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# COMPARATIVE ANALYSIS OF ROENTGENOLOGIC METHODS FOR AGE EVALUATION USING HAND BONES

*ABSTRACT: The use of bone roentgenology for age estimation is convenient inasmuch as it is a comparatively economical, sufficiently precise and technically uncomplicated method. It is also a non-invasive method, in particular when peripheric structures like hand bones are assessed, which is important in investigations of living subjects. The primary aim of the present study was to choose the most reliable method of age evaluation out of several roentgenologic methods using hand bones. Two different populations have been included in the present study: a) Israelis (365 cadavers, the mean age 46.5 years (S.D. = 21.2 years) for males, and 56.5 (S.D. = 21.5) years for females), and b) Turkmenians (643 living subjects, the mean age 49 years (S.D. = 17.1 years) for males, and 47.9 (S.D. = 14.6) years for females). Standard posteroanterior radiograms of both hands were performed for all subjects, to assess: a) bone mineral density (BMD) on the distal and the middle phalanges of the IIIrd finger, b) osseometric indices (OSM) on the II-Vth metacarpal bones, and 3) an osseographic score (OSS) which recorded the occurrence of the following: (a) osteophytes and exostoses, (b) osteoporosis, (c) osteosclerosis, and (d) non-traumatic articular deformities, on the phalanges of the II-Vth fingers. All measurements were taken on both hands and pulled together after respective standardization.*
*The study investigated ethnic differences in bone age measurements and their usefulness in chronological age prediction. Multiple regression analysis was employed in order to explore the possibility of predicting chronological age of an individual by OSS, OSM and BMD. The equations we elaborated led to polynomial functions, showing that OSS and its power functions are stronger predictor variables of an individual's age. The cubed regression of OSS showed the highest values (R = 0.930 – 0.936 in Israelis and R = 0.896 – 0.908 in Turkmenians, p less than 0.001). The error of age prediction of most equations (approximately ±7-10 years) compares favourably with current methods of age prediction. Moreover, these equations allow to extend the upper limit of age estimation to beyond 70 years, when gross skeletal changes that are currently in use become relatively useless.*

*KEY WORDS: Bone aging – Roentgenography – Age evaluation – Human identification – Bone mineral density – Israel – Turkmenia*

## INTRODUCTION

The forensic methods of age estimation in use today are based almost exclusively on skeletal changes with age (Lovejoy *et al.* 1985, Loth, Iscan 1994, Plato *et al.* 1994). These which have been proposed for the study of human fossils are of very limited value in studying living populations. Another drawback of modern age evaluation via methods of physical anthropology is the lack of consensus regarding the best method of age evaluation,

which ideally should be both precise and inexpensive (Lovejoy *et al.* 1985, Plato *et al.* 1994). Particular methods of bone age evaluation are usually reliable and appropriate only for one age group. Moreover, most investigators use their own methods (Kerley 1965, Loth, Iscan 1994) or modify those of others (Ericksen 1991), with the end result that the data on aging from various sources are often uncomparable. Thus, despite numerous investigations in this field since the 1920s, experts today still have no sure way of attaining a pinpoint accuracy in every instance of age evaluation.

The preference of the skeletal system for assessing aging was motivated by the relative stability of the skeletal system's parameters during short time intervals vs. their considerable change over long periods, the large number of criteria available for such evaluation, and the relative simplicity of their recording (Kiebzak 1991). The use of roentgenology for age estimation is likewise convenient inasmuch as it is comparatively economical, sufficiently precise and technically uncomplicated (Kobyliansky *et al.* 1985, Ostlere, Gold 1991). In practice, however, even within the framework of roentgenography, only selected parts of the skeletal system can be evaluated for age estimation. The hand bones are advantageous in this respect, because a single X-ray picture of the hand encompasses 27 entire bones, the distal parts of the ulna and radius, and also the sesamoid bones (Kobyliansky *et al.* 1985). Several age-related traits are best evinced on hand bones, e.g. spur formation in the exostoses which develop at the attachments of the flexor and extensor tendons of the distal phalanx (Kellgren, Lawrence 1957). An additional incentive for use of the hand in living population study is the fact that when only hands are filmed the risks of radiation exposure for the investigated person are minimized (Yegorov *et al.* 1993).

Several radiographic procedures are widely used to assess bone health and age status. The primary aim of the present study was to choose the most reliable method of age evaluation out of several roentgenologic methods proposed in the literature, including osseometric, osseographic and densitometric methods. We expected that the chosen method should enable direct and reasonably accurate evaluation of actual age as a function of bone age. An additional goal was to ascertain whether human actual age in forensic medicine could be predicted by the chosen method. First, however, we shall briefly describe the major roentgenologic methods of bone age evaluation.
a) Photodensitometry was the first quantitative method of estimating bone mineral density (BMD) by measuring bone absorption of X-ray ionization. It is known that BMD may serve as an objective estimate of the degree of bone loss, thereby comprising an indirect measure of an individual's aging. Kimura (1992) suggested that the parameters related to the cortical mass and BMD are evidently age-associated. Photodensitometry is a technique that employs a radiographic film and a standardized wedge to estimate BMD as proportional to the mineral mass (Ostlere, Gold 1991). Because variations in the amount of soft tissue surrounding the bone and within the medullary canal are not accounted for by photodensitometry, acceptable accuracy of this technique can be obtained only at peripheral anatomical sites, where there is less soft tissue, e.g. the hand and forearm.

Recent technological advances, however, have resulted in increasingly more precise and accurate methods of estimating BMD, including radiographic absorptiometry, single- and dual-photon absorptiometry, dual-energy X-ray absorptiometry and quantitative computed tomography (Genant *et al.* 1991, Nickoloff 1992, Adams 1992, Trouerbach *et al.* 1993). However, the accuracy and precision of radiographic densitometry of hand bones are high enough (Virtama 1957, Trouerbach *et al.* 1988) and not inferior to dual-photon absorptiometry (Nikoloff 1992). This is why photodensitometry is still widely used (e.g. Kimura 1992, Oyster 1992, Trouerbach *et al.* 1993). Though errors do crop up rarely in the calculation of BMD by photodensitometry, they are mostly artefacts of the radiography rather than a fault in the densitometric device.
b) Radiogrammetry involves the caliper measurement of cortical bone indices from a simple radiogram. As a consequence of osteoporotic changes, the resolution of spongiosa and the thinness and fibrilization of compacta, there occurs a widening of the bone marrow cavities of long bones. Basing on the fact that the endosteal loss and periosteal gain are both intercorrelated and age-dependent, Dequeker (1976) argued that basic measurements of cortical area thickness could serve in indirect evaluation of bone mass. His basic measurements were the outer diameter or periosteal width (D) and the inner diameter or medullary space (d) of the cortex at the midpoint of the shaft, while cortical thickness (CT) was calculated by the simple formula: $CT = D - d$. Garn (1970) earlier proposed another estimate which also takes into account the size of the bone, namely the cortical area percent (CAP). More recently, Kaur and Jit (1990) calculated the cortical index (CI) as the ratio of combined cortical thickness (the sum of thicknesses of cortex on both sides of the bone image) to the total diameter of the bone.

The technique of radiogrammetry is highly practical, requiring merely reproducible X-ray photographs and fine caliper measurements. A recent comparison of radiogrammetry with gravimetric or absorptiometric methods of BMD estimation, has shown it to be sufficiently precise and accurate (Yegorov *et al.* 1993).
c) Characteristic age-related architectural changes of adult bones include not only the enlargement of the medullary cavity and trabeculation of cortical bone but also scalloping of the inner surface of the cortex (Ostlere, Gold 1991), the appearance of osteophytes and exostoses (Kellgren, Lawrence 1957), osteoporotic foci and resorption lacunae, the incipience of nuclei of sclerosis and joint deformations (Kallman *et al.* 1989, 1990), geometric changes in different parts of bones (Nekliudov 1968), deformity of bone ends and narrowing of joint spaces (Trouerbach *et al.* 1993).

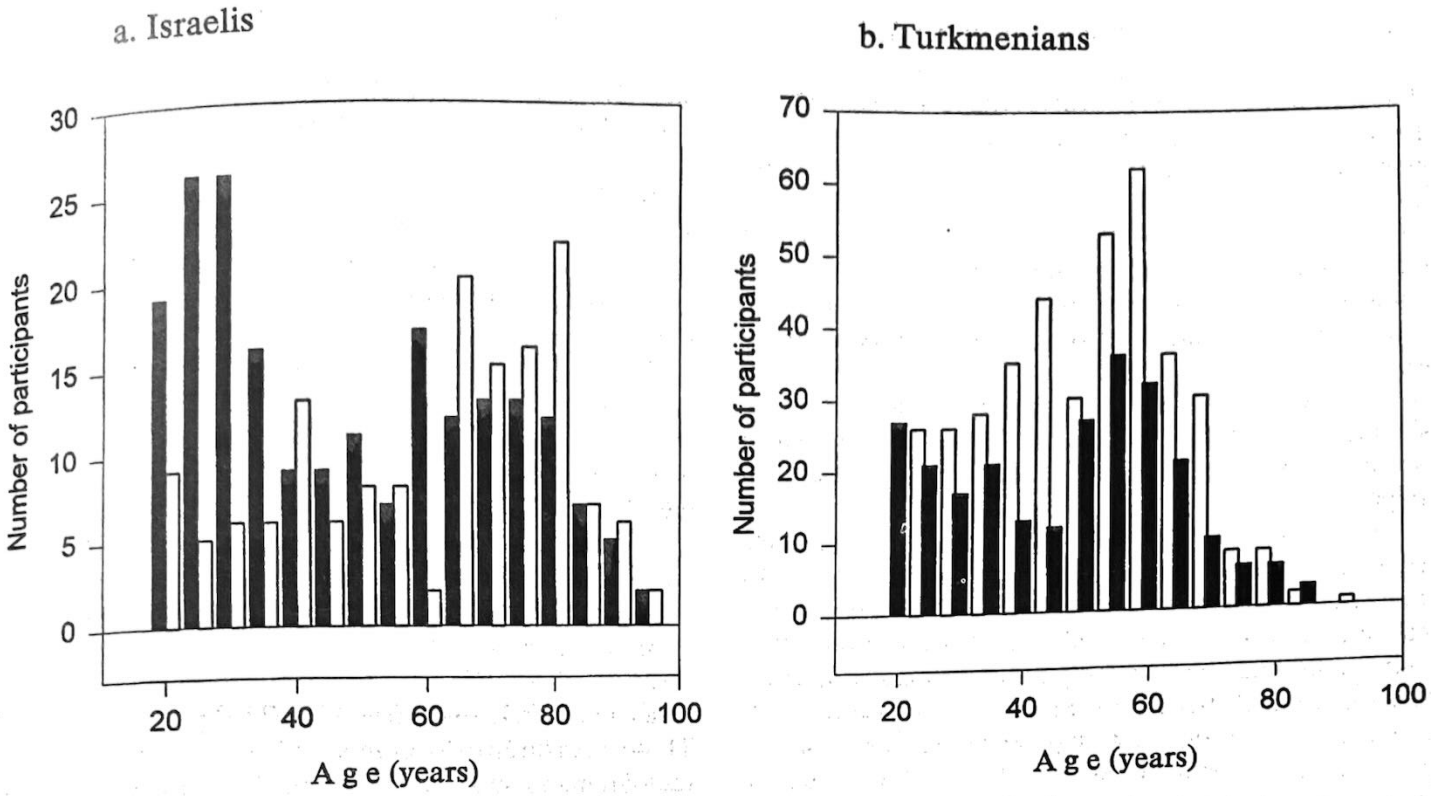


FIGURE 1. Age content of the two ethnic samples, by sex. Black columns – males, white columns – females.

Pavlovsky (1987) reported a new osseographic method (OSS) for bone aging assessment as based on afore mentioned radiographic features of the hand. OSS entails descriptive criteria of bone aging as, for example, the appearance of the osteophytes, exostoses, and signs of osteoporosis, osteoarthritis or sclerosis on phalangeal bones. The age dependence of OSS is very strong and can be rather accurately described by the function:

$$X(t) = \begin{cases} 0, & \text{if } t < t_0 \\ B(t - t_0 & \text{if } t \geq t_0 \end{cases}$$

where X and t are the individual's OSS measurement and age; $t_0$ is a specific point after which X starts to grow with age (visible bone changes are incurred, whereas at age $t < t_0$ no bone changes are detectable), and B is the rate of bone change per time (age) unit, i.e. the regression coefficient. The stochastic model (Kobyliansky *et al.* 1995) also used the terms TM (the mean age at which transition into the visible stage of bone aging occurs) and q – the probability that an individual will first develop involutive bone change at age $t_i \geq t_0$, i.e. the probability that the individual will move into the visible stage of aging.

Previously, Nekliudov (1968) proposed another osseographic score. This method bases on the use of the scale of osteophyte formation (Kellgren, Lawrence 1957). The studied traits are: form of tuberosity of the distal phalanges, form of the phalangeal bases, contours of the joint cavity margins, and exostoses (Heberden's spurs and osteophytes) on shafts of the distal phalanges. The method takes in consideration the X-ray images of distal phalanges only.

## MATERIAL AND METHODS

### Data collection and sample

Two different populations have been included in the present study:

a) An Israeli one comprised of 365 cadavers, aged 17 to 96 years, consisting of 206 males and 159 females, examined by one of the authors (D.K.) at the L. Greenberg Institute of Forensic Medicine, Tel-Aviv, Israel. The compilation of the sample was carried out over a period of two years (1993-1994). The mean age for males was 46.5 (S.D. = 21.2) years, and for females – 56.5 (S.D. = 21.5) years (*Figure 1a*). The two main ethnic groups in Israel were represented in the sample, namely Jews and Arabs (80 and 20 percent of the sample, respectively). The geographic origin of the Jews included about 30 countries of the world, mainly East European ones.

b) Turkmenians from rural regions of the former Soviet Republic of Turkmenia. The sample comprised the anthropological measurements and X-ray pictures of 643 living subjects, the members of about 100 nuclear families (from each pedigree only unrelated parents were selected for further analysis). These families had lived in little villages for more than 3 generations and had no intermixture with non-Turkmenian people. This material

was gathered during the summer of 1993, by a joint expedition of the Department of Anatomy and Anthropology, Tel Aviv University (Israel), and the Moscow University Anthropological Institute (Russia). The mean age for males was 49 years (S.D. = 17.1 years), and for females – 47.9 (S.D. = 14.6) years (*Figure 1b*).

The choice of the Turkmenian population was not accidental but rather dictated by the following requirements: 1) absence of intermixture with other populations; 2) willingness to participate in the study by residents and local authorities; 3) a well-established anthropological station and all the necessary laboratory facilities to perform the field work; and 4) similarity of socio-economic and occupational status in the overall rural population.

Basic socio-demographic data, including chronologic age and records of previous morbidity were collected for each of the subjects in the Israeli sample. Data on morbidity (by interview with relatives of the deceased or by autopsy) were available for 316 subjects. No cases with prior diabetes mellitus, hyperparathyroidism, chronic obstructive lung disease, ovariectomy, malignancies, severe atherosclerosis, confinement to bed or known use of corticosteroids (or hormone replacement therapy) were included to the study, because these diseases or drugs influence the bone mass (Kahn *et al.* 1994). Other pathological manifestations, albeit of not influence on bone development and metabolism, were evident in 144 subjects. Occupational history was available for 223 subjects in the Israeli sample and for the entire Turkmenian sample.

## BONE AGING ASSESSMENT

### X-ray filming

Standardized posteroanterior radiograms of both hands were performed for all subjects. Both hands were placed on the same film-containing plate to avoid any film or development variation. The hands of subjects were radiographed (AGFA Curix XP film, Belgium) with an anode-film distance of 80-100 cm in the dorsal-volar projection, using a standard radiographic technique (Pavlovsky 1987), without intensifying screens, with the AGFA-Gevamatic 60 System (AGFA, Germany), together with an aluminium step wedge, 120 mm long, which consisted of 99.9% Al and 0.1% other elements, each step having an area of 10 mm x 10 mm and 0-12 mm height. For affixation of hands of cadavers to the film plate, we used rubber bands with side hooks. Films were automatically developed using the recommended AGFA-Gevamatic machine and the appropriate protocol (6 minutes at 20° C).

### Bone mineral density (BMD)

BMD was measured according to a special method applicable to phalanges, as described by Pavlovsky (1987) and Trouerbach *et al.* (1988). The laser densitometric analysis was performed using the 0.1 mm diameter spot beam. The data were scanned by a helium-neon linear laser densitometer LKB 2202 (UltroScan XL, Sweden) at 4 different points on the images of IIIrd finger bones of both hands and along the wedge image longitudinally on the films. Each measure was then standardized for a film exposure, estimated by the densitometry value of the film background against the wedge. The results were computed using the standard nomograms of Pavlovsky (1987).

In the course of the present analysis, the BMD measurements of compact and cancellous (spongious) bone on the distal phalanx (CD and SD, correspondingly) and on the middle phalanx (CM and SM, correspondingly) of the IIIrd finger were taken on each hand.

Paired T-test was applied to compute the intra-observer error of BMD estimation. The measurements were taken twice on 30 subjects by the same investigator (O.P.). The error did not exceed 1.5-2% in most cases.

### The osseometric measurements (OSM)

These measurements comprised bone dimensions on radiogram, as suggested previously (Garn *et al.* 1967, Dequeker 1976, Plato, Norris 1980). The measurements and indices employed in our investigation entailed the following dimensions of the II-Vth metacarpal bones:

1. Maximal length of bone (L), in mm
2. Width of bone in the middle of the diaphysis (D), in mm
3. Width of the medullar canal in the middle of the diaphysis (d), in mm
4. Cortical thickness (in mm): $CT = D - d$
5. Cortical index (in percent) : $CI = [(D - d)/ D ] \times 100$
6. Cortical area (in percent): $CAP = [(D^2 - d^2)/ D^2] \times 100$.

These measurements were taken on the light table with digitized Ultra-Cal caliper (F.V. Fowler Co.,USA), linked to an Olivetti M24 PC.

Paired T-test was applied to compute the intra-observer error of OSM. The measurements were taken twice on 30 subjects by the same investigator. The correlation between two OSM measurements was not less than 0.9 in all cases (*Table 1*).

### The osseographic scores

All roentgenograms were analyzed by an observer oblivious to the sex, age and ethnic group of subjects. For each roentgenogram an equidistant osseographic score (OSS) was estimated, as fully described recently by Pavlovsky (1987) and Kobyliansky *et al.* (1995). In brief, to assess the OSS rank of an individual we recorded the occurrence of the following: (1) osteophytes in the periarticular regions of the bone and at the sites of muscle-tendon attachment; (2) manifestation of osteoporosis; (3) osteosclerosis, (4) non-traumatic articular deformities, and (5) enlargement of *tuberositas unquicularis* on distal phalanges. The phalanges of the II-Vth fingers were observed. The number of rearrangement elements of the

TABLE 1. Intra-observer error in OSS and OSM measurements in right hand in Israeli sample.

| Measure | Observation | Value of Measurement Mean | S.D. | S.E. | Correlation | t Value |
|---|---|---|---|---|---|---|
| OSS (N=100) | I | 6.25 | 4.74 | .75 | | |
| | II | 6.33 | 4.52 | .72 | .986 S* | .20 N |
| OSM ( N = 30 ) | | | | | | |
| 2nd metacarpal bone | | | | | | |
| LENGTH | I | 67.13 | 6.09 | 1.97 | | |
| | II | 67.83 | 6.70 | 2.01 | .986 S | 1.76 N |
| WIDTH | I | 9.34 | 1.03 | .10 | | |
| | II | 9.39 | 1.09 | .11 | .957 S | 5.98 N |
| CAVITY WIDTH | I | 4.73 | 1.15 | .26 | | |
| | II | 4.70 | 1.13 | .27 | .962 S | 7.55 N |
| 3rd metacarpal bone | | | | | | |
| LENGTH | I | 64.31 | 6.93 | 1.27 | | |
| | II | 65.10 | 7.18 | 1.31 | .909 S | .62 N |
| WIDTH | I | 9.08 | .93 | .19 | | |
| | II | 9.19 | .93 | .16 | .957 N | .91 N |
| CAVITY WIDTH | I | 5.06 | 1.04 | .19 | | |
| | II | 4.99 | 1.09 | .27 | .962 S | 8.57 N |
| 4th metacarpal bone | | | | | | |
| LENGTH | I | 57.95 | 4.79 | .88 | | |
| | II | 58.80 | 5.34 | .99 | .898 S | .81 N |
| WIDTH | I | 7.45 | .88 | .90 | | |
| | II | 7.50 | .96 | .14 | .924 N | .91 N |
| CAVITY WIDTH | I | 3.91 | .93 | .13 | | |
| | II | 3.93 | .86 | .12 | .968 S | .93 N |
| 5th metacarpal bone | | | | | | |
| LENGTH | I | 53.83 | 4.74 | 1.78 | | |
| | II | 54.11 | 4.77 | 1.55 | .909 S | .80 N |
| WIDTH | I | 8.44 | 1.18 | .31 | | |
| | II | 8.46 | 1.25 | .19 | .943 N | .92 N |
| CAVITY WIDTH | I | 4.78 | 1.02 | .19 | | |
| | II | 4.81 | 1.03 | .18 | .980 S | 1.38 N |

Roman numbers – attempts of estimation.
* Significance of t: S ($p<<0.05$), N ($p>>0.05$).

bone with age were recorded in total, without differentiation into individual types.

Paired T-test was applied to compute the intra- and inter-observer error of OSS estimation. To this end, the measurements of OSS were taken twice on 100 subjects by the same investigator (O.P.) and once by another (D.K.) (*Table 1*). The precision of OSS evaluations was high (not less than 98% in each comparison).

### Statistical Analysis

Paired T-test for comparing measurements on two hands was performed in order to resolve the question as to the existence of possible direct asymmetry in the measured traits. When the means of bilateral traits on both hands showed no differences, they were combined for subsequent analyses. As a rule, the asymmetric traits first underwent standardization and then the standardized data from both sides were combined. Thus, the mean of each measurement became zero and variance became 1.

In our analysis of variance, the observed variability in the sample was divided into two components – variability of the observations within a sex or ethnic group and variability of the group means between sex or ethnic groups. Therefore, our general sample was divided into 4 sex-ethnic groups (Israelis and Turkmenians, males and females). Two-way ANOVA with covariate age was then applied to assess ethnic and sex differences in each of our age-related bone traits.

To study relationships among our measures of bone aging, PCA of all quantitative traits was performed. The factors retained in the PCA by the eigenvalue 1 criterion, underwent transformation via an orthogonal rotation, the so-called VARIMAX rotation.

Multiple regression analysis was used by us for the evaluation of the relationships between different potential predictor factors (age, sex, ethnic group, health status, geographical origin and occupation) and their possible contribution to the variation of each of the age-related traits (OSS, OSM and BMD). The multiple regression analysis was used also to explore the possibility of predicting chronological age of an individual using his/her values of bone age measures. An attempt was made to find the most parsimonious and predictive combination of bone age traits.

All the aforenamed computations were performed on SPSS/PC Statistical Package (1990).

## RESULTS

### General Considerations

#### *OSS*

*Figure 2* shows the mean values of right hand OSS in both ethnic groups for both males and females. The patterns were similar for the left hand, and are therefore not shown. As seen in *Figure 2*, the age dependence of OSS, although not strictly linear, is obvious.

#### *BMD*

*Figure 3* shows the mean values of BMD measurements in both ethnic groups (CD as an example). Due to technical difficulties in the course of data sampling, the number of Israelis whose BMD was assessed, is small (only 124 from the 365 of the overall sample). There is no definite association between BMD values and age in Israeli males, while females show a pattern well fitting by the cubed polynomial regression on age ($r^2 = 0.424$, $p < 0.01$). Turkmenian males and females show similar association between BMD values and age. In both cases the cubed polynomial regression fits the data well ($p < 0.01$).

#### *OSM*

The data on three linear measurements (length, width and bone marrow cavity width) were obtained for each metacarpal bone except the Ist. The linear regression of widths of medullar cavities of metacarpal bones upon age

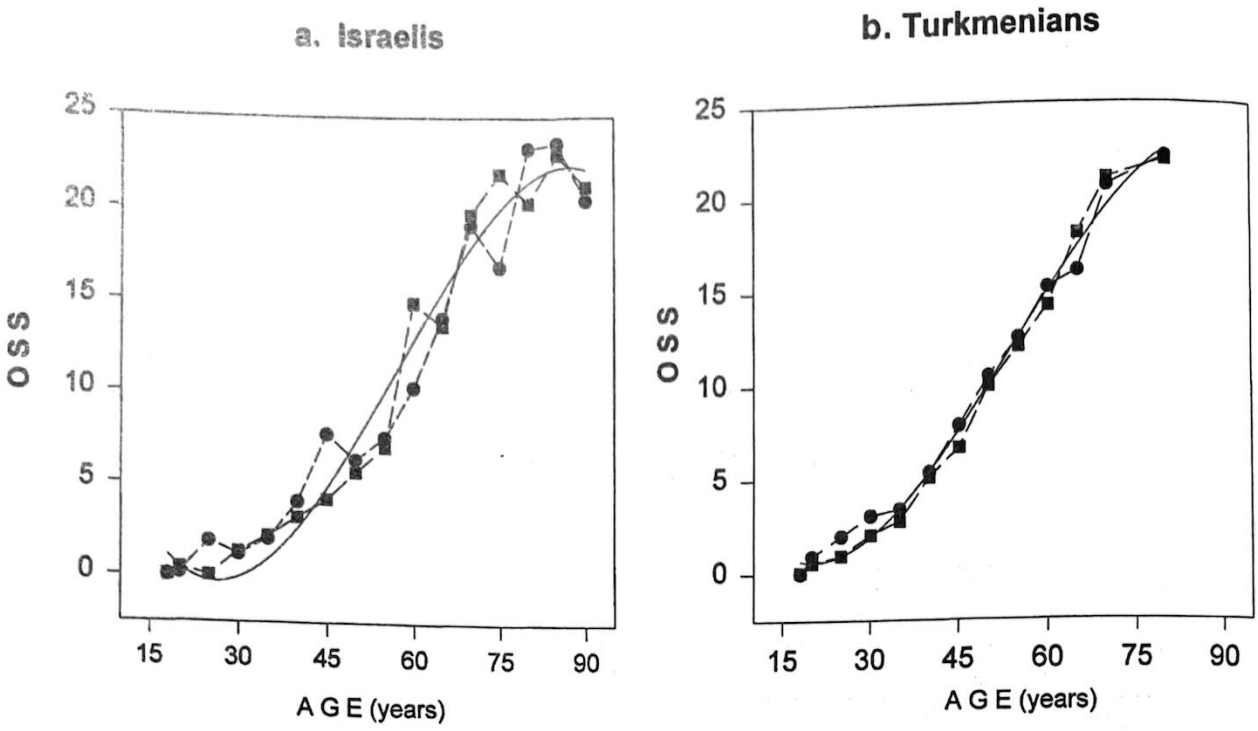


FIGURE 2. The mean values of osteographic score in both ethnic samples.
● – observed OSS in males
■ – observed OSS in females
Line – OSS predicted by a stochastic model, in total sample.

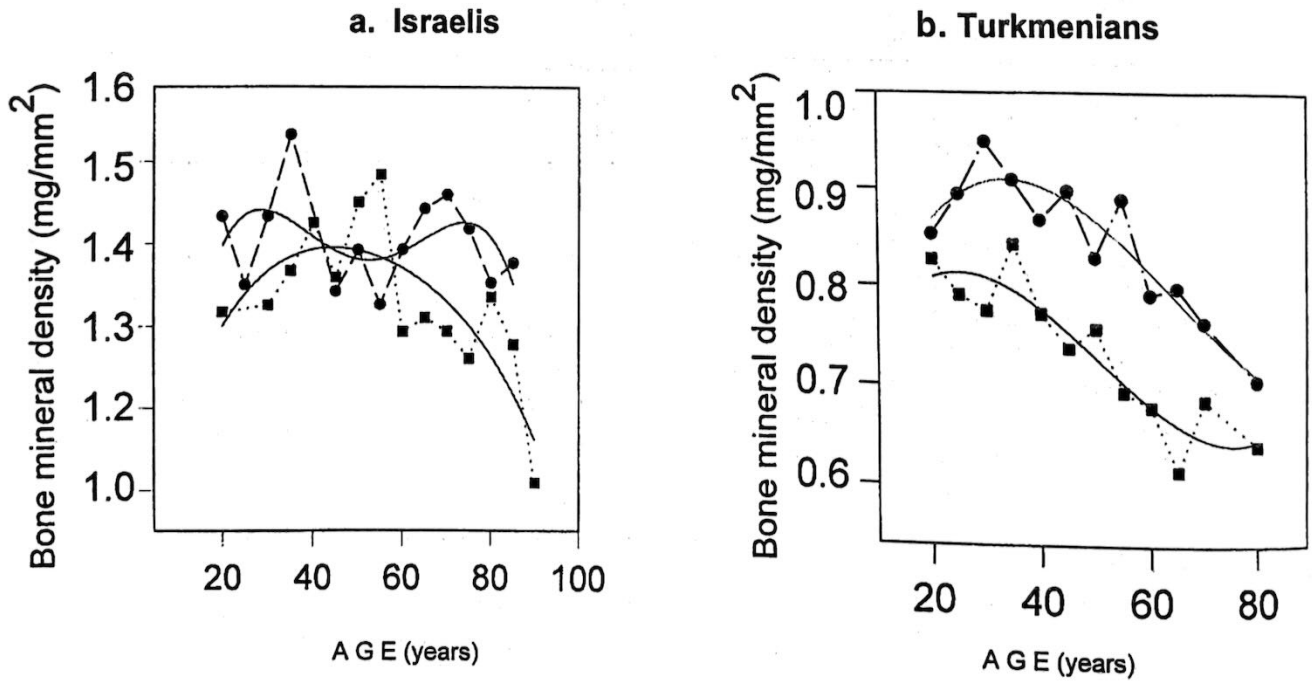


FIGURE 3. Bone mineral density (distal phalanx compacta) in both ethnic samples.
● – observed CD in males
■ – observed CD in females
Line – CD predicted in each sex.

TABLE 2. Paired T-test between bone aging traits of both hands.

| Sample | ISRAELI | | | | | TURKMENIAN | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TRAIT side | N | Mean | S.D. | Corr-elat. | t Value | ** | N | Mean | S.D. | Corr-elat. | t Value | |
| OSS | | | | | | | | | | | | |
| – right | 346 | 9.10 | 9.16 | | | | 570 | 9.20 | 7.40 | | | |
| – left | 346 | 8.94 | 9.08 | .95 | 1.15 | S | 570 | 8.87 | 7.20 | .94 | 3.11 | S |
| BMD, mg/mm² | | | | | | | | | | | | |
| CD | | | | | | | | | | | | |
| – right | 123 | 1.24 | .31 | | | | 642 | .81 | .22 | | | |
| – left | 123 | 1.23 | .32 | .64 | .83 | M | 642 | .78 | .21 | .61 | 3.26 | S |
| CM | | | | | | | | | | | | |
| – right | 123 | 1.35 | .18 | | | | 642 | 1.02 | .23 | | | |
| – left | 123 | 1.28 | .25 | .69 | 3.50 | S | 642 | .95 | .22 | .69 | 8.59 | S |
| SD | | | | | | | | | | | | |
| – right | 124 | .66 | .14 | | | | 642 | .46 | .12 | | | |
| – left | 124 | .63 | .17 | .60 | 1.63 | S | 642 | .43 | .11 | .63 | 7.63 | S |
| SM | | | | | | | | | | | | |
| – right | 122 | .47 | .09 | | | | 634 | .32 | .08 | | | |
| – left | 122 | .43 | .10 | .66 | 4.45 | S | 634 | .29 | .08 | .62 | 9.33 | S |
| OSM | | | | | | | | | | | | |
| CT2*, mm | | | | | | | | | | | | |
| – right | 276 | 4.59 | .96 | | | | 465 | 4.78 | .934 | | | |
| – left | 276 | 4.50 | .86 | .72 | 2.08 | M | 465 | 4.88 | .838 | .56 | 2.00 | S |
| CT3 , mm | | | | | | | | | | | | |
| – right | 274 | 4.26 | .94 | | | | 464 | 4.53 | 1.037 | | | |
| – left | 274 | 4.24 | .97 | .75 | .38 | N | 464 | 4.65 | .905 | .55 | 1.96 | S |
| CT4 , mm | | | | | | | | | | | | |
| – right | 274 | 3.48 | .72 | | | | 464 | 3.97 | .870 | | | |
| – left | 274 | 3.47 | .74 | .72 | .24 | N | 464 | 3.95 | .784 | .57 | .54 | M |
| CT5 , mm | | | | | | | | | | | | |
| – right | 259 | 3.57 | .75 | | | | 465 | 4.19 | .890 | | | |
| – left | 259 | 3.60 | .71 | .61 | .52 | N | 465 | 3.84 | .728 | .41 | 6.32 | S |
| CI2 , % | | | | | | | | | | | | |
| – right | 276 | 50.70 | 10.05 | | | | 465 | 55.19 | 9.35 | | | |
| – left | 276 | 50.70 | 9.88 | .75 | .15 | N | 465 | 57.94 | 9.06 | .61 | 4.92 | S |
| CI3 , % | | | | | | | | | | | | |
| – right | 274 | 47.97 | 9.94 | | | | 464 | 53.25 | 11.46 | | | |
| – left | 274 | 47.37 | 10.04 | .77 | .22 | N | 464 | 55.33 | 9.81 | .57 | 3.09 | S |
| CI4 , % | | | | | | | | | | | | |
| – right | 274 | 48.68 | 9.94 | | | | 464 | 56.17 | 11.24 | | | |
| – left | 274 | 47.48 | 9.94 | .70 | 1.35 | S | 464 | 57.02 | 10.55 | .60 | 1.35 | S |
| CI5 , % | | | | | | | | | | | | |
| – right | 259 | 43.43 | 9.74 | | | | 465 | 51.92 | 9.72 | | | |
| – left | 259 | 44.74 | 9.84 | .65 | 2.74 | S | 465 | 49.41 | 8.82 | .55 | 4.04 | S |
| CAP2,% | | | | | | | | | | | | |
| – right | 276 | 74.84 | 10.07 | | | | 465 | 79.05 | 8.98 | | | |
| – left | 276 | 74.95 | 9.87 | .75 | .55 | M | 465 | 81.49 | 7.99 | .55 | 4.65 | S |
| CAP3,% | | | | | | | | | | | | |
| – right | 274 | 71.81 | 10.07 | | | | 464 | 76.83 | 11.64 | | | |
| – left | 274 | 71.61 | 10.07 | .77 | .41 | N | 464 | 79.08 | 8.90 | .57 | 3.31 | S |
| CAP4,% | | | | | | | | | | | | |
| – right | 274 | 73.07 | 9.97 | | | | 464 | 79.52 | 10.44 | | | |
| – left | 274 | 72.52 | 9.97 | .69 | 1.25 | S | 464 | 80.41 | 9.63 | .49 | 1.45 | S |
| CAP5,% | | | | | | | | | | | | |
| – right | 269 | 67.87 | 9.86 | | | | 465 | 75.94 | 9.86 | | | |
| – left | 269 | 68.98 | 9.96 | .65 | 2.51 | S | 465 | 73.64 | 9.38 | .55 | 3.51 | S |

* Abbreviations: CT – cortical thickness, CI – cortical index, CAP – cortical area percent; number of finger added;

** Significance of t: S ($p<<0.05$), N ($p>>0.05$) and M ($p\sim0.05$).

TABLE 3. One-way analysis of variance between mineralization data on different phalanges.

| Sample | ISRAELI | | | | | TURKMENIAN | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TRAIT | N | Mean | S.D. | Cochran's Probability | F | N | Mean | S.D. | Cochran's Probability | F |
| CD (R.) | 134 | 1.23 | .28 | .01 | .00 | 225 | .79 | .12 | .03 | .00 |
| CM (R.) | 135 | 1.34 | .16 | | | 227 | .91 | .16 | | |
| CD (R.) | 135 | 1.23 | .28 | .01 | .00 | 225 | .79 | .12 | .01 | .00 |
| CM (L.) | 136 | 1.26 | .19 | | | 226 | .91 | .15 | | |
| SD (R.) | 134 | .66 | .11 | .00 | .00 | 230 | .46 | .06 | .00 | .00 |
| SM (R.) | 134 | .47 | .07 | | | 228 | .32 | .04 | | |
| SD (R.) | 135 | .66 | .11 | .00 | .00 | 230 | .46 | .06 | .00 | .00 |
| SM (L.) | 134 | .43 | .07 | | | 224 | .29 | .04 | | |

Abbreviations: CD - distal phalanx compacta, SD - distal phalanx spongiosa, CM - middle phalanx compacta, SM - middle phalanx spongiosa; R.- right hand, L.- left hand.

TABLE 4. Modelling patterns in bone change (OSS) with age in different subpopulations, using stochastic model.

| Ethnic group, sex, geographic origin | N | $t_0$ | S.E. $t_0$ | q | S.E. q | b | S.E. b | TM | Age range |
|---|---|---|---|---|---|---|---|---|---|
| Israelis, males | 206 | 19.0 | 0.61 | 0.086 | 0.008 | 0.358 | 0.002 | 30.6 | 17-95 |
| Jews, males | 156 | 20.4 | 1.02 | 0.092 | 0.009 | 0.387 | 0.002 | 31.2 | 17-95 |
| Arabs, males | 50 | 19.0 | 0.77 | 0.083 | 0.017 | 0.287 | 0.009 | 31.0 | 17-76 |
| Israelis, females | 159 | 19.0 | 1.10 | 0.085 | 0.014 | 0.394 | 0.002 | 30.7 | 17-96 |
| Turkmenians, males | 232 | 17.5 | 0.89 | 0.103 | 0.013 | 0.401 | 0.002 | 27.2 | 17-90 |
| Turkmenians, females | 328 | 18.8 | 0.81 | 0.204 | 0.021 | 0.402 | 0.002 | 23.7 | 17-96 |
| Samples united, males | 438 | 18.5 | 0.48 | 0.110 | 0.009 | 0.392 | 0.002 | 27.9 | 17-95 |
| Samples united, females | 487 | 17.9 | 0.57 | 0.096 | 0.010 | 0.384 | 0.001 | 28.2 | 17-96 |

$t_0$ – age of start of visible bone changes
q – the probability to develop involutive bone changes
b – the rate of bone change at age older than $t_0$
TM – the mean age at which visible bone changes occur (see Introduction).

was statistically significant in both ethnic samples (the concomitant Pearson correlation ranged between 0.539 – 0.543 in males, and 0.557 – 0.566 in females; $p < 0.001$ in all cases). The measurements of metacarpal length and periosteal width did not show marked changes with age. The three osteometric indices – CT, CI and CAP – were strongly related to age, though the patterns were clearly curvilinear and different among ethnic groups. Several polynomial regressions (simple nonlinear functions – cubed, Hompertz' and logarithmic regressions) were checked. Cubed regression was found to best fit the data, namely, 0.486 – 0.672 ($p < 0.01$) for Israelis and 0.535 – 0.782 ($p < 0.01$) for Turkmenians (males and females, respectively).

## Comparison of bilateral measurements on both hands

### *OSS*

The OSS was measured on both hands to detect possible directional asymmetry. The paired T-test for comparison

TABLE 5. One-way analysis of variance between sexes and ethnic groups in OSS residuals.

| GROUPS | N | Mean | S.D. | S.E. | Probability Cochrans | F |
|---|---|---|---|---|---|---|
| MALES (Israel) | 206 | .00 | 1.00 | .04 | .990 | .995 |
| FEMALES (Israel) | 159 | .00 | 1.00 | .02 | | |
| MALES (Turkmen.) | 252 | .24 | .99 | .02 | .168 | .068 |
| FEMALES (Turkmen.) | 289 | .07 | .91 | .07 | | |
| JEWS * (Israel) | 156 | .56 | 1.08 | .03 | .459 | .784 |
| ARABS* (Israel) | 50 | .02 | .99 | .12 | | |
| ISRAELIS * | 206 | .08 | 1.26 | .02 | .000 | .360 |
| TURKMEN. * | 252 | .00 | 1.00 | .03 | | |

* Males only.

TABLE 6. Two-way ANOVA of BMD measurements by sex with age as covariate.

| Sample | | ISRAELI (N = 124) | | | | TURKMENIAN (N = 578) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Trait | Source of variation | Group mean | Total mean | F | P* | Group mean | Total mean | F | P |
| C | Explained | | 1.22 | 34.07 | S | | .79 | 36.70 | S |
| | Sex M | 1.39 | | | | .85 | | | |
| | F | 1.06 | | 41.74 | S | .75 | | 46.12 | S |
| D | Age | | | 26.39 | S | | | 27.27 | S |
| | R Squared | | | .36 | | | | .31 | |
| S | Explained | | .64 | 16.97 | S | | .44 | 38.87 | S |
| | Sex M | .70 | | | | .48 | | | |
| | F | .59 | | 20.52 | S | .41 | | 69.12 | S |
| D | Age | | | 13.42 | S | | | 8.58 | S |
| | R Squared | | | .22 | | | | .22 | |
| C | Explained | | 1.28 | 11.64 | S | | .97 | 60.23 | S |
| | Sex M | 1.32 | | | | 1.00 | | | |
| | F | 1.24 | | .23 | M | .95 | | 12.13 | S |
| M | Age | | | 23.05 | S | | | 108.35 | S |
| | R Squared | | | .16 | | | | .15 | |
| S | Explained | | .44 | 8.94 | S | .31 | | 17.74 | S |
| | Sex M | .48 | | | | | .32 | | |
| | F | .41 | | 13.49 | S | .30 | | 18.79 | S |
| M | Age | | | 4.38 | S | | | 16.68 | S |
| | R Squared | | | .13 | | | | .04 | |

* Significance of F: S ($p < 0.01$), N ($p > 0.05$) and M ($p \sim 0.05$).

of two sides was performed in each ethnic sample. As can be seen from the results of the T-test (*Table 2a, b*), the sides showed no significant difference in the Israeli sample and consequently the data were combined to obtain a mean value of scores from both sides for further study. In the Turkmenian sample, the right side had significantly higher OSS values and therefore the data on each side were standardized before pooling.

***BMD***

As seen in *Table 2a*, in Israelis, the paired T-test showed no significant difference in BMD values of CD, but the sides did differ (albeit only marginally significant) in all other BMD comparisons. In Turkmenians, the right hand was significantly more mineralized than the left one (see *Table 2b*). Hence data on right and left hands in both samples were standardized and then combined for further analysis.

ANOVA was performed in both ethnic samples to answer the question regarding the possible similarity of the homologous BMD measurements between neighbouring phalanges of the same finger. Thus, the mean value and variance of CD were compared with these for CM. The comparison led to the rejection of the hypothesis that the distributions of compact BMD data on neighbouring phalanges were the same, with a probability of $p < 0.01$. A similar comparison was performed for SD vs. SM, and here also the same hypothesis was rejected (*Table 3*).

***OSM***

The paired T-test for comparison of OSM on two sides was performed (*Table 2*). Most of the OSM indices in the Israeli sample did not differ significantly between the hands, barring the CI and CAP of the IVth and Vth metacarpals. In Turkmenians, a very different pattern was presented, with most of the indices significantly different excepting these for the IVth metacarpal bone. To avoid inconsistency and remove the side differences, all OSM indices for both sides were standardized before pooling.

**Sex comparisons**

***OSS***

The curves of bone aging, as measured by OSS, were derived separately for males and females in two ethnic groups (*Figure 2*). In general, the slopes of the sex-specific curves are nearly identical and have a typical sigmoidal shape, showing an early "slow" phase followed by a phase of rapid increase in OSS means (after 30 – 35 years of age in both sexes and ethnic groups).

To compare the OSS in our array of samples we performed parametric ANOVA for age-adjusted OSS in men and women of both ethnic groups. We adjusted the OSS in the investigated groups by age, using the following approach: first we obtained the parameter estimates for the combined sample, composed of both sexes in each ethnic group, then we obtained the residual OSS values from the stochastic model fully described in Kobyliansky *et al.* (1995) and finally we compared the former with the latter.

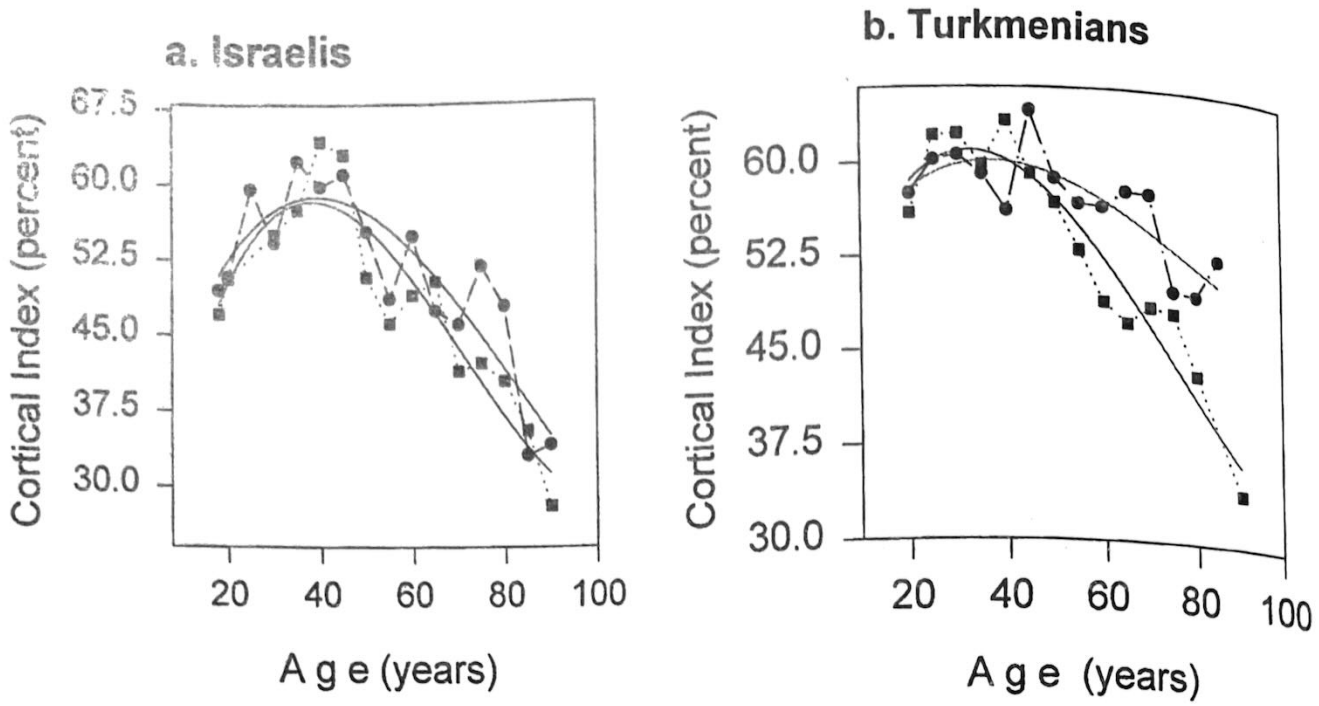


FIGURE 4. Osteometric index (CI of IInd metacarpal bone) in both ethnic samples.
● – observed CI2 in males; ■ – observed CI2 in females; Line – CI2 predicted for each sex.

In *Table 4* we provide estimates of the major parameters of the afore-mentioned stochastic model. These are given separately for women and men and for both ethnic groups. The null hypothesis in the first stage of this analysis was that there is no difference in OSS residuals between the sex specific distributions within each ethnic group (*Table 5*). The F-value probability of no group differences was very high in the Israeli sample and marginal in the Turkmenians. Cochran's probability of variance equality was also sufficiently large in both ethnic groups, hence the null-hypothesis that the two sexes have the same mean and variance could not be rejected.

### *BMD*

To compare the sex differences in BMD in our sample we performed two-way ANOVA. Age-adjustment was made by including age as a covariate with sex in ANOVA. The null hypothesis in this analysis was that there is no difference in bone aging as measured by BMD among the sex specific distributions. As seen in *Table 6*, sex-derived differences were significant in both samples for all BMD indices, excluding CM in the Israeli sample.

### *OSM*

The curves of bone aging, measured by OSM indices, were derived separately for males and females in each ethnic group (*Figures 4a, b*). In general, the slopes of the curves have a typical shape, showing an early phase of gradual increase, followed by a phase of gradual decrease (from 40 – 60 years on in both sexes).

To learn about sexual dimorphism in OSM indices, one-way ANOVA of each OSM index as a dependent variable was performed in each ethnic sample. The contribution of sex was considered, with age as a covariate. The sex-derived differences in Israelis were significant only in the case of CT for all four metacarpal bones ($p < 0.001$). ANOVA did not reveal significant differences between the sexes in the other OSM indices – CI and CAP. In Turkmenians, one-way ANOVA showed similar results, for CT of all four metacarpal bones. However, CI and CAP of the IInd and IIIrd metacarpals were also significantly higher in males (*Table 7*).

## Ethnic comparison of the studied populations

### *OSS*

Comparison of Israelis with Turkmenians was performed in the same way as the above sex comparisons. To test the differences between Israeli and Turkmenian populations of the same sex, subpopulations of both were pooled for computing the stochastic model parameters. Our null hypothesis assumed no differences among the population specific distributions insofar as age adjusted OSS residuals. Since the distributions of age adjusted residuals of bone aging in men and women overlapped almost completely, suffice here to mention only results obtained on male samples. As shown in *Table 5*, the obtained F-value probability of the null hypothesis was high ($p > 0.5$), which meant that the hypothesis that the populations had the same mean could not be rejected.

Apart from an Israeli – Turkmenian comparison, a similar comparison of Israeli Jews with autochthonous Arabs was also performed. As shown in *Table 5*, which compares male samples, the obtained F-value probability

TABLE 7. One-way analysis of variance between OSM in both sexes.

| Sample | | ISRAELI | | | | TURKMENIAN | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| TRAIT Sex | N | Mean | S.D. | F Ratio | F Prob. | N | Mean | S.D. | F Ratio | F Prob. |
| CT2 | | | | | | | | | | |
| Males | 172 | 4.96 | .65 | 24.31 | S | 229 | 5.35 | .67 | 64.33 | S |
| Females | 115 | 4.38 | .70 | | | 285 | 4.60 | .71 | | |
| CT3 | | | | | | | | | | |
| Males | 171 | 4.67 | .70 | 28.47 | S | 220 | 5.10 | .72 | 50.87 | S |
| Females | 115 | 3.97 | .77 | | | 284 | 4.37 | .78 | | |
| CT4 | | | | | | | | | | |
| Males | 172 | 3.77 | .75 | 30.56 | S | 220 | 4.35 | .75 | 38.10 | S |
| Females | 115 | 3.26 | .69 | | | 284 | 3.79 | .65 | | |
| CT5 | | | | | | | | | | |
| Males | 170 | 3.76 | .69 | 40.65 | S | 229 | 4.39 | .66 | 39.55 | S |
| Females | 112 | 3.36 | .66 | | | 286 | 3.86 | .61 | | |
| CI2 | | | | | | | | | | |
| Males | 172 | 52.20 | 9.08 | 2.25 | N | 220 | 57.68 | 7.07 | 2.25 | S |
| Females | 115 | 49.63 | 10.38 | | | 285 | 56.08 | 8.34 | | |
| CI3 | | | | | | | | | | |
| Males | 171 | 49.52 | 9.26 | 5.38 | N | 220 | 56.26 | 8.29 | 5.38 | S |
| Females | 115 | 46.34 | 9.93 | | | 284 | 53.43 | 9.41 | | |
| CI4 | | | | | | | | | | |
| Males | 172 | 50.20 | 0.08 | 1.37 | N | 220 | 56.86 | 0.03 | .09 | N |
| Females | 115 | 48.03 | 9.38 | | | 284 | 56.47 | 9.35 | | |
| CI5 | | | | | | | | | | |
| Males | 170 | 45.28 | 7.86 | .40 | N | 229 | 50.43 | 7.85 | .10 | N |
| Females | 112 | 45.37 | 7.73 | | | 286 | 50.77 | 7.79 | | |
| CAP2 | | | | | | | | | | |
| Males | 172 | 76.64 | 6.49 | .61 | N | 220 | 81.39 | 6.43 | 2.67 | S |
| Females | 115 | 77.07 | 7.68 | | | 285 | 79.78 | 7.69 | | |
| CAP3 | | | | | | | | | | |
| Males | 171 | 74.14 | 7.44 | .01 | N | 220 | 79.84 | 7.47 | 5.35 | S |
| Females | 115 | 73.62 | 9.14 | | | 284 | 77.14 | 9.15 | | |
| CAP4 | | | | | | | | | | |
| Males | 172 | 74.40 | 9.09 | .37 | N | 220 | 80.19 | 9.04 | .07 | N |
| Females | 115 | 74.46 | 8.68 | | | 284 | 79.88 | 8.60 | | |
| CAP5 | | | | | | | | | | |
| Males | 170 | 69.29 | 7.99 | .13 | N | 229 | 74.49 | 7.96 | .15 | N |
| Females | 112 | 69.51 | 8.11 | | | 286 | 74.91 | 8.10 | | |

Significance of F: S ($p < 0.01$), N ($p > 0.05$).

was higher than 0.05, while Cochran's probability was significantly small ($p < 0.001$), so again the null-hypothesis that the populations have the same mean OSS could not be rejected, despite high heterogeneity in the variance of the OSS values in the two populations.

### *BMD*

We compared Israeli subjects with Turkmenians in both sexes, and this by using ANOVA. The hypothesis regarding no difference in BMD between the population specific distributions was rejected because the means in both samples differed significantly, with both Israeli males and females showing much more BMD than their Turkmenian counterparts (for distal compacta, F ratio = 12.6, $p < 0.01$). Yet the variance of BMD distribution in both populations was similar (Cohran's $p > 0.5$).

Since the number of subjects with available BMD measurements in Israeli sample was small, we could not compare ethnic groups – Jews and Arabs – within the confines of the Israeli sample.

### *OSM*

The comparison of Israelis and Turkmenians was performed by one-way ANOVA with each of the OSM indices as dependent variable. The ethnic differences were found to be significant in all OSM indices (see *Figure 4*).

Comparison of Jews and autochthonous Arabs was performed with regard to sex differences. In our two-way ANOVA (with each of the OSM indices as a dependent variable) we included ethnic group and sex as the main factors, with age as a covariate. The ethnic differences were significant only in the case of CI and CAP of the IInd metacarpal bone. Two-way ANOVA did not reveal significant differences between ethnic groups in other OSM indices.

TABLE 8a. Results of principal components analysis of age-related roentgenologic variables in Israeli sample.

| Trait | Communality | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|---|
| **FEMALES** | | | | |
| OSS | .752 | −.829 | | |
| CD | .884 | .641 | −.330 | .602 |
| SD | .944 | .578 | −.443 | .643 |
| CM | .850 | .712 | −.585 | |
| SM | .754 | .550 | −.667 | |
| CI2 | .862 | .915 | | |
| CI3 | .907 | .938 | | |
| CI4 | .870 | .909 | | |
| CI5 | .927 | .717 | .584 | |
| CT2 | .777 | .877 | | |
| CT3 | .937 | .948 | | |
| CT4 | .819 | .804 | | .360 |
| CT5 | .833 | .676 | .580 | |
| CAP2 | .840 | .909 | | |
| CAP3 | .936 | .712 | .602 | |
| CAP4 | .867 | .916 | | |
| CAP5 | .887 | .920 | | |
| Eigenvalue 1 | | 11.1 | 2.3 | 1.2 |
| % of factor | | 65.3 | 13.5 | 7.4 |
| Cumulative % | | 65.3 | 78.8 | 86.2 |
| **MALES** | | | | |
| OSS* | .609 | | −.776 | |
| CD | .894 | −.454 | .347 | .752 |
| SD | .868 | | | .855 |
| CM | .853 | | .914 | |
| SM | .802 | | .767 | −.425 |
| CI2** | .946 | .968 | | |
| CI3 | .993 | .991 | | |
| CI4 | .991 | .989 | | |
| CI5 | .984 | .990 | | |
| CT2 | .982 | .989 | | |
| CT3 | .984 | .978 | | |
| CT4 | .969 | .984 | | |
| CT5 | .974 | .967 | | |
| CAP2 | .992 | .988 | | |
| CAP3 | .992 | .992 | | |
| CAP4 | .986 | .983 | | |
| CAP5 | .985 | .981 | | |
| Eigenvalue 1 | | 12.0 | 1.8 | 1.5 |
| % of factor | | 70.7 | 10.7 | 9.3 |
| Cumulative % | | 70.7 | 81.4 | 90.8 |

* All traits are average of bilateral standardized data.
** Number of fingers added.
Blank spaces represent a load value lesser than 0.3.

TABLE 8b. Results of principal components analysis of age-related roentgenologic variables in Turkmenian sample.

| Trait | Communality | FACTOR 1 | FACTOR 2 | FACTOR 3 | FACTOR 4 |
|---|---|---|---|---|---|
| **FEMALES** | | | | | |
| OSS | .463 | −.622 | | | |
| CD | .693 | | | .786 | |
| SD | .779 | | | .873 | |
| CM | .722 | .404 | | .725 | |
| SM | .604 | | | .754 | |
| CT2 | .775 | .820 | | | |
| CT3 | .832 | .837 | | | |
| CT4 | .694 | .758 | | | |
| CT5 | .875 | .370 | .832 | | |
| CI2 | .842 | .850 | .319 | | |
| CI3 | .879 | .863 | .321 | | |
| CI4 | .804 | .821 | .311 | | |
| CI5 | .967 | .422 | .876 | | |
| CAP2 | .819 | .833 | .324 | | |
| CAP3 | .850 | .846 | .316 | | |
| CAP4 | .766 | .794 | .314 | | |
| CAP5 | .964 | .409 | .880 | | |
| Eigenvalue 1 | | 10.2 | 1.9 | 1.2 | |
| % of factor | | 60.0 | 11.4 | 7.1 | |
| Cumulative % | | 60.0 | 71.4 | 78.5 | |
| **MALES** | | | | | |
| OSS | .459 | | | | −.668 |
| CD | .658 | | | .774 | |
| SD | .691 | | | .831 | |
| CM | .601 | | | .735 | |
| SM | .656 | | | .798 | |
| CT2 | .776 | .858 | | | |
| CT3 | .752 | .681 | .376 | | .343 |
| CT4 | .774 | .437 | | | .700 |
| CT5 | .893 | | .880 | | |
| CI2 | .912 | .926 | | | |
| CI3 | .825 | .753 | .388 | | .310 |
| CI4 | .877 | .566 | | | .674 |
| CI5 | .961 | .381 | .880 | | |
| CAP2 | .906 | .925 | | | |
| CAP3 | .812 | .760 | .373 | | |
| CAP4 | .881 | .542 | | | .705 |
| CAP5 | .957 | .371 | .881 | | |
| Eigenvalue 1 | | 8.6 | 2.2 | 1.3 | 1.2 |
| % of factor | | 50.6 | 13.3 | 8.0 | 6.9 |
| Cumulative % | | 50.6 | 63.9 | 71.9 | 78.8 |

## Principal component analysis (PCA)

To study relationships among our measures of bone aging, principal component analysis was undertaken (*Table 8a, b*). The first three factors with eigenvalues greater than 1.0 were retained in the present analysis for both ethnic groups and sexes. Notably, however, the principal decomposition of correlation matrices for men and women showed a different pattern. The first three extracted factors in the Israeli sample (namely F1, F2 and F3) explained 89.4 % of the total variation in males and 94.8 % of the total variation in females. The communality estimates show that a substantial portion of the variation of all the traits under study is

TABLE 9a. Polynomial regression analysis of individual's age on bone aging variables in Israeli sample.

| METHOD | Subpopulation | | Regression statistics: Correlation coefficient | | | | |
|---|---|---|---|---|---|---|---|
| | Variable | Variab. | N | Mult.R | $R^2$ | Sign.F | S.E.E.* |
| OSS | Males (all) | OSS | 206 | .879 | .773 | <.001 | |
| | | $OSS^2$ | | .928 | .862 | <.001 | |
| | | $OSS^3$ | | .930 | .866 | <.010 | 7.80 |
| | Males (35+ years) | OSS | 136 | .775 | .600 | <.001 | |
| | | $OSS^2$ | | .846 | .716 | <.005 | 7.77 |
| | Females (all) | OSS | 159 | .849 | .721 | <.001 | |
| | | $OSS^2$ | | .929 | .863 | <.001 | |
| | | $OSS^3$ | | .936 | .877 | <.001 | 7.55 |
| | Females (35+ years) | OSS | 121 | .736 | .542 | <.001 | |
| | | $OSS^2$ | | .841 | .708 | <.005 | |
| | | $OSS^3$ | | .844 | .712 | <.100 | 7.75 |
| BMD | CD Males | | 78 | | | >.050 | |
| | Females | | 59 | .573 | .328 | <.001 | 18.95 |
| | SD Males | | 78 | | | >.050 | |
| | Females | | 59 | .542 | .294 | <.001 | 19.44 |
| | CM Males | | 78 | | | >.050 | |
| | Females | | 58 | .651 | .424 | <.001 | 17.55 |
| | SM Males | | 77 | | | >.050 | |
| | Females | | 59 | | | >.050 | |

attributable to these three factors, which are briefly discussed:

1. F1 is obviously a general factor of bone aging. Here, all study variables but one showed strong positive correlation with this factor, which ranged between 0.550 (SM) and 0.948 (CT3). The negative scores for OSS in females showed that unlike the two other age-related measures (OSM and BMD) the OSS tends to rise with age. The explanation for this is that while osteoporotic changes lead to a decrease in both the BMD and OSM values, they tend to boost the OSS values. In males, F1 is rather a factor of OSM, since all OSM indices possess remarkably high and similar correlations with F1 (between 0.946 and 0.993).
2. F2 in Israeli females is the factor of mineralization, which deals with the unexplained residuals of BMD and OSM. The negative scores (–0.330 to –0.667) indicate that the BMD residuals in the female sample tend to decline, while some of the OSM residuals behave in the opposite way. The possible explanation for this can be the loss of bone due to intracortical porosity, before decrease of cortical area due to thinning has commenced and while cortical bone exhibits alterations in the degree of calcification (Laval-Jeantet *et al.* 1983). In Israeli males, F2 shows correspondance between bone loss and bone morphology change. F2 correlates positively with BMD (from 0.347 to 0.914) and negatively with OSS (–0.776).
3. F3 is mostly a factor of distal phalanx mineralization in both sexes of Israelis. It is strongly correlated with age-related changes in the distal phalanx BMD, which occurred mainly during middle and old age (0.602 to 0.643 in females and 0.752 to 0.855 in males).

In the Turkmenian sample, the factor analysis retained 4 factors in males and 3 in females, which explained 78.8 and 78.5 % of the variation, respectively.

F1 in Turkmenian females is the same general factor of bone aging as in Israeli females, but weaker. F2 in Turkmenian females is created by the unexplained residuals of OSM, while F3 is clearly a BMD factor. In Turkmenian males, both F1 and F2 are factors of OSM, whereas F3 deals with BMD only. F4 correlates positively with OSM and negatively with OSS.

**Prediction of age: Multiple regression analysis**

To simultaneously evaluate effects of various potential predictor factors (age, sex, health status, occupation, etc.) on the variability of OSS, OSM and BMD values, multiple regression analysis was used.

***OSS***

Only three variables were positively associated with OSS: age, overall health status of an individual and the health status of his/her hands (according to Pavlovsky 1987). These three variables collectively explain in the Israeli sample about 88.5% of the total variation in OSS values, with age alone contributing to about 83.9%. As previously

TABLE 9a. Continuation.

| METHOD | Variable | Subpopulation | Variab. | N | Regression statistics: Correlation coefficient Mult.R | $R^2$ | Sign.F | S.E.E.* |
|---|---|---|---|---|---|---|---|---|
| OSM | CT** | Males | | 194 | | | >.050 | |
| | | Females | CT2 | 129 | .645 | .416 | <.001 | |
| | | | CI4 | | .689 | .475 | <.001 | 14.85 |
| | CI | Males | | 194 | | | >.050 | |
| | | Females | CI2 | 128 | .671 | .451 | <.001 | |
| | | | CI4 | | .713 | .509 | <.001 | 14.43 |
| | CAP | Males | | 193 | | | >.050 | |
| | | Females | CAP2 | 128 | .680 | .463 | | |
| | | | CAP4 | | .706 | .498 | | 14.52 |
| | | Males (all) | | 192 | | | >.050 | |
| | CT | Males (60+ys) | | 45 | | | >.050 | |
| | + | | | | | | | |
| | CI | Females | CAP2 | 129 | .687 | .472 | <.001 | |
| | + | (all) | CT4 | | .749 | .561 | <.001 | |
| | CAP | | CI2 | | .763 | .583 | <.001 | 13.36 |
| | *** | Females | CAP2 | 31 | .535 | .287 | <.001 | |
| | | (60+ys) | CT2 | | .584 | .341 | <.001 | 6.15 |
| ALL METHODS | OSS | Females | OSS | 55 | .680 | .463 | <.001 | |
| | + | | CT3 | | .749 | .561 | <.001 | |
| | BMD | | CI2 | | .849 | .721 | <.001 | |
| | + | | CM | | .889 | .791 | <.001 | 10.51 |
| | OSM | | | | | | | |
| | | Females | CAP3 | 56 | .731 | .534 | <.010 | |
| | OSM | | CI2 | | .849 | .721 | <.001 | |
| | + | | SM | | .867 | .751 | <.001 | 9.52 |
| | BMD | | | | | | | |
| | OSS | Females | OSS | 140 | .851 | .725 | <.001 | |
| | + | | CAP2 | | .859 | .739 | <.001 | |
| | OSM | | CAP5 | | .867 | .751 | <.001 | 10.86 |

* S.E.E. – standard error of age estimate (in years)

** Entering into stepwise regression all indices of the same heading (CT, CI or CAP)

*** Entering into regression all OSM indices (12 in total). Blank spaces indicate a p level more than 5%.

shown, the OSS values were similar in males and females in both ethnic groups, so that sex was not retained by multiple linear regression.

At the next stage, multiple regression analysis was employed in order to explore the possibility of predicting chronological age of an individual by the OSS and its derivatives. The multiple determination coefficients are presented in *Table 9a, b*. The equation coefficients, derived from the multiple regression, are shown in *Table 10a, b*.

The results of the analysis clearly indicated that OSS is indeed a strong predictor variable of an individual's age, its cubed regression showing highest values ($R = 0.930 - 0.936$ in Israelis and $R = 0.896 - 0.908$ in Turkmenians, *Table 9a, b*), with high statistical significance ($p < 0.001$).

When we compared regression of the entire sex-specific sample with that of an age-limited subsample (namely, the age of 35 years, at which both males and females have "overgrown" the TM age, or visual stage of bone aging), we could see that the standard error of estimate did not improve, while the regression was shown to be weaker and less significant ($R = 0.846 - 0.844$ in Israeli males and females, $p < 0.005$ and 0.1, respectively).

***BMD***

The partial regression coefficients showed that chronological age, sex and health status are the potential predictor variables of each of the BMD measures in both samples ($p < 0.001$).

The multiple regression analysis was used in order to explore the possibility of predicting chronological age from BMD only. Various non-linear regressions were tested in both samples as well (logarithmic, squared, cubed and

TABLE 9b. Polynomial regression analysis of individual's age on bone aging variables in Turkmenian sample.

| METHOD | Variable | Subpopulation | Variab. | N | Regression statistics: Correlation coefficient Mult.R | $R^2$ | Sign.F | S.E.E. |
|---|---|---|---|---|---|---|---|---|
| OSS | | Males | OSS | 252 | .858 | .736 | <.001 | |
| | | | $OSS^2$ | | .884 | .782 | <.001 | |
| | | | $OSS^3$ | | .908 | .825 | <.001 | 6.92 |
| | | Females | OSS | 331 | .861 | .742 | <.001 | |
| | | | $OSS^2$ | | .892 | .797 | <.001 | |
| | | | $OSS^3$ | | .896 | .804 | <.001 | 6.95 |
| OSM | CI + CT + CAP | Females (all) | CI2 | 280 | .663 | .440 | <.001 | |
| | | | CT3 | | .714 | .511 | <.001 | |
| | | | $CAP2^3$ | | .744 | .553 | <.050 | 10.07 |
| | | Females (60+ys) | CAP2 | 101 | .542 | .294 | <.001 | |
| | | | CT2 | | .575 | .331 | <.001 | 6.05 |
| ALL METHODS | OSS + OSM | Females | OSS | 271 | .857 | .735 | <.001 | |
| | | | $OSS^2$ | | .882 | .778 | <.001 | |
| | | | $CI4^3$ | | .896 | .803 | <.001 | |
| | | | CI2 | | .901 | .813 | <.001 | 6.51 |
| | | Females (45+old) | OSS | 197 | .730 | .533 | <.001 | |
| | | | CT2 | | .784 | .616 | <.001 | 5.98 |
| | OSS + BMD | Males | OSS | 246 | .882 | .778 | <.001 | |
| | | | $OSS^2$ | | .908 | .825 | <.001 | |
| | | | $CI4^3$ | | .914 | .835 | <.001 | |
| | | | $OSS^3$ | | .924 | .854 | <.001 | 7.18 |
| | | Males | OSS | 231 | .884 | .782 | <.010 | |
| | | | $OSS^2$ | | .915 | .838 | <.001 | |
| | | | CD | | .917 | .842 | <.001 | |
| | | | $OSS^3$ | | .919 | .845 | <.010 | 6.79 |
| | | Females | OSS | 268 | .845 | .715 | <.001 | |
| | | | $OSS^2$ | | .879 | .772 | <.001 | |
| | | | $CD^2$ | | .881 | .777 | <.010 | 6.92 |
| | | Females | OSS | 268 | .845 | .715 | <.001 | |
| | | | CM | | .849 | .721 | <.001 | |
| | | | SD | | .850 | .724 | <.001 | |
| | | | CD | | .851 | .725 | <.010 | 7.69 |

Hompertz' functions), but proved no better than simple linear regression. The results of our linear regression analysis showed BMD to be a weak potential predictor variable of age in the females (the best result in Israeli females was $R = 0.651$ for middle phalanx compacta, with $p < 0.001$). For Israeli males this correlation was very small and non-significant. The multiple determination coefficients are presented in *Table 9a*. Although the Turkmenian sample showed non-linear dependence on age, the coefficient of this correlation was relatively small, so that it was not possible to compute the error of estimate available for forensic investigations (not exceeding 10 years). Hence, BMD alone could not be used for actual age prediction.

### *OSM*

Only chronological age and sex were the potential predictor variables of the total variance in OSM indices in both samples. These two variables explained only about 47.7% of the total variance in the Israeli sample, with sex alone contributing to about 46.3%. Surprisingly, occupation, which is traditionally linked to bone robustness, was not found to influence the OSM indices, which means that these indices can be deemed to be pure indices of aging.

TABLE 10a. Equations derived from stepwise regression analysis of the relation between age and roentgenologic variables in Israeli sample.

| | Method | # | Regression equation | S.E.E. |
|---|---|---|---|---|
| OSS | | | Males (all) | |
| | | 1 | $AGE = 23.4 + .002\ OSS^3 - .2\ OSS^2 + 5.6\ OSS$ | 7.80 |
| | | | Males (age > 35 years) | |
| | | 2 | $AGE = 33.4 - .07\ OSS^2 + 3.5\ OSS$ | 7.77 |
| | | | Females (all) | |
| | | 3 | $AGE = 23.6 + .003\ OSS^3 - .24\ OSS^2 + 6.2\ OSS$ | 7.55 |
| | | | Females (age > 35 years) | |
| | | 4 | $AGE = 33.0 + 0.001\ OSS^3 - .13\ OSS^2 + 4.3\ OSS$ | 7.75 |
| | BMD | | No available equation exists.* | |
| | OSM | | Females (age > 60 years) | |
| | | 5 | $AGE = 110.3 + 6.0\ CT2 - .88\ CAP2$ | 6.15 |
| ALL METHODS | OSS+ BMD+ OSM | 6 | Females<br>$AGE = 2.1\ OSS + 1.8\ CT3 + .06\ CM + .25\ CI2 - .012\ CD$ | 10.51 |
| | OSM + BMD | 7 | Females<br>$AGE = 136.1 - 1.39\ CAP3 + .04\ CI2 - 1.12\ SM$ | 9.52 |
| | OSS + OSM | 8 | Females<br>$AGE = 42.5 + 1.6\ OSS - .47CAP2 + .43CAP5$ | 10.86 |

The abbreviations are the same as in *Table 8*.
* Only equations with S.E.E. <= 11 years are given in *Table*.

TABLE 10b. Turkmenian sample.

| | Method | # | Regression equation | S.E.E. |
|---|---|---|---|---|
| OSS | | | Females | |
| | | 1 | $AGE = 25.2 + 4.17\ OSS - .14\ OSS^2 + .002\ OSS^3$ | 6.92 |
| | | | Males | |
| | | 2 | $AGE = 26.7 + 4.18\ OSS - .15\ OSS^2 + .002\ OSS^3$ | 6.89 |
| | BMD | | No available equation exists.* | |
| OSM | | | Females | |
| | | 3 | $AGE = 235.6 - 5.5\ CI2 - 5.7\ CT3 + .0003\ CAP2^3$ | 10.07 |
| | | | Females (age > 60 years) | |
| | | 4 | $AGE = -379.1 - .001\ CAP2^3 - .27\ CAP2^2 + 19.9\ CAP2$ | 6.15 |
| ALL METHODS | OSS | | Females | |
| | | 5 | $AGE = 52.1 + 2.3\ OSS - .03\ OSS^2 - .00002\ CI4^3 - .25\ CI2$ | 6.51 |
| | + | | Females ( age > 45 years ) | |
| | | 6 | $AGE = 68.0 + .8\ OSS - 4.4\ CT2$ | 5.98 |
| | OSM | | Males | |
| | | 7 | $AGE = 35.8 + 4.5\ OSS - .15\ OSS^2 - 2.9\ CT4 + .002\ OSS^3$ | 6.51 |
| | OSS | | Females | |
| | | 8 | $AGE = 31.9 + 2.9\ OSS - .05\ OSS^2 - 2.6\ CM^2$ | 6.92 |
| | + | 9 | $AGE = 38.5 + 1.6\ OSS - .07\ CM + .6\ SD - .05\ CD$ | 7.69 |
| | | | Males | |
| | BMD | 10 | $AGE = 26.8 + 4.4\ OSS - .14\ OSS^2 - 5.0\ CD + .002\ OSS^3$ | 6.79 |

* Only equations with S.E.E. <= 11 years are given in *Table*.

Multiple regression analysis was used to assess the possibility of predicting chronological age from OSM. Ultimately two approaches were adopted. In the first approach, the OSM indices of the same name (CT, CI or CAP) were subjected to regression analysis. Various non-linear combinations (logarithmic, squared, cubed and Hompertz' functions) were tested in both ethnic samples, but in the Israeli female sample proved no better than linear correlations. The multiple determination coefficients are presented in *Table 9a*. For Israeli males the correlation was very small and non-significant. In the Turkmenian sample, the correlation coefficients were relatively small, although significant, and thus no equation with error of estimate not exceeding 10 years could be derived. Hence, the chronological age prediction could not be based exclusively on CT, CI or CAP only.

In the second approach, all of the 12 indices (CT, CI and CAP of all four studied metacarpals) were subjected to stepwise regression analysis. Again, various non-linear combinations (logarithmic, squared, cubed and Hompertz' functions) were tested in both ethnic samples, but proved no better than linear correlations. In females of the Israeli and Turkmenian samples, the correlation was high enough ($R = 0.744 - 0.763$, $p < 0.05$ and 0.001, respectively). For males of both ethnic groups this correlation was very small and non-significant. Hence, in males, OSM alone cannot be used for age prediction. Since OSM indices show accelerated decrease in postmenopausal age, we introduced all the 12 indices in females aged 60 years and older to stepwise regression analysis. This approach led to real improvement in age prediction, with the error of estimate brought down to 6 years. The correlation coefficients were relatively small, but significant in females of both ethnic groups. The multiple determination coefficients are presented in *Table 9a, b*.

**Multiple regression analysis of combinations of bone age measures with chronological age**

In this analysis, all 3 categories of bone age traits were introduced into stepwise multiple regression to separately predict the chronological age of study individuals in both studied samples. *Table 9a* shows that for Israeli females, 4 measurements were retained in regression (equation #6, *Table 10a*). They commonly explained 79.1% of the total age variation, with a prediction error of ± 10.5 years. The major age predictor was shown to be OSS, which alone predicted 46.3% of the age variation. However, OSS was much more efficient by itself (equation #3, *Table 10a*), when it predicted about 77%. Owing to technical difficulties during imaging of the hand in the Israeli sample, not in every case could all three roentgenologic methods be applied for age assessment. Thus, the model OSS-BMD-OSM was considerably less efficient than the one using only OSS and its derivatives (equations 1 and 3, *Table 10a*). As one can surmise from *Table 9a, b*, no usable sex-related equation could be derived from the combinations in Israeli males nor those in Turkmenians of both sexes, because stepwise regression retains only the OSS in combination with OSM.

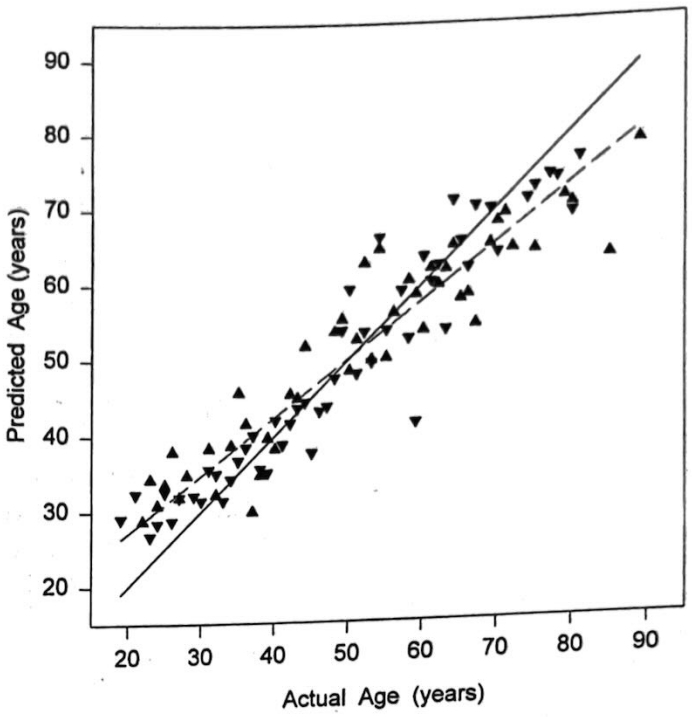


FIGURE 5. Predicted chronologic age by cubed regression of OSS.
▲ – predicted age in males
▼ – predicted age in females
Broken line – regression of the predicted age in total population.
Solid line – line of ideal prediction.

As for the combinations OSS-BMD, these were useful only in the Turkmenian sample, for both males and females (where the standard error was around 7 years). Again, OSS alone predicted 71.5% and 78.2% of age variation, in females and males, respectively. The equations #8-10 (*Table 10b*) are of crucial importance in cases where measurements of metacarpal bones are not feasible as, for example, when only dismembered or badly imaged hands are available).

Adding OSM data to the OSS data in the Israeli sample improved the precision of prediction in females (OSS alone predicts 72.5% of age variation), but not in males. In Turkmenians, similar combination proved useful for age prediction in both males and females (standard error of 7.2 and 6.5 years, respectively). When we compared regression of the entire female sample with that of the age-limited subsample (aged above 35 years, when the slope of OSM with age in females shows definite decrease), we found the standard error of estimate to reduce somewhat (by about half a year), albeit the regression was weaker ($R = 0.784$ instead of $R = 0.901$, $p < 0.001$).

Where OSS cannot be evaluated (owing to trauma to the hand or faulty X-ray conditions), combinations of OSM-BMD may prove of use. In fact, such combinations were able to predict chronological age only in the Israeli female sample (with a standard error of 9.5 years), but not in

their Turkmenian counterparts nor in males of either ethnic group, because the stepwise regression retained only the OSM, which was shown to be useful only in the female sample.

In *Figure 5* we show the plot of predicted age against actual age in Turkmenian males and females as based on equations # 1 and 2 (*Table 10b*), which were computed by cubed regression of OSS on age. The data include all studied individuals, with the age range of 18-90 years. The predicted-by-OSS age could be depicted by an ideal prediction line (that is, the line crossing the scatogram field under 45°). Our model accurately predicted 90% of the observed data. In more advanced ages the prediction by stepwise determination method yielded values lower than the observed, whereas in ages below 30 years it tended to predict higher values, leading to an overall standard error of ± 6.9 years. Partly, this could be explained by the S-like form of the OSS distribution with age (*Figure 2*), where in young persons, there is no definite increase in OSS values with age, while in old age, the rate of increase in OSS values diminishes.

## DISCUSSION

### Bilateral asymmetry of age-related traits

A two-sided comparison leads to very dissimilar results in both our samples. Thus, in Turkmenians, the right hand is significantly more mineralized and yields higher OSS than the left one. According to Garn (1970) and Plato and Norris (1980), this is in part a reflection of dextral dominance and hence of greater activity of the right hand in the majority of people. No such dominance, however, is seen in the Israeli sample. One possible explanation could be the high percentage of left-handed individuals in Israel, which is attributed by Kobyliansky *et al.* (1978) to a more liberal educational system which does not inhibit the expression of sinistrality in Israeli children.

### Ethnic comparison of age-related traits

Significant differences in BMD were found between the two studied populations, with Israeli males and females showing much more BMD than their Turkmenian counterparts. The ethnic differences were also significant in all the OSM indices. These findings indicate that OSS is a more objective measure of bone age *per se* than either OSM or BMD, both of which seem to be dependent more on ethnic differences, or on concomitant climatic and geographical factors, thus describing many secondary processes in populations, aside from 'pure' aging. It is of interest, however, to note that Livshits *et al.* (1996) showed that ethnic differences in parameter estimates for OSS are of a dual nature, with the $t_0$ value (age at which the first signs of OSS appear) depending on climatic conditions, while the rate of bone change (B) is dependent on genetic differences among study samples.

### Sex comparison

Adams *et al.* (1970) have conjectured that the dynamics of bone change might not differ between the sexes. The parameter estimates of the stochastic model lend support to this conjecture. Indeed our OSS data point to a high and significant correlation between Israeli males and females, while in Turkmenians, the combination of three model parameters revealed a nearly identical distribution of bone age estimates among men and women. For example, in Jews, where both the $t_0$ and TM are higher in males than in females (20.4 and 31.2 vs. 19.0 and 28.8), the q of females tended to compensate for this disparity (0.102 in females vs. 0.092 in males), with the B estimates nearly equal (0.387 vs. 0.380, respectively). Moreover, when we compared the obtained distributions of OSS estimates adjusted for age, no significant differences owing to sex were observed neither in the Israeli nor in the Turkmenian sample. This finding is consistent with findings of our previous investigation of sex differences in various populations from Europe and Asia (Kobyliansky *et al.* 1995). Thus, as far as OSS values are concerned, they should enable age prediction by equations not dependent on sex. With the OSM and BMD patterns, however, there was pronounced sexual dimorphism in our studied populations both in terms of absolute values as well as changes with age. This latter result also corresponds well to what has been shown from many previous studies (e.g. Garn 1967, Kimura 1992, Plato *et al.* 1994). Bottom line, then, retains the need for sex-specific equations in age prediction.

### Age prediction using osseographic scores

A main goal of the present study was to substantiate the utility of a new multiple regression method for calculating an expected age, and also to demonstrate that this method may be beneficial in anthropological study and in forensic medicine, for prediction of the actual age of an individual. Our close acquaintance with the basic principles of age-dependent distributions, with sources of variance, and with the interactions between bone age indices (OSS, BMD and OSM), enabled us to employ the mentioned indices in attempts to develop statistically grounded equations for age prediction.

Since both OSS and Nekliudov's (1968) score are evaluated by the same principle, we first compared them to decide which merited further elaboration (Karasik 1995). The all-phalangeal bone age assessments of Pavlovsky (OSS) were found by us to be superior to the assessments using the distal-phalangeal method of Nekliudov, regardless of sex and age category. Nekliudov's score, for example, proved a substantially poorer predictor of age (in Israeli males, $R = 0.766$, $p < 0.001$) than OSS ($R = 0.930$, $p < 0.001$, *Table 9a*). In this case, the standard error of age estimation by non-linear regression of Nekliudov's score was about 10.8 years, whereas by OSS it was only 7.8 years. Thus, taking into consideration also data on middle and proximal phalanges, an investigator can improve

age prediction by decreasing the error of estimation. Consequently, we recommend the use of OSS in a substantial part of the equations for age prediction. Indeed, its advantage over Nekliudov's method is that it can be useful in forensic cases, where only severely damaged hands or dismembered fingers are available.

**BMD and OSM as measurements of bone age**

Our findings concerning BMD are in agreement with the contention of Plato *et al.* (1994) that the rate of bone loss is not equal for cortical and trabecular bone. In our Israeli females, demineralization in compact bone occurs even in the young, albeit evident linear decrease commences later (at the age of 50 or more), with an overall 25% diminution throughout; as for cancellous bone, its mineral loss commences at the age of 60, with an overall 50% diminution throughout life. Older (60 +) females apparently show significant linear bone loss at all phalangeal points studied (see Plato 1987). Israeli men, in contrast, showed no or only slight decline in BMD values with age, displaying more bone on the distal phalanx than did Israeli females. The picture was quite different in Turkmenian males who, like Turkmenian females, showed an association between age and BMD values.

Although CT, CAP and CI values declined more rapidly in females than in males at successive age cohorts after 50 years of age (see also Thompson 1979), Israeli females, but not Turkmenian females, presented CAP and CI values similar to those of the males at comparable ages. The rates of decline in OSM and BMD values in both populations studied were generally similar to those already reported in the literature, e.g. Garn *et al.* (1967), Dequeker (1976) or Mazess (1982).

**Age prediction based on all the bone aging traits**

Multiple regression analysis was employed by us to explore the possibility of predicting chronological age of an individual by the OSS, OSM and BMD criteria. The results of the analysis clearly indicated that OSS is indeed a strong predictor variable of an individual's age, with its cubed regression yielding the highest values ($R = 0.930 - 0.936$ in Israelis and $R = 0.896 - 0.908$ in Turkmenians, $p < 0.001$). In contrast, BMD is a weak predictor variable of age and in females only (the best result being $R = 0.651$, with $p < 0.001$). No equation with adequate error of estimate (not exceeding 10 years) could be developed for forensic investigations. Nor could BMD alone be used for actual age prediction. On the other hand, OSM was found to be a fair predictor variable. For instance, in females of the Israeli and Turkmenian samples, the correlation of age on OSM indices was high enough ($R = 0.744 - 0.763$, $p < 0.05 - 0.001$, respectively). In males, however, OSM alone could not be used for age prediction.

The equations we elaborated, using different combinations of age-related traits, led to polynominal functions. We were able to show that in all combinations, the major age predictor is OSS, which alone predicts 71.5 – 78.2% of the age variation. Combinations of OSS-BMD are important in cases where metacarpal bones measurements are absent (for example, when only dismembered or badly imaged hands are available).

In the Israeli sample, adding OSM data to the OSS enhances also the precision of prediction in females (OSS alone predicts 72.5% of age variation), but not in males. In Turkmenians, similar combination can be useful in age prediction in both males and females (standard error of 7.2 and 6.5 years, respectively). When OSS cannot be evaluated (due to trauma or the X-ray conditions), combinations of OSM-BMD are useful in females.

Our standard errors of estimate (approximately ±7-10 years) compare favourably with similar data by Ericksen (1991), who used histological variables. We obtained our results on a big sample in which about 40% of subjects were more than 60 years of age. Our standard errors of estimate were slightly larger possibly because, according to Ericksen (1991) variability tends to increase with a larger sample size. The accuracy of age assessment diminishes as age increases (Loth, Iscan 1994). For instance, the ultimate modal age in current methods of bone age estimation is "60+" for pubic symphysis (Meindl, Lovejoy 1985), for auricular surface of the ilium (Loth, Iscan 1994) and for dental wear (Lovejoy *et al.* 1985), with an inaccuracy of 10, 7 and 11 years, respectively. Only evaluation of cranial sutures (Meindl, Lovejoy 1985), histological methods (Kerley 1965) or rib-phases technique (Loth, Iscan 1994) can discriminate between individuals over 70 years of age, and then with an inaccuracy of nearly 17, 12 and 15 years, respectively. Our study thus provides a more efficient method of age prediction endowed with acceptable accuracy. Moreover, it allows to extend the upper limit of age estimation to beyond 70 years, when gross skeletal changes become relatively useless. In this connection, our procedure can also contribute to a more accurate age estimation in elder females, in that our equations for the subsample of females pre-evaluated as "old" (aged more than 60 years) markedly improved the accuracy of prediction (the standard error dropping to ±6 years). Iscan and Loth (1989) suggest that in future, bodily regions chosen for study of bone age should include the rib, pubic symphysis, auricular surface of the ilium, clavicle, teeth, and the cranium. We contend that our results challenge this suggestion, and rather recommend the use of hand bones as a good tool for age estimation in adults.

## CONCLUSIONS

Admittedly, the results of the present study are rather preliminary, and additional investigation is in order. That said, our study does resolve at least a few problems regarding actual age prediction and its main findings are the following:

1) Having compared different roentgenologic methods, we recommend to rely jointly on three of them for a

better prediction of the actual age of individuals. The major advantages of this approach are non-invasiveness, relatively little exposure to X-ray and easy access to the evaluated hand bone structures, all of which are important in investigations of living subjects (e.g. for medico-legal and insurance purposes).

2) We suggest the use of OSS as a substantial component in equations for age prediction, taking into account, however, that the Nekliudov (1968) method is preferable in subjects with a very damaged hand or when only dismembered fingers are available.
3) Several linear and non-linear regression equations for various combinations of three groups of indices with age may be used to predict age with a standard error of estimate of approximately ±6-10 years. In this connection, our data can contribute to a more accurate age estimation in elder subjects, with equations formulated for subjects pre-evaluated as 'old', improving the accuracy markedly (the standard error dropping to ±6 years ).
4) The data collected in this study albeit relevant for Israeli and Turkmenian populations, do point to the existence of certain differences between ethnic groups in several age-related traits. In principle, regression equations derived from one population cannot be applied to another, when there is no knowledge about the distribution of age-related changes in the latter.
5) The method proposed herein is useful for comparing the aging process in individuals as well as in populations from different ethnic groups and geographical regions. A comparison of different populations which relies on patterns of bone aging can provide an additional tool for both genetic and environmental studies.
6) There is pronounced sexual dimorphism with regard to most of the bone aging variables in our studied populations, both in terms of absolute values as well as in changes with age.

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