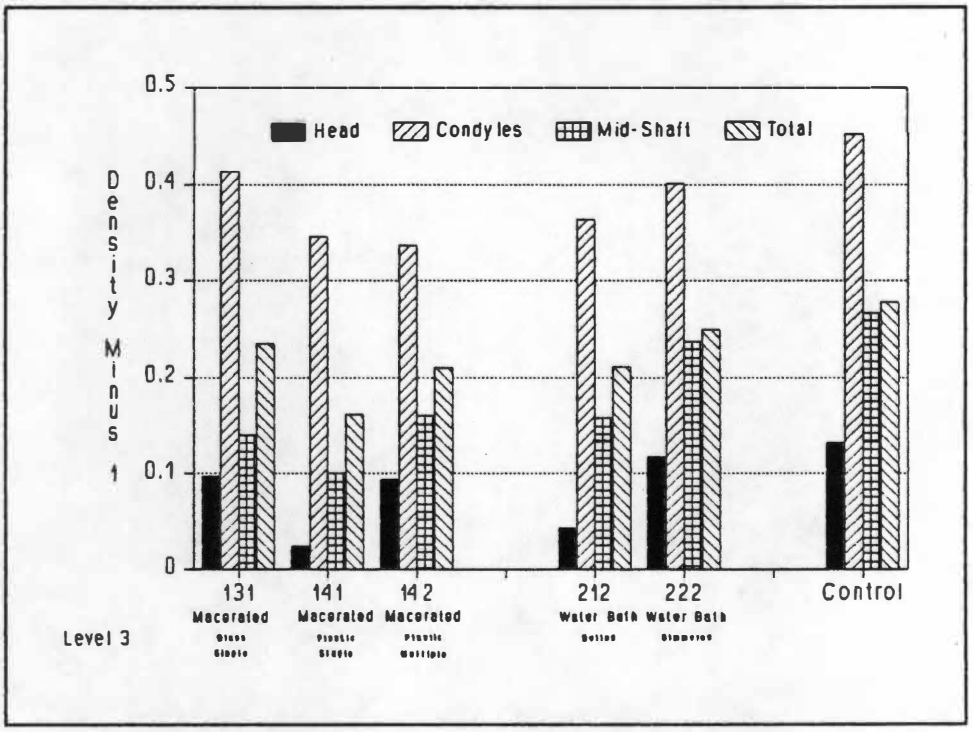

Figure 12. Differential Bone Types

The effects of these processes on various femoral regions serve to show how various bone types (i.e. trabecular and compact) respond to emersion in water. An attempt to ascertain some meaning from all of this data will be made in the following section.

6. Conclusion

Physical anthropologists and biologist are to be commended for the foresight and intuition to develop large scale collections of remains for the purpose of comparison, and metric analysis as well as for teaching aids. These collections have provided our clearest looks yet in to the murky past of human health, activity patterns and diet. But as the march of technology continues forward, so must the view that we take as to the appropriateness of our specimens and the techniques used to acquire them.

This study has focused on the alterations of bone when processed in aqueous solution. The author finds the process of immersing bone in aqueous as an unacceptable manner to process osseous materials. When bone is processed by insects, within a sheltered environment, the loss of inorganic material is almost non-existent. This study has shown that the use of water in almost every case, has caused an alteration in the baseline of the Bone Mineral Content.

In the case of macerating material, differing effects occur based upon the type of solution, the container, the ratio of osseous material to solution, and the duration of the processing. Of these variables, the most profound and easily remedied alteration is the long-term emersion, well past the point at which the periosteum has been breached, thus exposing

the matrix to the detrimental effects of the solution-matrix interaction.

In water baths, the effects are as dramatic and much more dynamic in nature. While heated tap water has the effect of stripping away calcium and phosphates from the matrix crystals, the addition of bleach to the solution causes a reaction totally unpredicted. The increases in expected density shown by the bleached femora indicated a yet inexplicable reaction that causes the inorganic minerals to be captured in an unknown configuration, increasing the overall density.

The importance of this study is that it has shown that the manner in which a specimen was skeletonized has a profound effect on the amount of bone matrix that survives. If the skeletons that our disciplines have collected for years are altered before we start our analysis, our conclusions are doomed to suffer, at the very least, that margin of error. If we can understand the effects of procurement and processing within these collections, we can 1) avoid complications in the future and 2) try to correct for alterations already introduced in our studies.

The author hopes this work will provide some insights into the effects we may have inadvertently imposed upon ourselves, thus serving as a cautionary note to all those who will be processing remains in the future and conducting studies based upon those remains.

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Literature Cited

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Appendices

Appendix 1

The following data are the raw scores that have been calculated on the differences between the observed total Bone Mineral Content and the expected BMC value. This model uses the regressional equation incorporating the three linear measurements and the type of processing against the differences in BMC observations.

The data below can be viewed as a two-tailed ANOVA that tests the statistical differences between groups of unequal size.

Tukey's Studentized Range (HSD)

Alpha= 0.05 Confidence= 0.95 df= 199 MSE= 79.88124
Critical Value of Studentized Range= 3.340

Comparisons significant at the 0.05 level are indicated by '***'.

LEVEL 1 Comparison		Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1	- 2	8.668	12.062	15.455	***
1	- 3	36.070	39.857	43.644	***
2	- 1	-15.455	-12.062	-8.668	***
2	- 3	23.829	27.796	31.762	***
3	- 1	-43.644	-39.857	-36.070	***
3	- 2	-31.762	-27.796	-23.829	***

Tukey's Studentized Range (HSD)

Alpha= 0.05 Confidence= 0.95 df= 197 MSE= 77.62447
Critical Value of Studentized Range= 3.894

Comparisons significant at the 0.05 level are indicated by '***'.

LEVEL 2 Comparison		Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
13	- 14	5.924	11.658	17.392	***
13	- 21	5.780	13.405	21.031	***
13	- 22	16.793	22.697	28.600	***
13	- 30	42.220	48.203	54.186	***
14	- 13	-17.392	-11.658	-5.924	***
14	- 21	-4.882	1.747	8.377	
14	- 22	6.494	11.039	15.584	***
14	- 30	31.898	36.545	41.193	***
21	- 13	-21.031	-13.405	-5.780	***
21	- 14	-8.377	-1.747	4.882	
21	- 22	2.515	9.292	16.069	***
21	- 30	27.952	34.798	41.644	***
22	- 13	-28.600	-22.697	-16.793	***
22	- 14	-15.584	-11.039	-6.494	***
22	- 21	-16.069	-9.292	-2.515	***
22	- 30	20.651	25.506	30.362	***
30	- 13	-54.186	-48.203	-42.220	***
30	- 14	-41.193	-36.545	-31.898	***
30	- 21	-41.644	-34.798	-27.952	***
30	- 22	-30.362	-25.506	-20.651	***

Tukey's Studentized Range (HSD)

Alpha= 0.05 Confidence= 0.95 df= 196 MSE= 77.14179
Critical Value of Studentized Range= 4.070

Comparisons significant at the 0.05 level
are indicated by '***'.

LEVEL 3 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
141 - 131	0.970	8.360	15.749	***
141 - 212	13.602	21.765	29.928	***
141 - 142	24.078	30.759	37.440	***
141 - 222	24.627	31.057	37.486	***
141 - 302	50.055	56.563	63.071	***
131 - 141	-15.749	-8.360	-0.970	***
131 - 212	5.459	13.405	21.352	***
131 - 142	15.985	22.399	28.814	***
131 - 222	16.545	22.697	28.849	***
131 - 302	41.969	48.203	54.438	***
212 - 141	-29.928	-21.765	-13.602	***
212 - 131	-21.352	-13.405	-5.459	***
212 - 142	1.702	8.994	16.286	***
212 - 222	2.229	9.292	16.354	***
212 - 302	27.664	34.798	41.932	***
142 - 141	-37.440	-30.759	-24.078	***
142 - 131	-28.814	-22.399	-15.985	***
142 - 212	-16.286	-8.994	-1.702	***
142 - 222	-4.982	0.298	5.577	
142 - 302	20.428	25.804	31.180	***
222 - 141	-37.486	-31.057	-24.627	***
222 - 131	-28.849	-22.697	-16.545	***
222 - 212	-16.354	-9.292	-2.229	***
222 - 142	-5.577	-0.298	4.982	
222 - 302	20.447	25.506	30.566	***
302 - 141	-63.071	-56.563	-50.055	***
302 - 131	-54.438	-48.203	-41.969	***
302 - 212	-41.932	-34.798	-27.664	***
302 - 142	-31.180	-25.804	-20.428	***
302 - 222	-30.566	-25.506	-20.447	***

Tukey's Studentized Range (HSD)

Alpha= 0.05 Confidence= 0.95 df= 186 MSE= 68.14161
Critical Value of Studentized Range= 4.913

Comparisons significant at the 0.05 level
are indicated by '***'.

LEVEL 4 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1312 - 1412	-5.223	11.568	28.358	
1312 - 1414	57.774	73.768	89.762	***
1312 - 1421	55.004	75.946	96.887	***
1312 - 1423	100.543	115.483	130.422	***
1312 - 1314	100.683	116.389	132.095	***
1312 - 2128	111.181	125.769	140.357	***
1312 - 1422	117.799	132.889	147.979	***
1312 - 2220	119.896	133.993	148.089	***
1312 - 2226	122.054	135.976	149.897	***
1312 - 1313	138.801	155.149	171.496	***
1312 - 3029	147.092	160.567	174.042	***
1312 - 1424	162.091	177.557	193.023	***
1312 - 1311	178.012	202.003	225.994	***
1312 - 1413	238.969	257.104	275.240	***
1312 - 1411	226.261	257.673	289.085	***
1412 - 1312	-28.358	-11.568	5.223	
1412 - 1414	47.750	62.200	76.651	***
1412 - 1421	44.590	64.378	84.165	***
1412 - 1423	90.641	103.915	117.189	***
1412 - 1314	90.690	104.821	118.953	***
1412 - 2128	101.323	114.201	127.079	***
1412 - 1422	107.878	121.321	134.764	***
1412 - 2220	110.107	122.425	134.743	***
1412 - 2226	112.290	124.408	136.525	***
1412 - 1313	128.740	143.581	158.421	***
1412 - 3029	137.398	148.999	160.601	***
1412 - 1424	152.125	165.989	179.853	***
1412 - 1311	167.444	190.435	213.426	***
1412 - 1413	228.746	245.537	262.327	***
1412 - 1411	215.451	246.105	276.760	***
1414 - 1312	-89.762	-73.768	-57.774	***
1414 - 1412	-76.651	-62.200	-47.750	***
1414 - 1421	-16.939	2.178	21.294	
1414 - 1423	29.463	41.715	53.966	***
1414 - 1314	29.446	42.621	55.796	***
1414 - 2128	40.180	52.001	63.821	***
1414 - 1422	46.687	59.121	71.555	***
1414 - 2220	49.016	60.225	71.433	***

LEVEL 4 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1414 - 2226	51.220	62.207	73.195	***
1414 - 1313	67.447	81.380	95.314	***
1414 - 3029	76.383	86.799	97.215	***
1414 - 1424	90.900	103.789	116.677	***
1414 - 1311	105.819	128.235	150.651	***
1414 - 1413	167.342	183.336	199.330	***
1414 - 1411	153.679	183.905	214.131	***
1421 - 1312	-96.887	-75.946	-55.004	***
1421 - 1412	-84.165	-64.378	-44.590	***
1421 - 1414	-21.294	-2.178	16.939	
1421 - 1423	21.294	39.537	57.780	***
1421 - 1314	21.567	40.444	59.320	***
1421 - 2128	31.866	49.823	67.780	***
1421 - 1422	38.577	56.943	75.310	***
1421 - 2220	40.487	58.047	75.607	***
1421 - 2226	42.610	60.030	77.450	***
1421 - 1313	59.790	79.203	98.616	***
1421 - 3029	67.556	84.621	101.686	***
1421 - 1424	82.934	101.611	120.288	***
1421 - 1311	99.881	126.057	152.234	***
1421 - 1413	160.218	181.159	202.100	***
1421 - 1411	148.617	181.728	214.838	***
1423 - 1312	-130.422	-115.483	-100.543	***
1423 - 1412	-117.189	-103.915	-90.641	***
1423 - 1414	-53.966	-41.715	-29.463	***
1423 - 1421	-57.780	-39.537	-21.294	***
1423 - 1314	-10.966	0.906	12.779	
1423 - 2128	-0.063	10.286	20.635	
1423 - 1422	6.362	17.406	28.451	***
1423 - 2220	8.867	18.510	28.153	***
1423 - 2226	11.107	20.493	29.879	***
1423 - 1313	26.957	39.666	52.375	***
1423 - 3029	36.374	45.084	53.794	***
1423 - 1424	50.521	62.074	73.628	***
1423 - 1311	64.844	86.520	108.197	***
1423 - 1413	126.683	141.622	156.561	***
1423 - 1411	112.509	142.190	171.872	***
1314 - 1312	-132.095	-116.389	-100.683	***
1314 - 1412	-118.953	-104.821	-90.690	***
1314 - 1414	-55.796	-42.621	-29.446	***
1314 - 1421	-59.320	-40.444	-21.567	***
1314 - 1423	-12.779	-0.906	10.966	
1314 - 2128	-2.048	9.380	20.807	
1314 - 1422	4.438	16.500	28.561	***

LEVEL 4 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1314 - 2220	6.811	17.603	28.396	***
1314 - 2226	9.023	19.586	30.150	***
1314 - 1313	25.158	38.759	52.361	***
1314 - 3029	34.210	44.178	54.145	***
1314 - 1424	48.639	61.168	73.697	***
1314 - 1311	63.402	85.614	107.825	***
1314 - 1413	125.009	140.715	156.421	***
1314 - 1411	111.209	141.284	171.358	***
2128 - 1312	-140.357	-125.769	-111.181	***
2128 - 1412	-127.079	-114.201	-101.323	***
2128 - 1414	-63.821	-52.001	-40.180	***
2128 - 1421	-67.780	-49.823	-31.866	***
2128 - 1423	-20.635	-10.286	0.063	
2128 - 1314	-20.807	-9.380	2.048	
2128 - 1422	-3.445	7.120	17.685	
2128 - 2220	-0.866	8.224	17.314	
2128 - 2226	1.390	10.207	19.023	***
2128 - 1313	17.086	29.380	41.674	***
2128 - 3029	26.705	34.798	42.891	***
2128 - 1424	40.692	51.788	62.884	***
2128 - 1311	54.799	76.234	97.670	***
2128 - 1413	116.747	131.336	145.924	***
2128 - 1411	102.398	131.904	161.411	***
1422 - 1312	-147.979	-132.889	-117.799	***
1422 - 1412	-134.764	-121.321	-107.878	***
1422 - 1414	-71.555	-59.121	-46.687	***
1422 - 1421	-75.310	-56.943	-38.577	***
1422 - 1423	-28.451	-17.406	-6.362	***
1422 - 1314	-28.561	-16.500	-4.438	***
1422 - 2128	-17.685	-7.120	3.445	
1422 - 2220	-8.771	1.104	10.979	
1422 - 2226	-6.537	3.087	12.710	
1422 - 1313	9.374	22.260	35.145	***
1422 - 3029	18.712	27.678	36.643	***
1422 - 1424	32.921	44.668	56.415	***
1422 - 1311	47.334	69.114	90.894	***
1422 - 1413	109.126	124.216	139.305	***
1422 - 1411	95.027	124.784	154.542	***
2220 - 1312	-148.089	-133.993	-119.896	***
2220 - 1412	-134.743	-122.425	-110.107	***
2220 - 1414	-71.433	-60.225	-49.016	***
2220 - 1421	-75.607	-58.047	-40.487	***
2220 - 1423	-28.153	-18.510	-8.867	***
2220 - 1314	-28.396	-17.603	-6.811	***

LEVEL 4 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
2220 - 2128	-17.314	-8.224	0.866	
2220 - 1422	-10.979	-1.104	8.771	
2220 - 2226	-5.994	1.983	9.959	
2220 - 1313	9.449	21.156	32.862	***
2220 - 3029	19.405	26.574	33.743	***
2220 - 1424	33.123	43.564	54.005	***
2220 - 1311	46.906	68.010	89.115	***
2220 - 1413	109.015	123.112	137.208	***
2220 - 1411	94.414	123.680	152.947	***
2226 - 1312	-149.897	-135.976	-122.054	***
2226 - 1412	-136.525	-124.408	-112.290	***
2226 - 1414	-73.195	-62.207	-51.220	***
2226 - 1421	-77.450	-60.030	-42.610	***
2226 - 1423	-29.879	-20.493	-11.107	***
2226 - 1314	-30.150	-19.586	-9.023	***
2226 - 2128	-19.023	-10.207	-1.390	***
2226 - 1422	-12.710	-3.087	6.537	
2226 - 2220	-9.959	-1.983	5.994	
2226 - 1313	7.678	19.173	30.669	***
2226 - 3029	17.772	24.591	31.410	***
2226 - 1424	31.378	41.581	51.785	***
2226 - 1311	45.040	66.028	87.015	***
2226 - 1413	107.207	121.129	135.051	***
2226 - 1411	92.515	121.698	150.880	***
1313 - 1312	-171.496	-155.149	-138.801	***
1313 - 1412	-158.421	-143.581	-128.740	***
1313 - 1414	-95.314	-81.380	-67.447	***
1313 - 1421	-98.616	-79.203	-59.790	***
1313 - 1423	-52.375	-39.666	-26.957	***
1313 - 1314	-52.361	-38.759	-25.158	***
1313 - 2128	-41.674	-29.380	-17.086	***
1313 - 1422	-35.145	-22.260	-9.374	***
1313 - 2220	-32.862	-21.156	-9.449	***
1313 - 2226	-30.669	-19.173	-7.678	***
1313 - 3029	-5.532	5.418	16.369	
1313 - 1424	9.084	22.408	35.732	***
1313 - 1311	24.185	46.854	69.524	***
1313 - 1413	85.609	101.956	118.303	***
1313 - 1411	72.110	102.525	132.939	***
3029 - 1312	-174.042	-160.567	-147.092	***
3029 - 1412	-160.601	-148.999	-137.398	***
3029 - 1414	-97.215	-86.799	-76.383	***
3029 - 1421	-101.686	-84.621	-67.556	***
3029 - 1423	-53.794	-45.084	-36.374	***
3029 - 1314	-54.145	-44.178	-34.210	***
3029 - 2128	-42.891	-34.798	-26.705	***
3029 - 1422	-36.643	-27.678	-18.712	***
3029 - 2220	-33.743	-26.574	-19.405	***
3029 - 2226	-31.410	-24.591	-17.772	***
3029 - 1313	-16.369	-5.418	5.532	
3029 - 1424	7.405	16.990	26.575	***
3029 - 1311	20.742	41.436	62.131	***
3029 - 1413	83.063	96.538	110.013	***
3029 - 1411	68.134	97.106	126.078	***
1424 - 1312	-193.023	-177.557	-162.091	***
1424 - 1412	-179.853	-165.989	-152.125	***
1424 - 1414	-116.677	-103.789	-90.900	***
1424 - 1421	-120.288	-101.611	-82.934	***
1424 - 1423	-73.628	-62.074	-50.521	***
1424 - 1314	-73.697	-61.168	-48.639	***
1424 - 2128	-62.884	-51.788	-40.692	***
1424 - 1422	-56.415	-44.668	-32.921	***
1424 - 2220	-54.005	-43.564	-33.123	***
1424 - 2226	-51.785	-41.581	-31.378	***
1424 - 1313	-35.732	-22.408	-9.084	***
1424 - 3029	-26.575	-16.990	-7.405	***
1424 - 1311	2.404	24.446	46.489	***
1424 - 1413	64.082	79.548	95.014	***
1424 - 1411	50.166	80.116	110.066	***
1311 - 1312	-225.994	-202.003	-178.012	***
1311 - 1412	-213.426	-190.435	-167.444	***
1311 - 1414	-150.651	-128.235	-105.819	***
1311 - 1421	-152.234	-126.057	-99.881	***
1311 - 1423	-108.197	-86.520	-64.844	***
1311 - 1314	-107.825	-85.614	-63.402	***
1311 - 2128	-97.670	-76.234	-54.799	***
1311 - 1422	-90.894	-69.114	-47.334	***
1311 - 2220	-89.115	-68.010	-46.906	***
1311 - 2226	-87.015	-66.028	-45.040	***
1311 - 1313	-69.524	-46.854	-24.185	***
1311 - 3029	-62.131	-41.436	-20.742	***
1311 - 1424	-46.489	-24.446	-2.404	***
1311 - 1413	31.110	55.101	79.093	***
1311 - 1411	20.551	55.670	90.789	***
1413 - 1312	-275.240	-257.104	-238.969	***
1413 - 1412	-262.327	-245.537	-228.746	***
1413 - 1414	-199.330	-183.336	-167.342	***
1413 - 1421	-202.100	-181.159	-160.218	***

LEVEL 4 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1413 - 1423	-156.561	-141.622	-126.683	***
1413 - 1314	-156.421	-140.715	-125.009	***
1413 - 2128	-145.924	-131.336	-116.747	***
1413 - 1422	-139.305	-124.216	-109.126	***
1413 - 2220	-137.208	-123.112	-109.015	***
1413 - 2226	-135.051	-121.129	-107.207	***
1413 - 1313	-118.303	-101.956	-85.609	***
1413 - 3029	-110.013	-96.538	-83.063	***
1413 - 1424	-95.014	-79.548	-64.082	***
1413 - 1311	-79.093	-55.101	-31.110	***
1413 - 1411	-30.843	0.569	31.980	
1411 - 1312	-289.085	-257.673	-226.261	***
1411 - 1412	-276.760	-246.105	-215.451	***
1411 - 1414	-214.131	-183.905	-153.679	***
1411 - 1421	-214.838	-181.728	-148.617	***
1411 - 1423	-171.872	-142.190	-112.509	***
1411 - 1314	-171.358	-141.284	-111.209	***
1411 - 2128	-161.411	-131.904	-102.398	***
1411 - 1422	-154.542	-124.784	-95.027	***
1411 - 2220	-152.947	-123.680	-94.414	***
1411 - 2226	-150.880	-121.698	-92.515	***
1411 - 1313	-132.939	-102.525	-72.110	***
1411 - 3029	-126.078	-97.106	-68.134	***
1411 - 1424	-110.066	-80.116	-50.166	***
1411 - 1311	-90.789	-55.670	-20.551	***
1411 - 1413	-31.980	-0.569	30.843	

Tukey's Studentized Range (HSD)

Alpha= 0.05 Confidence= 0.95 df= 183 MSE= 68.89892
Critical Value of Studentized Range= 5.047

Comparisons significant at the 0.05 level are indicated by '***'.

LEVEL 5 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
13120 - 14120	-5.779	11.568	28.914	
13120 - 21282	-0.197	19.676	39.549	
13120 - 14140	57.244	73.768	90.292	***
13120 - 14210	54.311	75.946	97.580	***
13120 - 22262	79.307	94.896	110.486	***
13120 - 22201	96.499	111.933	127.367	***
13120 - 14230	100.049	115.483	130.917	***
13120 - 13140	100.163	116.389	132.615	***
13120 - 14220	117.299	132.889	148.478	***
13120 - 13130	138.260	155.149	172.037	***
13120 - 21281	142.823	158.413	174.002	***
13120 - 30290	146.645	160.567	174.488	***
13120 - 22202	148.650	164.876	181.102	***
13120 - 22261	156.279	171.577	186.875	***
13120 - 14240	161.579	177.557	193.535	***
13120 - 13110	177.218	202.003	226.789	***
13120 - 14130	238.368	257.104	275.841	***
13120 - 14110	225.221	257.673	290.125	***
14120 - 13120	-28.914	-11.568	5.779	
14120 - 21282	-10.460	8.108	26.676	
14120 - 14140	47.271	62.200	77.130	***
14120 - 14210	43.935	64.378	84.821	***
14120 - 22262	69.441	83.329	97.217	***
14120 - 22201	86.652	100.366	114.079	***
14120 - 14230	90.202	103.915	117.628	***
14120 - 13140	90.222	104.821	119.421	***
14120 - 14220	107.433	121.321	135.209	***
14120 - 13130	128.249	143.581	158.913	***
14120 - 21281	132.957	146.845	160.733	***
14120 - 30290	137.013	148.999	160.985	***
14120 - 22202	138.709	153.308	167.907	***
14120 - 22261	146.449	160.010	173.570	***
14120 - 14240	151.666	165.989	180.312	***
14120 - 13110	166.683	190.435	214.188	***
14120 - 14130	228.191	245.537	262.883	***
14120 - 14110	214.436	246.105	277.775	***
21282 - 13120	-39.549	-19.676	0.197	
21282 - 14120	-26.676	-8.108	10.460	

LEVEL 5 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
21282 - 14140	36.290	54.092	71.894	***
21282 - 14210	33.644	56.270	78.896	***
21282 - 22262	58.282	75.221	92.159	***
21282 - 22201	75.462	92.257	109.053	***
21282 - 14230	79.011	95.807	112.602	***
21282 - 13140	79.187	96.713	114.239	***
21282 - 14220	96.275	113.213	130.151	***
21282 - 13130	117.331	135.473	153.614	***
21282 - 21281	121.798	138.737	155.675	***
21282 - 30290	125.474	140.891	156.308	***
21282 - 22202	127.674	145.200	162.726	***
21282 - 22261	135.231	151.901	168.572	***
21282 - 14240	140.584	157.881	175.178	***
21282 - 13110	156.672	182.327	207.983	***
21282 - 14130	217.556	237.429	257.301	***
21282 - 14110	204.876	237.997	271.118	***
14140 - 13120	-90.292	-73.768	-57.244	***
14140 - 14120	-77.130	-62.200	-47.271	***
14140 - 21282	-71.894	-54.092	-36.290	***
14140 - 14210	-17.572	2.178	21.927	
14140 - 22262	8.282	21.128	33.974	***
14140 - 22201	25.508	38.165	50.822	***
14140 - 14230	29.058	41.715	54.372	***
14140 - 13140	29.010	42.621	56.233	***
14140 - 14220	46.275	59.121	71.967	***
14140 - 13130	66.986	81.380	95.775	***
14140 - 21281	71.799	84.645	97.491	***
14140 - 30290	76.038	86.799	97.560	***
14140 - 22202	77.496	91.108	104.719	***
14140 - 22261	85.319	97.809	110.300	***
14140 - 14240	90.474	103.789	117.104	***
14140 - 13110	105.077	128.235	151.393	***
14140 - 14130	166.813	183.336	199.860	***
14140 - 14110	152.678	183.905	215.132	***
14210 - 13120	-97.580	-75.946	-54.311	***
14210 - 14120	-84.821	-64.378	-43.935	***
14210 - 21282	-78.896	-56.270	-33.644	***
14210 - 14140	-21.927	-2.178	17.572	
14210 - 22262	-0.024	18.951	37.926	
14210 - 22201	17.140	35.988	54.835	***
14210 - 14230	20.690	39.537	58.384	***
14210 - 13140	20.942	40.444	59.945	***
14210 - 14220	37.968	56.943	75.918	***
14210 - 13130	59.147	79.203	99.259	***
14210 - 21281	63.492	82.467	101.442	***

LEVEL 5 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
14210 - 30290	66.991	84.621	102.251	***
14210 - 22202	69.429	88.930	108.431	***
14210 - 22261	76.896	95.632	114.368	***
14210 - 14240	82.316	101.611	120.907	***
14210 - 13110	99.014	126.057	153.101	***
14210 - 14130	159.524	181.159	202.793	***
14210 - 14110	147.520	181.728	215.935	***
22262 - 13120	-110.486	-94.896	-79.307	***
22262 - 14120	-97.217	-83.329	-69.441	***
22262 - 21282	-92.159	-75.221	-58.282	***
22262 - 14140	-33.974	-21.128	-8.282	***
22262 - 14210	-37.926	-18.951	0.024	
22262 - 22201	5.627	17.037	28.447	***
22262 - 14230	9.176	20.586	31.996	***
22262 - 13140	9.032	21.493	33.953	***
22262 - 14220	26.373	37.992	49.612	***
22262 - 13130	46.940	60.252	73.564	***
22262 - 21281	51.897	63.516	75.136	***
22262 - 30290	56.408	65.670	74.933	***
22262 - 22202	57.519	69.979	82.440	***
22262 - 22261	65.455	76.681	87.906	***
22262 - 14240	70.524	82.660	94.797	***
22262 - 13110	84.605	107.107	129.608	***
22262 - 14130	146.619	162.208	177.797	***
22262 - 14110	132.034	162.777	193.519	***
22201 - 13120	-127.367	-111.933	-96.499	***
22201 - 14120	-114.079	-100.366	-86.652	***
22201 - 21282	-109.053	-92.257	-75.462	***
22201 - 14140	-50.822	-38.165	-25.508	***
22201 - 14210	-54.835	-35.988	-17.140	***
22201 - 22262	-28.447	-17.037	-5.627	***
22201 - 14230	-7.647	3.549	14.746	
22201 - 13140	-7.810	4.456	16.722	
22201 - 14220	9.545	20.956	32.366	***
22201 - 13130	30.086	43.215	56.345	***
22201 - 21281	35.069	46.479	57.890	***
22201 - 30290	39.635	48.634	57.632	***
22201 - 22202	40.677	52.943	65.208	***
22201 - 22261	48.635	59.644	70.653	***
22201 - 14240	53.688	65.624	77.560	***
22201 - 13110	67.676	90.070	112.464	***
22201 - 14130	129.737	145.171	160.605	***
22201 - 14110	115.076	145.740	176.404	***
14230 - 13120	-130.917	-115.483	-100.049	***

LEVEL 5 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
14230 - 14120	-117.628	-103.915	-90.202	***
14230 - 21282	-112.602	-95.807	-79.011	***
14230 - 14140	-54.372	-41.715	-29.058	***
14230 - 14210	-58.384	-39.537	-20.690	***
14230 - 22262	-31.996	-20.586	-9.176	***
14230 - 22201	-14.746	-3.549	7.647	
14230 - 13140	-11.359	0.906	13.172	
14230 - 14220	5.996	17.406	28.816	***
14230 - 13130	26.536	39.666	52.795	***
14230 - 21281	31.520	42.930	54.340	***
14230 - 30290	36.086	45.084	54.082	***
14230 - 22202	37.127	49.393	61.659	***
14230 - 22261	45.086	56.095	67.103	***
14230 - 14240	50.138	62.074	74.010	***
14230 - 13110	64.126	86.520	108.914	***
14230 - 14130	126.188	141.622	157.056	***
14230 - 14110	111.526	142.190	172.855	***
13140 - 13120	-132.615	-116.389	-100.163	***
13140 - 14120	-119.421	-104.821	-90.222	***
13140 - 21282	-114.239	-96.713	-79.187	***
13140 - 14140	-56.233	-42.621	-29.010	***
13140 - 14210	-59.945	-40.444	-20.942	***
13140 - 22262	-33.953	-21.493	-9.032	***
13140 - 22201	-16.722	-4.456	7.810	
13140 - 14230	-13.172	-0.906	11.359	
13140 - 14220	4.039	16.500	28.960	***
13140 - 13130	24.707	38.759	52.811	***
13140 - 21281	29.563	42.024	54.484	***
13140 - 30290	33.880	44.178	54.475	***
13140 - 22202	35.238	48.487	61.735	***
13140 - 22261	43.094	55.188	67.282	***
13140 - 14240	48.224	61.168	74.111	***
13140 - 13110	62.667	85.614	108.561	***
13140 - 14130	124.489	140.715	156.941	***
13140 - 14110	110.214	141.284	172.354	***
14220 - 13120	-148.478	-132.889	-117.299	***
14220 - 14120	-135.209	-121.321	-107.433	***
14220 - 21282	-130.151	-113.213	-96.275	***
14220 - 14140	-71.967	-59.121	-46.275	***
14220 - 14210	-75.918	-56.943	-37.968	***
14220 - 22262	-49.612	-37.992	-26.373	***
14220 - 22201	-32.366	-20.956	-9.545	***
14220 - 14230	-28.816	-17.406	-5.996	***
14220 - 13140	-28.960	-16.500	-4.039	***
14220 - 13130	8.948	22.260	35.572	***

LEVEL 5 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
14220 - 21281	13.904	25.524	37.144	***
14220 - 30290	18.416	27.678	36.940	***
14220 - 22202	19.526	31.987	44.448	***
14220 - 22261	27.463	38.688	49.914	***
14220 - 14240	32.532	44.668	56.804	***
14220 - 13110	46.613	69.114	91.615	***
14220 - 14130	108.626	124.216	139.805	***
14220 - 14110	94.042	124.784	155.527	***
13130 - 13120	-172.037	-155.149	-138.260	***
13130 - 14120	-158.913	-143.581	-128.249	***
13130 - 21282	-153.614	-135.473	-117.331	***
13130 - 14140	-95.775	-81.380	-66.986	***
13130 - 14210	-99.259	-79.203	-59.147	***
13130 - 22262	-73.564	-60.252	-46.940	***
13130 - 22201	-56.345	-43.215	-30.086	***
13130 - 14230	-52.795	-39.666	-26.536	***
13130 - 13140	-52.811	-38.759	-24.707	***
13130 - 14220	-35.572	-22.260	-8.948	***
13130 - 21281	-10.048	3.264	16.576	
13130 - 30290	-5.895	5.418	16.731	
13130 - 22202	-4.325	9.727	23.779	
13130 - 22261	3.459	16.429	29.398	***
13130 - 14240	8.643	22.408	36.174	***
13130 - 13110	23.434	46.854	70.275	***
13130 - 14130	85.067	101.956	118.844	***
13130 - 14110	71.103	102.525	133.946	***
21281 - 13120	-174.002	-158.413	-142.823	***
21281 - 14120	-160.733	-146.845	-132.957	***
21281 - 21282	-155.675	-138.737	-121.798	***
21281 - 14140	-97.491	-84.645	-71.799	***
21281 - 14210	-101.442	-82.467	-63.492	***
21281 - 22262	-75.136	-63.516	-51.897	***
21281 - 22201	-57.890	-46.479	-35.069	***
21281 - 14230	-54.340	-42.930	-31.520	***
21281 - 13140	-54.484	-42.024	-29.563	***
21281 - 14220	-37.144	-25.524	-13.904	***
21281 - 13130	-16.576	-3.264	10.048	
21281 - 30290	-7.108	2.154	11.416	
21281 - 22202	-5.998	6.463	18.924	
21281 - 22261	1.939	13.165	24.390	***
21281 - 14240	7.008	19.144	31.280	***
21281 - 13110	21.089	43.590	66.092	***
21281 - 14130	83.102	98.692	114.281	***
21281 - 14110	68.518	99.260	130.003	***

LEVEL 5 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
30290 - 13120	-174.488	-160.567	-146.645	***
30290 - 14120	-160.985	-148.999	-137.013	***
30290 - 21282	-156.308	-140.891	-125.474	***
30290 - 14140	-97.560	-86.799	-76.038	***
30290 - 14210	-102.251	-84.621	-66.991	***
30290 - 22262	-74.933	-65.670	-56.408	***
30290 - 22201	-57.632	-48.634	-39.635	***
30290 - 14230	-54.082	-45.084	-36.086	***
30290 - 13140	-54.475	-44.178	-33.880	***
30290 - 14220	-36.940	-27.678	-18.416	***
30290 - 13130	-16.731	-5.418	5.895	
30290 - 21281	-11.416	-2.154	7.108	
30290 - 22202	-5.989	4.309	14.607	
30290 - 22261	2.248	11.011	19.774	***
30290 - 14240	7.087	16.990	26.893	***
30290 - 13110	20.057	41.436	62.816	***
30290 - 14130	82.616	96.538	110.459	***
30290 - 14110	67.175	97.106	127.038	***
22202 - 13120	-181.102	-164.876	-148.650	***
22202 - 14120	-167.907	-153.308	-138.709	***
22202 - 21282	-162.726	-145.200	-127.674	***
22202 - 14140	-104.719	-91.108	-77.496	***
22202 - 14210	-108.431	-88.930	-69.429	***
22202 - 22262	-82.440	-69.979	-57.519	***
22202 - 22201	-65.208	-52.943	-40.677	***
22202 - 14230	-61.659	-49.393	-37.127	***
22202 - 13140	-61.735	-48.487	-35.238	***
22202 - 14220	-44.448	-31.987	-19.526	***
22202 - 13130	-23.779	-9.727	4.325	
22202 - 21281	-18.924	-6.463	5.998	
22202 - 30290	-14.607	-4.309	5.989	
22202 - 22261	-5.393	6.702	18.796	
22202 - 14240	-0.263	12.681	25.625	
22202 - 13110	14.180	37.127	60.074	***
22202 - 14130	76.003	92.229	108.455	***
22202 - 14110	61.727	92.797	123.868	***
22261 - 13120	-186.875	-171.577	-156.279	***
22261 - 14120	-173.570	-160.010	-146.449	***
22261 - 21282	-168.572	-151.901	-135.231	***
22261 - 14140	-110.300	-97.809	-85.319	***
22261 - 14210	-114.368	-95.632	-76.896	***
22261 - 22262	-87.906	-76.681	-65.455	***
22261 - 22201	-70.653	-59.644	-48.635	***
22261 - 14230	-67.103	-56.095	-45.086	***
22261 - 13140	-67.282	-55.188	-43.094	***

LEVEL 5 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
22261 - 14220	-49.914	-38.688	-27.463	***
22261 - 13130	-29.398	-16.429	-3.459	***
22261 - 21281	-24.390	-13.165	-1.939	***
22261 - 30290	-19.774	-11.011	-2.248	***
22261 - 22202	-18.796	-6.702	5.393	
22261 - 14240	-5.780	5.979	17.739	
22261 - 13110	8.125	30.426	52.726	***
22261 - 14130	70.229	85.527	100.825	***
22261 - 14110	55.500	86.096	116.692	***
14240 - 13120	-193.535	-177.557	-161.579	***
14240 - 14120	-180.312	-165.989	-151.666	***
14240 - 21282	-175.178	-157.881	-140.584	***
14240 - 14140	-117.104	-103.789	-90.474	***
14240 - 14210	-120.907	-101.611	-82.316	***
14240 - 22262	-94.797	-82.660	-70.524	***
14240 - 22201	-77.560	-65.624	-53.688	***
14240 - 14230	-74.010	-62.074	-50.138	***
14240 - 13140	-74.111	-61.168	-48.224	***
14240 - 14220	-56.804	-44.668	-32.532	***
14240 - 13130	-36.174	-22.408	-8.643	***
14240 - 21281	-31.280	-19.144	-7.008	***
14240 - 30290	-26.893	-16.990	-7.087	***
14240 - 22202	-25.625	-12.681	0.263	
14240 - 22261	-17.739	-5.979	5.780	
14240 - 13110	1.674	24.446	47.219	***
14240 - 14130	63.569	79.548	95.526	***
14240 - 14110	49.175	80.116	111.058	***
13110 - 13120	-226.789	-202.003	-177.218	***
13110 - 14120	-214.188	-190.435	-166.683	***
13110 - 21282	-207.983	-182.327	-156.672	***
13110 - 14140	-151.393	-128.235	-105.077	***
13110 - 14210	-153.101	-126.057	-99.014	***
13110 - 22262	-129.608	-107.107	-84.605	***
13110 - 22201	-112.464	-90.070	-67.676	***
13110 - 14230	-108.914	-86.520	-64.126	***
13110 - 13140	-108.561	-85.614	-62.667	***
13110 - 14220	-91.615	-69.114	-46.613	***
13110 - 13130	-70.275	-46.854	-23.434	***
13110 - 21281	-66.092	-43.590	-21.089	***
13110 - 30290	-62.816	-41.436	-20.057	***
13110 - 22202	-60.074	-37.127	-14.180	***
13110 - 22261	-52.726	-30.426	-8.125	***
13110 - 14240	-47.219	-24.446	-1.674	***
13110 - 14130	30.316	55.101	79.887	***
13110 - 14110	19.388	55.670	91.952	***

LEVEL 5 Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
14130 - 13120	-275.841	-257.104	-238.368	***
14130 - 14120	-262.883	-245.537	-228.191	***
14130 - 21282	-257.301	-237.429	-217.556	***
14130 - 14140	-199.860	-183.336	-166.813	***
14130 - 14210	-202.793	-181.159	-159.524	***
14130 - 22262	-177.797	-162.208	-146.619	***
14130 - 22201	-160.605	-145.171	-129.737	***
14130 - 14230	-157.056	-141.622	-126.188	***
14130 - 13140	-156.941	-140.715	-124.489	***
14130 - 14220	-139.805	-124.216	-108.626	***
14130 - 13130	-118.844	-101.956	-85.067	***
14130 - 21281	-114.281	-98.692	-83.102	***
14130 - 30290	-110.459	-96.538	-82.616	***
14130 - 22202	-108.455	-92.229	-76.003	***
14130 - 22261	-100.825	-85.527	-70.229	***
14130 - 14240	-95.526	-79.548	-63.569	***
14130 - 13110	-79.887	-55.101	-30.316	***
14130 - 14110	-31.883	0.569	33.020	
14110 - 13120	-290.125	-257.673	-225.221	***
14110 - 14120	-277.775	-246.105	-214.436	***
14110 - 21282	-271.118	-237.997	-204.876	***
14110 - 14140	-215.132	-183.905	-152.678	***
14110 - 14210	-215.935	-181.728	-147.520	***
14110 - 22262	-193.519	-162.777	-132.034	***
14110 - 22201	-176.404	-145.740	-115.076	***
14110 - 14230	-172.855	-142.190	-111.526	***
14110 - 13140	-172.354	-141.284	-110.214	***
14110 - 14220	-155.527	-124.784	-94.042	***
14110 - 13130	-133.946	-102.525	-71.103	***
14110 - 21281	-130.003	-99.260	-68.518	***
14110 - 30290	-127.038	-97.106	-67.175	***
14110 - 22202	-123.868	-92.797	-61.727	***
14110 - 22261	-116.692	-86.096	-55.500	***
14110 - 14240	-111.058	-80.116	-49.175	***
14110 - 13110	-91.952	-55.670	-19.388	***
14110 - 14130	-33.020	-0.569	31.883	

Appendix 2

Principal Component Analysis
of the Control Specimens

48 Observations 3 Variables

Simple Statistics

	Log of the Total Length	Log of the Condyle Width	Log of the Condyle Depth
Mean	5.278612117	4.081474923	4.115710821
StD	0.039877915	0.064909828	0.057514144

Covariance Matrix

	Log of the Total Length	Log of the Condyle Width	Log of the Condyle Depth
Log of the Total Length	0.0015902481	0.0012427280	0.0009937165
Log of the Condyle Width	0.0012427280	0.0042132858	0.0027203527
Log of the Condyle Depth	0.0009937165	0.0027203527	0.0033078768

Total Variance = 0.0091114107

Eigenvalues of the Covariance Matrix

	Eigenvalue	Difference	Proportion	Cumulative
PRIN1	0.006987	0.005851	0.766855	0.76685
PRIN2	0.001136	0.000147	0.124642	0.89150
PRIN3	0.000989	.	0.108503	1.00000

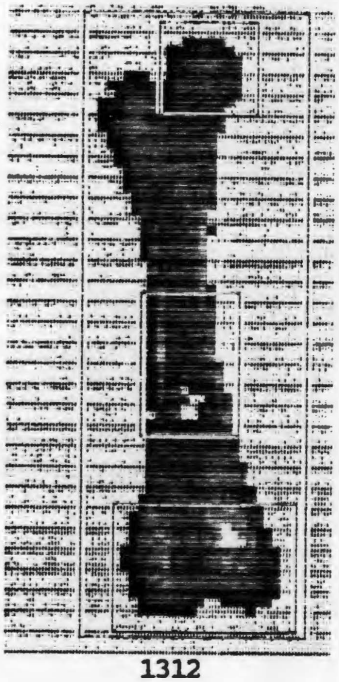
Eigenvectors

	PRIN1	PRIN2	PRIN3
Log of the Total Length	0.282708	0.911628	0.298347
Log of the Condyle Width	0.733197	-.004832	-.679999
Log of the Condyle Depth	0.618465	-.410989	0.669768

Appendix 3

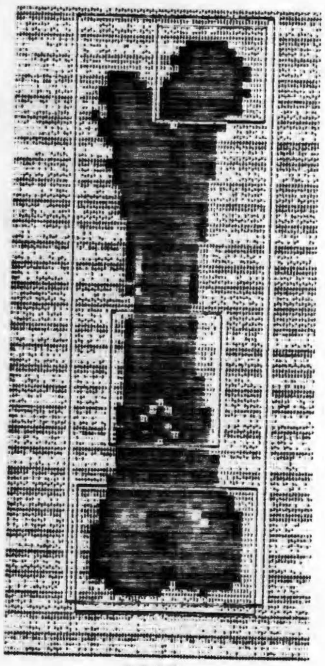
Density Imagery

L H



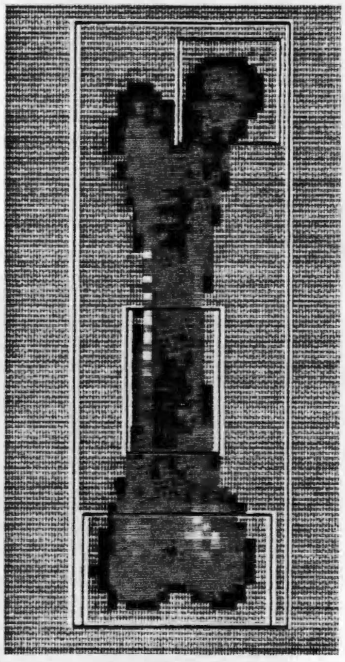
1312

L H



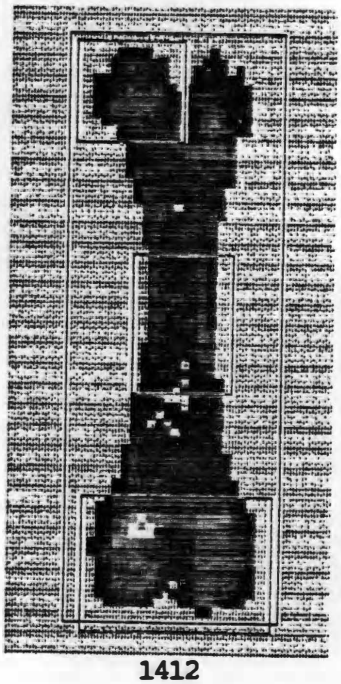
1313

L H



1314

L H



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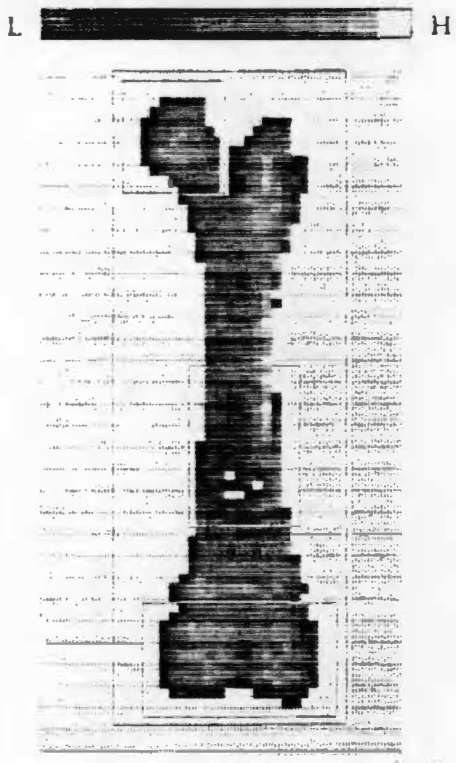

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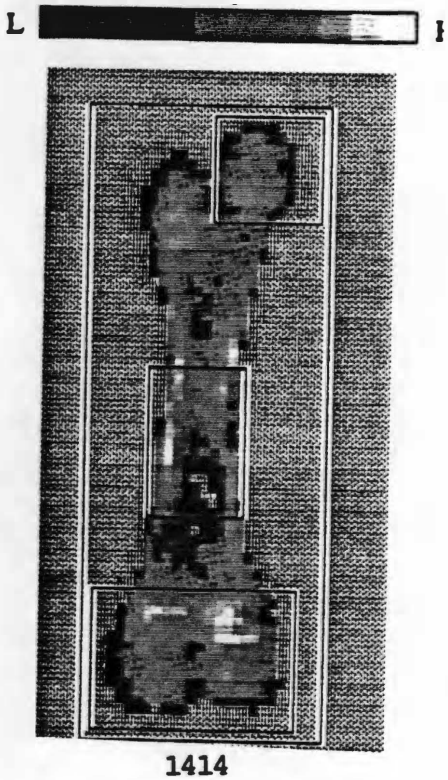

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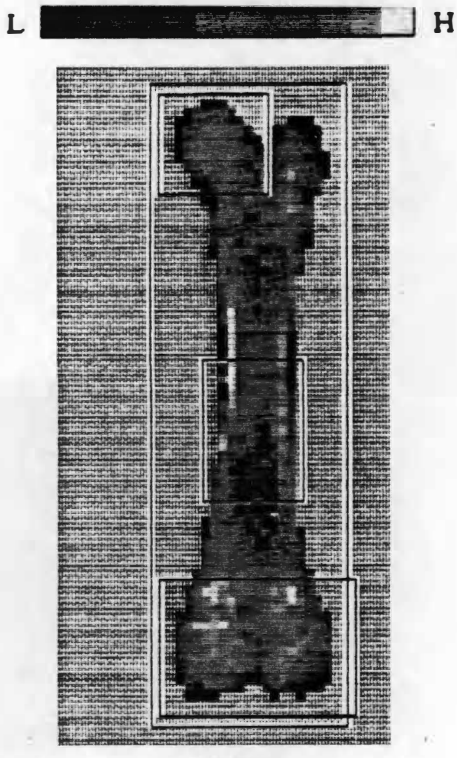

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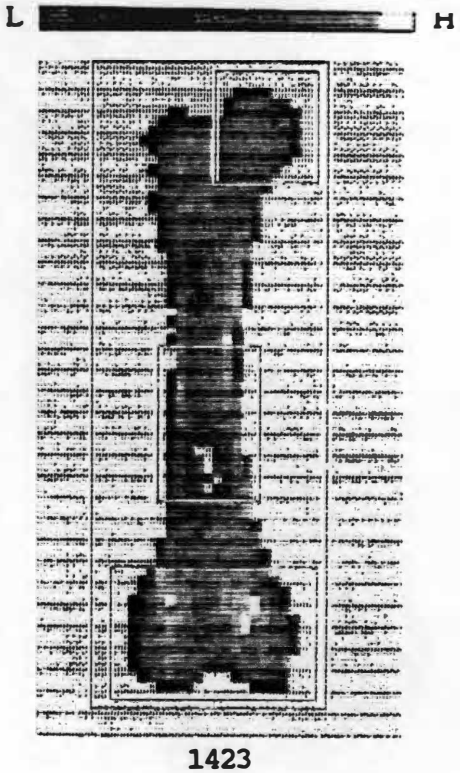

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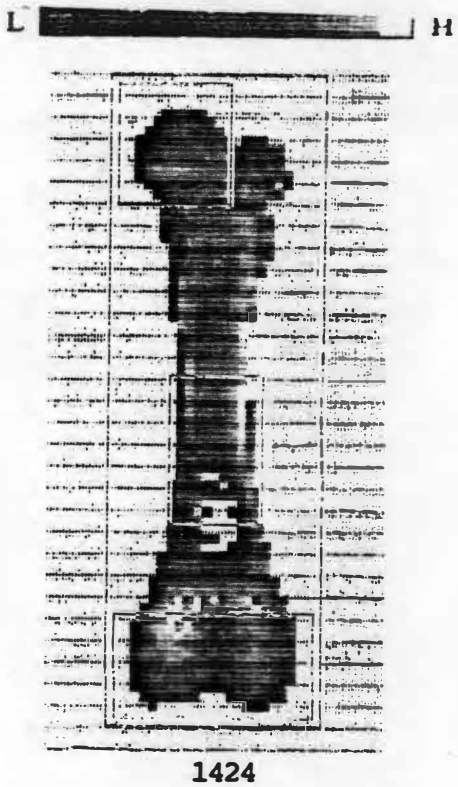

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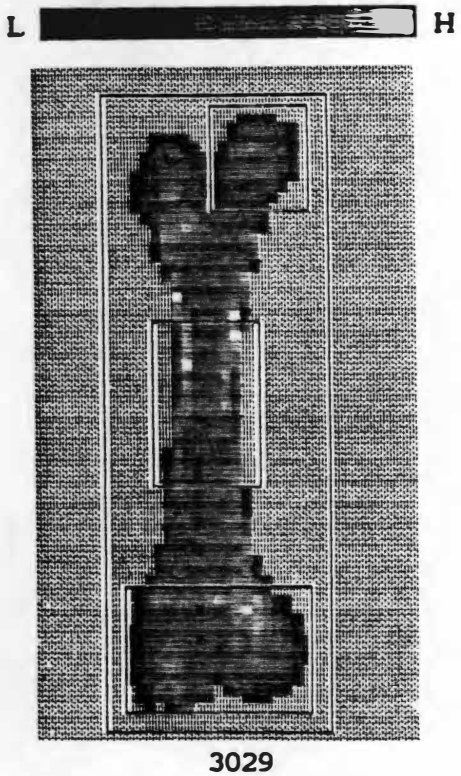
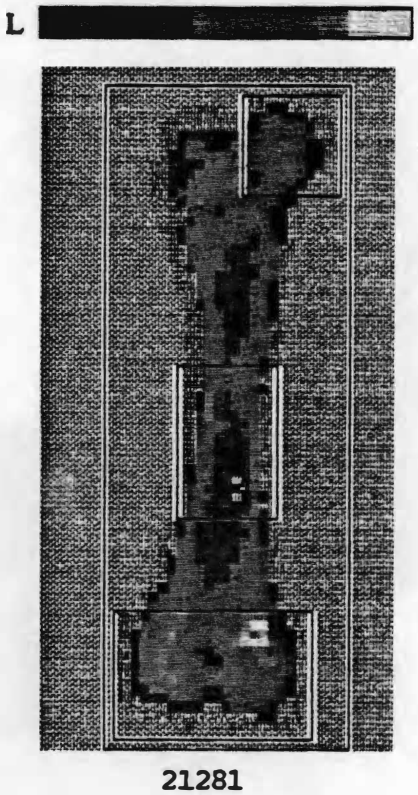
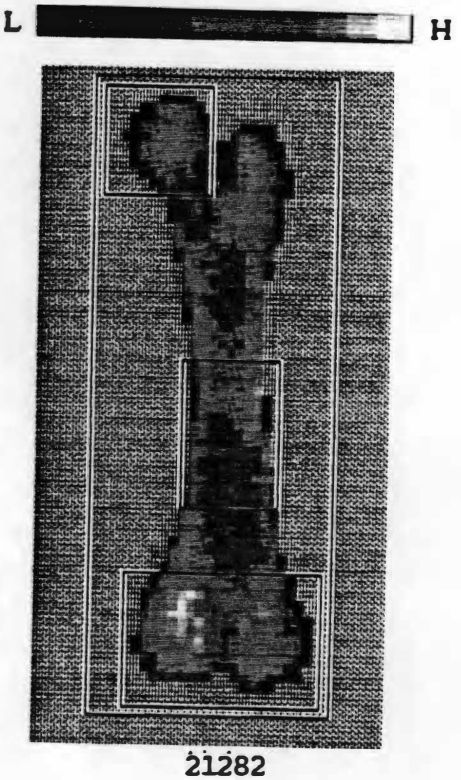


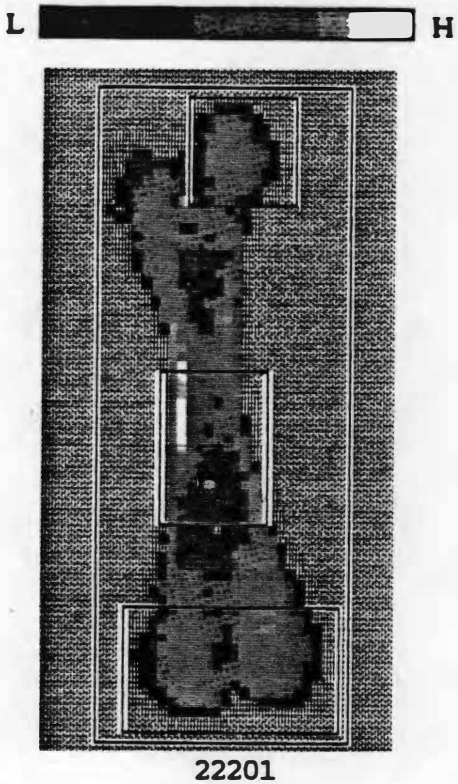
3029



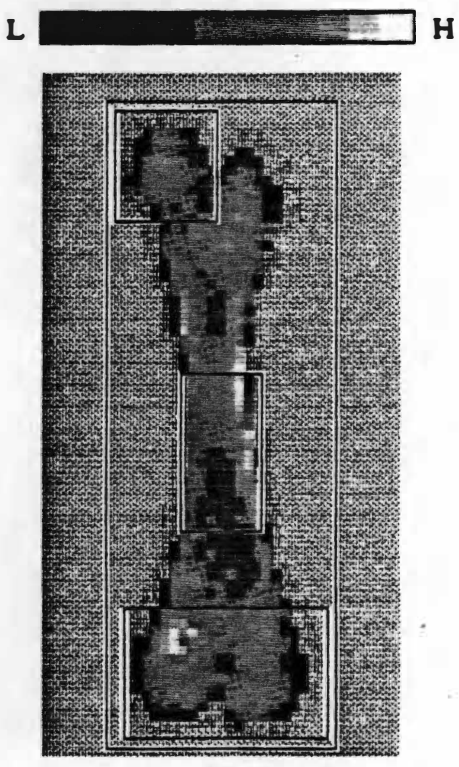
21281



21282



22201



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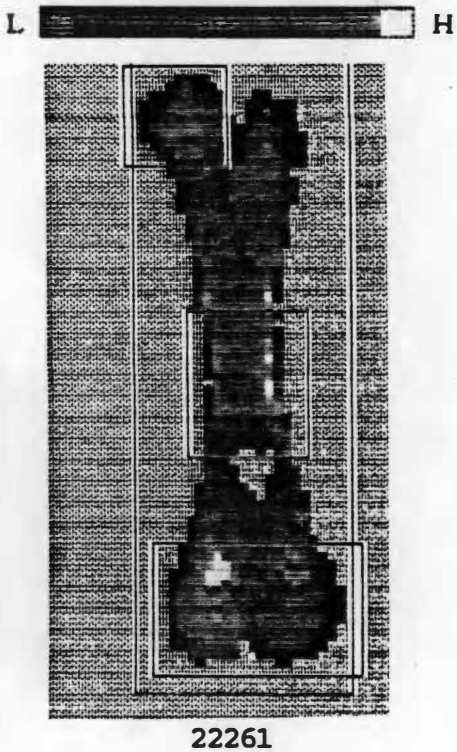
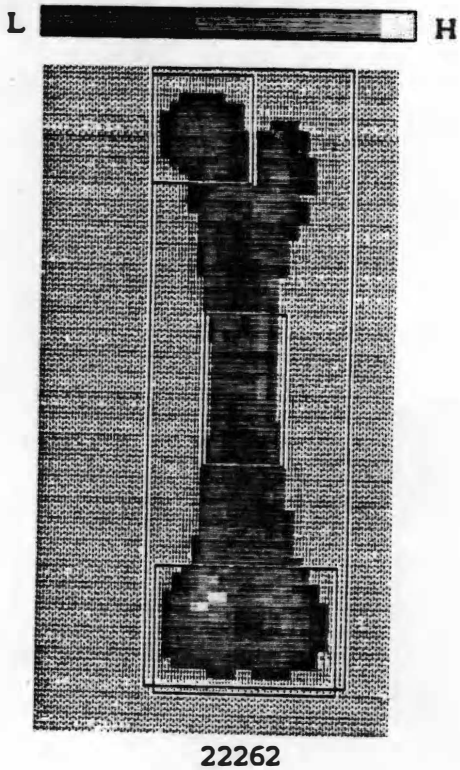


22261



22262

Appendix 4

Level 1

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
1	HEADBMD	1.0770920	0.1058370	0.8230000	1.3640000	0.0112015	9.8261846	0.0001
	CONDBMD	1.3603182	0.1464923	0.9210000	1.6600000	0.0214600	10.7689721	0.0001
	MSBMD	1.1392727	0.1116885	0.8320000	1.3610000	0.0124743	9.8034889	0.0001
	TOTBMD	1.2046818	0.1120723	0.9260000	1.6120000	0.0125602	9.3030608	0.0001
	TOTBMC	89.3868068	11.8086929	60.0710000	120.5580000	139.4452268	13.2107783	0.0001
2	HEADBMD	1.0987536	0.1079824	0.8330000	1.4550000	0.0116602	9.8277130	0.0001
	CONDBMD	1.3957536	0.1456331	1.0310000	1.8440000	0.0212090	10.4340149	0.0001
	MSBMD	1.2171304	0.1325738	0.8320000	1.5640000	0.0175758	10.8923274	0.0001
	TOTBMD	1.2396087	0.1464466	0.9250000	1.9800000	0.0214466	11.8139345	0.0001
	TOTBMC	91.0902899	10.8546054	64.7250000	122.7180000	117.8224577	11.9163144	0.0001
3	HEADBMD	1.1315625	0.0878475	0.9700000	1.2720000	0.0077172	7.7633824	0.0001
	CONDBMD	1.4522083	0.1493455	1.0870000	1.8330000	0.0223041	10.2840283	0.0001
	MSBMD	1.2672500	0.0999748	1.0580000	1.5770000	0.0099950	7.8891130	0.0001
	TOTBMD	1.2778333	0.0986341	1.0860000	1.4440000	0.0097287	7.7188585	0.0001
	TOTBMC	93.8060833	9.9406974	78.9370000	126.9920000	98.8174651	10.5970712	0.0001

Level 2

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
13	HEADBMD	1.0947600	0.1186656	0.8280000	1.3640000	0.0140815	10.8394164	0.0001
	CONDBMD	1.4125200	0.1184557	1.0650000	1.6100000	0.0140318	8.3861276	0.0001
	MSBMD	1.1399200	0.1168225	0.8320000	1.3020000	0.0136475	10.2483057	0.0001
	TOTBMD	1.2351200	0.1360194	0.9260000	1.6120000	0.0185013	11.0126464	0.0001
	TOTBMC	92.1237200	12.3445390	73.5730000	115.9410000	152.3876434	13.3999572	0.0001
14	HEADBMD	1.0699677	0.1003616	0.8230000	1.2630000	0.0100725	9.3798749	0.0001
	CONDBMD	1.3396032	0.1521405	0.9210000	1.6600000	0.0231467	11.3571308	0.0001
	MSBMD	1.1390159	0.1105493	0.8880000	1.3610000	0.0122211	9.7056845	0.0001
	TOTBMD	1.1926032	0.0997055	0.9840000	1.4810000	0.0099412	8.3603215	0.0001
	TOTBMC	88.3007302	11.5093591	60.0710000	120.5580000	132.4653470	13.0342740	0.0001
21	HEADBMD	1.0425882	0.1125445	0.8330000	1.2400000	0.0126663	10.7947188	0.0001
	CONDBMD	1.3635882	0.1778472	1.0310000	1.5970000	0.0316296	13.0425895	0.0001
	MSBMD	1.1577059	0.1380085	0.8320000	1.3700000	0.0190463	11.9208601	0.0001
	TOTBMD	1.2108824	0.2305699	0.9250000	1.9800000	0.0531625	19.0414794	0.0001
	TOTBMC	86.7392353	10.8310410	64.7250000	105.0870000	117.3114491	12.4868993	0.0001

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
22	HEADBMD	1.1171154	0.1008856	0.9240000	1.4550000	0.0101779	9.0309040	0.0001
	CONDBMD	1.4062692	0.1337836	1.1620000	1.8440000	0.0178980	9.5133683	0.0001
	MSBMD	1.2365577	0.1260841	0.9950000	1.5640000	0.0158972	10.1963758	0.0001
	TOTBMD	1.2490000	0.1074804	1.0560000	1.5990000	0.0115520	8.6053173	0.0001
	TOTBMC	92.5127500	10.5791962	74.6890000	122.7180000	111.9193926	11.4353927	0.0001
30	HEADBMD	1.1315625	0.0878475	0.9700000	1.2720000	0.0077172	7.7633824	0.0001
	CONDBMD	1.4522083	0.1493455	1.0870000	1.8330000	0.0223041	10.2840283	0.0001
	MSBMD	1.2672500	0.0999748	1.0580000	1.5770000	0.0099950	7.8891130	0.0001
	TOTBMD	1.2778333	0.0986341	1.0860000	1.4440000	0.0097287	7.7188585	0.0001
	TOTBMC	93.8060833	9.9406974	78.9370000	126.9920000	98.8174651	10.5970712	0.0001

Level 3

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
131	HEADBMD	1.0947600	0.1186656	0.8280000	1.3640000	0.0140815	10.8394164	0.0001
	CONDBMD	1.4125200	0.1184557	1.0650000	1.6100000	0.0140318	8.3861276	0.0001
	MSBMD	1.1399200	0.1168225	0.8320000	1.3020000	0.0136475	10.2483057	0.0001
	TOTBMD	1.2351200	0.1360194	0.9260000	1.6120000	0.0185013	11.0126464	0.0001
	TOTBMC	92.1237200	12.3445390	73.5730000	115.9410000	152.3876434	13.3999572	0.0001
141	HEADBMD	1.0239524	0.1014172	0.8230000	1.2630000	0.0102854	9.9044836	0.0001
	CONDBMD	1.3464545	0.1205715	1.1330000	1.6600000	0.0145375	8.9547432	0.0001
	MSBMD	1.1002273	0.1168699	0.8930000	1.3580000	0.0136586	10.6223383	0.0001
	TOTBMD	1.1605000	0.1021906	1.0010000	1.4810000	0.0104429	8.8057431	0.0001
	TOTBMC	87.4480455	9.8112471	73.1600000	120.5580000	96.2605691	11.2195156	0.0001
142	HEADBMD	1.0935366	0.0923946	0.8890000	1.2450000	0.0085368	8.4491513	0.0001
	CONDBMD	1.3359268	0.1679451	0.9210000	1.6510000	0.0282056	12.5714324	0.0001
	MSBMD	1.1598293	0.1024719	0.8880000	1.3610000	0.0105005	8.8350869	0.0001
	TOTBMD	1.2098293	0.0951593	0.9840000	1.4140000	0.0090553	7.8655160	0.0001
	TOTBMC	88.7582683	12.4165223	60.0710000	118.0020000	154.1700252	13.9891443	0.0001
212	HEADBMD	1.0425882	0.1125445	0.8330000	1.2400000	0.0126663	10.7947188	0.0001
	CONDBMD	1.3635882	0.1778472	1.0310000	1.5970000	0.0316296	13.0425895	0.0001
	MSBMD	1.1577059	0.1380085	0.8320000	1.3700000	0.0190463	11.9208601	0.0001
	TOTBMD	1.2108824	0.2305699	0.9250000	1.9800000	0.0531625	19.0414794	0.0001
	TOTBMC	86.7392353	10.8310410	64.7250000	105.0870000	117.3114491	12.4868993	0.0001
222	HEADBMD	1.1171154	0.1008856	0.9240000	1.4550000	0.0101779	9.0309040	0.0001
	CONDBMD	1.4062692	0.1337836	1.1620000	1.8440000	0.0178980	9.5133683	0.0001
	MSBMD	1.2365577	0.1260841	0.9950000	1.5640000	0.0158972	10.1963758	0.0001
	TOTBMD	1.2490000	0.1074804	1.0560000	1.5990000	0.0115520	8.6053173	0.0001
	TOTBMC	92.5127500	10.5791962	74.6890000	122.7180000	111.9193926	11.4353927	0.0001

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
302	HEADBMD	1.1315625	0.0878475	0.9700000	1.2720000	0.0077172	7.7633824	0.0001
	CONDBMD	1.4522083	0.1493455	1.0870000	1.8330000	0.0223041	10.2840283	0.0001
	MSBMD	1.2672500	0.0999748	1.0580000	1.5770000	0.0099950	7.8891130	0.0001
	TOTBMD	1.2778333	0.0986341	1.0860000	1.4440000	0.0097287	7.7188585	0.0001
	TOTBMC	93.8060833	9.9406974	78.9370000	126.9920000	98.8174651	10.5970712	0.0001

Level 4

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
1312	HEADBMD	1.1720000	0.1234889	1.0470000	1.3640000	0.0152495	10.5365927	0.0001
	CONDBMD	1.4568000	0.0935318	1.3170000	1.5480000	0.0087482	6.4203606	0.0001
	MSBMD	1.2008000	0.1142134	1.0240000	1.3000000	0.0130447	9.5114421	0.0001
	TOTBMD	1.2976000	0.1228182	1.1720000	1.4560000	0.0150843	9.4650245	0.0001
	TOTBMC	103.9490000	12.4817628	89.0020000	115.9410000	155.7944035	12.0075834	0.0001
1313	HEADBMD	1.0455000	0.1209545	0.8280000	1.2100000	0.0146300	11.5690614	0.0001
	CONDBMD	1.3761250	0.1611427	1.0650000	1.5530000	0.0259670	11.7098911	0.0001
	MSBMD	1.0625000	0.1262096	0.8320000	1.2080000	0.0159289	11.8785484	0.0001
	TOTBMD	1.1690000	0.1329726	0.9260000	1.3270000	0.0176817	11.3749022	0.0001
	TOTBMC	85.5945000	12.8644272	73.5730000	113.1600000	165.4934866	15.0295021	0.0001
1314	HEADBMD	1.0771000	0.1081002	0.9300000	1.2920000	0.0116857	10.0362279	0.0001
	CONDBMD	1.4070000	0.1008233	1.2700000	1.6100000	0.0101653	7.1658335	0.0001
	MSBMD	1.1492000	0.0893418	1.0400000	1.3020000	0.0079820	7.7742595	0.0001
	TOTBMD	1.2358000	0.1427599	1.1070000	1.6120000	0.0203804	11.5520261	0.0001
	TOTBMC	89.1590000	7.3685430	81.1770000	101.9380000	54.2954253	8.2644971	0.0001
1412	HEADBMD	0.9417143	0.1002825	0.8230000	1.0960000	0.0100566	10.6489261	0.0001
	CONDBMD	1.2677143	0.0647861	1.1550000	1.3330000	0.0041972	5.1104650	0.0001
	MSBMD	1.0061429	0.0639021	0.8930000	1.0630000	0.0040835	6.3511938	0.0001
	TOTBMD	1.0771429	0.0493944	1.0010000	1.1380000	0.0024398	4.5856896	0.0001
	TOTBMC	84.5065714	7.5941959	73.1600000	96.9340000	57.6718116	8.9865152	0.0001
1413	HEADBMD	1.0377500	0.0388190	0.9860000	1.0800000	0.0015069	3.7406914	0.0001
	CONDBMD	1.3572000	0.1346373	1.1330000	1.4870000	0.0181272	9.9202248	0.0001
	MSBMD	1.0780000	0.0846995	0.9270000	1.1240000	0.0071740	7.8570936	0.0001
	TOTBMD	1.1584000	0.0576481	1.0620000	1.2150000	0.0033233	4.97[illegible]4	0.0001
	TOTBMC	83.7724000	5.9874454	75.6270000	90.0030000	35.8495023	[illegible]472769	0.0001
1414	HEADBMD	1.0710000	0.0890267	0.9580000	1.2[illegible]30	0.0079258	8.3124819	0.0001
	CONDBMD	1.3967778	0.1317391	1.[illegible]300	1.6600000	0.0173552	9.4316445	0.0001
	MSBMD	1.1706667	0.11[illegible]4	1.0300000	1.3580000	0.0132638	9.8378435	0.0001
	TOTBMD	1.2115556	0.1124490	1.0970000	1.4810000	0.0126448	9.2813739	0.0001
	TOTBM[illegible]	91.3847778	12.5096336	80.0250000	120.5580000	156.4909329	13.6889687	0.0001

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
1422	HEADBMD	1.0779231	0.0882935	0.9750000	1.2380000	0.0077957	8.1910769	0.0001
	CORDBMD	1.3810769	0.1207335	1.1860000	1.6510000	0.0145766	8.7419820	0.0001
	MSBMD	1.1465385	0.1124341	0.9770000	1.3380000	0.0126414	9.8063994	0.0001
	TOTBMD	1.2072308	0.1046471	1.0230000	1.4140000	0.0109510	8.6683632	0.0001
	TOTBMC	88.0536154	12.7465989	68.0130000	118.0020000	162.4757834	14.4759518	0.0001
1423	HEADBMD	1.1071429	0.0926498	0.9550000	1.2450000	0.0085840	8.3683654	0.0001
	CORDBMD	1.3731429	0.1553942	0.9590000	1.5570000	0.0241474	11.3166825	0.0001
	MSBMD	1.1761429	0.0877136	1.0430000	1.3610000	0.0076937	7.4577309	0.0001
	TOTBMD	1.2260000	0.0776808	1.1140000	1.3420000	0.0060343	6.3361180	0.0001
	TOTBMC	91.4406429	11.2521043	72.0410000	110.9280000	126.6098509	12.3053644	0.0001
1424	HEADBMD	1.0992727	0.1130275	0.8890000	1.2430000	0.0127752	10.2820263	0.0001
	CORDBMD	1.2883636	0.1975268	0.9210000	1.4900000	0.0390169	15.3316067	0.0001
	MSBMD	1.1612727	0.1266721	0.8880000	1.3290000	0.0160458	10.9080396	0.0001
	TOTBMD	1.2107273	0.1156444	0.9840000	1.3420000	0.0133736	9.5516442	0.0001
	TOTBMC	86.9464545	15.0874303	60.0710000	104.3070000	227.6305541	17.3525538	0.0001
2128	HEADBMD	1.0425882	0.1125445	0.8330000	1.2400000	0.0126663	10.7947188	0.0001
	CORDBMD	1.3635882	0.1778472	1.0310000	1.5970000	0.0316296	13.0425895	0.0001
	MSBMD	1.1577059	0.1380085	0.8320000	1.3700000	0.0190463	11.9208601	0.0001
	TOTBMD	1.2108824	0.2305699	0.9250000	1.9800000	0.0531625	19.0414794	0.0001
	TOTBMC	86.7392353	10.8310410	64.7250000	105.0870000	117.3114491	12.4868993	0.0001
2220	HEADBMD	1.0797500	0.0854473	0.9240000	1.2750000	0.0073012	7.9136178	0.0001
	CORDBMD	1.3208333	0.0833868	1.1620000	1.4590000	0.0069534	6.3131980	0.0001
	MSBMD	1.2013750	0.0963349	0.9950000	1.4280000	0.0092804	8.0187226	0.0001
	TOTBMD	1.2026250	0.0821588	1.0560000	1.3900000	0.0067501	6.8316236	0.0001
	TOTBMC	88.4589167	8.6739851	74.6890000	113.6060000	75.2380183	9.8056651	0.0001
2226	HEADBMD	1.1491429	0.1034436	0.9810000	1.4550000	0.0107006	9.0018021	0.0001
	CORDBMD	1.4795000	0.1258354	1.3370000	1.8440000	0.0158346	8.5052674	0.0001
	MSBMD	1.2667143	0.1417007	1.0850000	1.5640000	0.0200791	11.1864802	0.0001
	TOTBMD	1.2887500	0.1118937	1.1560000	1.5990000	0.0125202	8.6823414	0.0001
	TOTBMC	95.9874643	10.9628111	78.7630000	122.7180000	120.1832277	11.4210863	0.0001
3029	HEADBMD	1.1315625	0.0878475	0.9700000	1.2720000	0.0077172	7.7633824	0.0001
	CORDBMD	1.4522083	0.1493455	1.0870000	1.8330000	0.0223041	10.2840283	0.0001
	MSBMD	1.2672500	0.0999748	1.0580000	1.5770000	0.0099950	7.8891130	0.0001
	TOTBMD	1.2778333	0.0986341	1.0860000	1.4440000	0.0097287	7.7188585	0.0001
	TOTBMC	93.8060833	9.9406974	78.9370000	126.9920000	98.8174651	10.5970712	0.0001

Level 5

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
13120	HEADBMD	1.1720000	0.1234889	1.0470000	1.3640000	0.0152495	10.5365927	0.0001
	CONDBMD	1.4568000	0.0935318	1.3170000	1.5480000	0.0087482	6.4203606	0.0001
	MSBMD	1.2008000	0.1142134	1.0240000	1.3000000	0.0130447	9.5114421	0.0001
	TOTBMD	1.2976000	0.1228182	1.1720000	1.4560000	0.0150843	9.4650245	0.0001
	TOTBMC	103.9490000	12.4817628	89.0020000	115.9410000	155.7944035	12.0075834	0.0001
13130	HEADBMD	1.0455000	0.1209545	0.8280000	1.2100000	0.0146300	11.5690614	0.0001
	CONDBMD	1.3761250	0.1611427	1.0650000	1.5530000	0.0259670	11.7098911	0.0001
	MSBMD	1.0625000	0.1262096	0.8320000	1.2080000	0.0159289	11.8785484	0.0001
	TOTBMD	1.1690000	0.1329726	0.9260000	1.3270000	0.0176817	11.3749022	0.0001
	TOTBMC	85.5945000	12.8644272	73.5730000	113.1600000	165.4934866	15.0295021	0.0001
13140	HEADBMD	1.0771000	0.1081002	0.9300000	1.2920000	0.0116857	10.0362279	0.0001
	CONDBMD	1.4070000	0.1008233	1.2700000	1.6100000	0.0101653	7.1658335	0.0001
	MSBMD	1.1492000	0.0893418	1.0400000	1.3020000	0.0079820	7.7742595	0.0001
	TOTBMD	1.2358000	0.1427599	1.1070000	1.6120000	0.0203804	11.5520261	0.0001
	TOTBMC	89.1590000	7.3685430	81.1770000	101.9380000	54.2954253	8.2644971	0.0001
14120	HEADBMD	0.9417143	0.1002825	0.8230000	1.0960000	0.0100566	10.6489261	0.0001
	CONDBMD	1.2677143	0.0647861	1.1550000	1.3330000	0.0041972	5.1104650	0.0001
	MSBMD	1.0061429	0.0639021	0.8930000	1.0630000	0.0040835	6.3511938	0.0001
	TOTBMD	1.0771429	0.0493944	1.0010000	1.1380000	0.0024398	4.5856896	0.0001
	TOTBMC	84.5065714	7.5941959	73.1600000	96.9340000	57.6718116	8.9865152	0.0001
14130	HEADBMD	1.0377500	0.0388190	0.9860000	1.0800000	0.0015069	3.7406914	0.0001
	CONDBMD	1.3572000	0.1346373	1.1330000	1.4870000	0.0181272	9.9202248	0.0001
	MSBMD	1.0780000	0.0846995	0.9270000	1.1240000	0.0071740	7.8570936	0.0001
	TOTBMD	1.1584000	0.0576481	1.0620000	1.2150000	0.0033233	4.9765254	0.0001
	TOTBMC	83.7724000	5.9874454	75.6270000	90.0030000	35.8495023	7.1472769	0.0001
14140	HEADBMD	1.0710000	0.0890267	0.9580000	1.2630000	0.0079258	8.3124819	0.0001
	CONDBMD	1.3967778	0.1317391	1.2490000	1.6600000	0.0173552	9.4316445	0.0001
	MSBMD	1.1706667	0.1151684	1.0300000	1.3580000	0.0132638	9.8378435	0.0001
	TOTBMD	1.2115556	0.1124490	1.0970000	1.4810000	0.0126448	9.2813739	0.0001
	TOTBMC	91.3847778	12.5096336	80.0250000	120.5580000	156.4909329	13.6889687	0.0001
14220	HEADBMD	1.0779231	0.0882935	0.9750000	1.2380000	0.0077957	8.1910769	0.0001
	CONDBMD	1.3810769	0.1207335	1.1860000	1.6510000	0.0145766	8.7419820	0.0001
	MSBMD	1.1465385	0.1124341	0.9770000	1.3380000	0.0126414	9.8063994	0.0001
	TOTBMD	1.2072308	0.1046471	1.0230000	1.4140000	0.0109510	8.6683632	0.0001
	TOTBMC	88.0536154	12.7465989	68.0130000	118.0020000	162.4757834	14.4759518	0.0001

	Variable	Mean	Std Dev	Minimum	Maximum	Variance	CV	Prob>|T|
14230	HEADBMD	1.1071429	0.0926498	0.9550000	1.2450000	0.0085840	8.3683654	0.0001
	CONDBMD	1.3731429	0.1553942	0.9590000	1.5570000	0.0241474	11.3166825	0.0001
	MSBMD	1.1761429	0.0877136	1.0430000	1.3610000	0.0076937	7.4577309	0.0001
	TOTBMD	1.2260000	0.0776808	1.1140000	1.3420000	0.0060343	6.3361180	0.0001
	TOTBMC	91.4406429	11.2521043	72.0410000	110.9280000	126.6098509	12.3053644	0.0001
14240	HEADBMD	1.0992727	0.1130275	0.8890000	1.2430000	0.0127752	10.2820263	0.0001
	CONDBMD	1.2883636	0.1975268	0.9210000	1.4900000	0.0390169	15.3316067	0.0001
	MSBMD	1.1612727	0.1266721	0.8880000	1.3290000	0.0160458	10.9080396	0.0001
	TOTBMD	1.2107273	0.1156444	0.9840000	1.3420000	0.0133736	9.5516442	0.0001
	TOTBMC	86.9464545	15.0874303	60.0710000	104.3070000	227.6305541	17.3525538	0.0001
21281	HEADBMD	1.0230769	0.1111174	0.8330000	1.2400000	0.0123471	10.8610994	0.0001
	CONDBMD	1.3446923	0.1800303	1.0310000	1.5970000	0.0324109	13.3882128	0.0001
	MSBMD	1.1446154	0.1559672	0.8320000	1.3700000	0.0243258	13.6261636	0.0001
	TOTBMD	1.2073846	0.2601998	0.9250000	1.9800000	0.0677039	21.5506949	0.0001
	TOTBMC	84.4976154	10.7622699	64.7250000	101.2290000	115.8264526	12.7367735	0.0001
21282	HEADBMD	1.1060000	0.1056125	1.0150000	1.2100000	0.0111540	9.5490506	0.0002
	CONDBMD	1.4250000	0.1801999	1.2690000	1.5870000	0.0324720	12.6456062	0.0005
	MSBMD	1.2002500	0.0334900	1.1760000	1.2470000	0.0011216	2.7902561	0.0001
	TOTBMD	1.2222500	0.1117687	1.1260000	1.3330000	0.0124922	9.1445068	0.0002
	TOTBMC	94.0245000	8.3554822	87.5600000	105.0870000	69.8140830	8.8864947	0.0002
22201	HEADBMD	1.0936429	0.0965494	0.9560000	1.2750000	0.0093218	8.8282381	0.0001
	CONDBMD	1.3193571	0.0896932	1.1620000	1.4540000	0.0080449	6.7982471	0.0001
	MSBMD	1.2009286	0.0942855	0.9950000	1.4180000	0.0088898	7.8510534	0.0001
	TOTBMD	1.2095000	0.0882494	1.0560000	1.3900000	0.0077880	7.2963562	0.0001
	TOTBMC	90.8287857	9.7169924	79.4810000	113.6060000	94.4199417	10.6981419	0.0001
22202	HEADBMD	1.0603000	0.0668831	0.9240000	1.1450000	0.0044733	6.3079379	0.0001
	CONDBMD	1.3229000	0.0783659	1.2330000	1.4590000	0.0061412	5.9237947	0.0001
	MSBMD	1.2020000	0.1042838	1.0300000	1.4280000	0.0108751	8.6758570	0.0001
	TOTBMD	1.1930000	0.0763180	1.1010000	1.3070000	0.0058244	6.3971541	0.0001
	TOTBMC	85.1411000	5.9095797	74.6890000	94.5640000	34.9231325	6.9409248	0.0001
22261	HEADBMD	1.1308000	0.0887768	1.0110000	1.3140000	0.0078813	7.8507929	0.0001
	CONDBMD	1.4444667	0.0967182	1.3420000	1.6680000	0.0093544	6.6957721	0.0001
	MSBMD	1.2158000	0.1178760	1.0850000	1.4980000	0.0138947	9.6953417	0.0001
	TOTBMD	1.2625333	0.0994864	1.1630000	1.4810000	0.0098976	7.8799063	0.0001
	TOTBMC	92.1036000	8.3161350	78.7630000	108.5890000	69.1581007	9.0291096	0.0001
22262	HEADBMD	1.1703077	0.1182183	0.9810000	1.4550000	0.0139756	10.1014708	0.0001
	CONDBMD	1.5199231	0.1463213	1.3370000	1.8440000	0.0214099	9.6268857	0.0001
	MSBMD	1.3254615	0.1482844	1.1030000	1.5640000	0.0219883	11.1873801	0.0001
	TOTBMD	1.3190000	0.1215435	1.1560000	1.5990000	0.0147728	9.2148252	0.0001
	TOTBMC	100.4688462	12.2113046	85.4340000	122.7180000	149.1159605	12.1543196	0.0001

Appendix 5

General Correctional Formulae

Level 2

Corrected Bone Mineral Content (CBMC)

= 7.16209 + (0.18627 * Total Length) + (-0.88195 * Condyle Width) + (0.14056 * Condyle Depth) + Process ± 0.45589

Where

Macerated in Glass	=	4.36923 ± 0.1467
Macerated in Plastic	=	7.20752 ± 0.1983
Simmered	=	9.67591 ± 0.2008
Boiled	=	3.08347 ± 0.0969

Level 3

CBMC = 9.57798 + (0.17614 * Total Length) + (-0.77693 * Condyle Width) + (0.03206 * Condyle Width) + Process ± 0.48106

Where

Macerated, Glass, Single	=	4.48443 ± 0.1444
Macerated, Plastic, Single	=	9.80572 ± 0.2319
Macerated, Plastic, Multiple	=	5.88759 ± 0.1554
Simmered	=	9.67591 ± 0.2008
Boiled	=	3.08371 ± 0.0969

Level 4

CBMC = 15.27406 + (0.15968 * Total Length) + (-0.88305 * Condyle Width)
+ (0.094448 * Condyle Depth) + Process ± 0.50873

Where

Macerated, Glass, Single, Distilled	=	-0.94228 ± 0.0714
Macerated, Glass, Single, Tap	=	8.59368 ± 0.2088
Macerated, Glass, Single, Tap & Biz	=	6.96859 ± 0.1789
Macerated, Plastic, Single, Distilled	=	17.02919 ± 0.3118
Macerated, Plastic, Single, Tap	=	5.73199 ± 0.1264
Macerated, Plastic, Single, Tap & Biz	=	7.75822 ± 0.1840
Macerated, Plastic, Multiple, Distilled	=	7.15694 ± 0.1294
Macerated, Plastic, Multiple, Tap	=	4.20647 ± 0.1005
Macerated. Plastic, Multiple, Tap & Biz	=	5.28137 ± 0.0916
Simmered, Multiple, 24 Hours	=	9.84391 ± 0.2008
Boiled, Multiple, 24 Hours	=	6.91698 ± 0.1594
Boiled, Multiple, 8 Hours	=	-0.01756 ± 0.0017

Vitae

Rex McDonald was born in a small town, graduated from the local High School and received his B.A from a regional state university.