Tzipi Kahana,[1] Ph.D.; Jehuda Hiss,[2] M.D.; and Patricia Smith,[3] Ph.D.

Quantitative Assessment of Trabecular Bone Pattern Identification

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ABSTRACT: The results of the research described in this paper demonstrate that the trabecular architecture is unique to each individual and stable enough to be used as a forensic marker for positive identification of human remains.

The trabecular bone architecture depicted on radiographs is often used as an individualizing forensic marker for positive identification of human remains.

The aim of the present study was to ascertain the reliability of the trabecular pattern in forensic identification. The trabecular pattern is potentially the best radiographic forensic marker since its presence on a radiograph doesn't depend on a previous pathology or traumatic event.

A sample of 305 radiographs of the left wrist of 103 postmenopausal women was studied using an image analyzer. The uniqueness and stability over time of the trabecular architecture was examined by creating line maps or ''densitographs'' of the ultra-distal point of the radius of each roentgenogram.

Pearson's correlation coefficients were calculated for all possible combinations of pairs of radiographs. The correlation coefficient of pairs of radiographs of the same individual, taken at different times (2 to 6 years apart), was always higher than 0.72, while the correlation coefficients of radiographs of different individuals was always below 0.62.

KEYWORDS: identification, X-ray, trabecula

Identification of human remains is an integral part of the medicolegal investigation of death. Beyond humanitarian considerations, identification is essential to the completion and certification of official documents, allowing them to proceed with the probate of wills and to apply for disbursement of benefits and insurance (1).

Recovered human remains vary in state of preservation either because of the normal chemical processes that affect the cadaver, the mechanism of death, or due to animal scavening. Because of this, the larger the number of methods of identification available to forensic anthropologists, the greater their probability of reaching a definitive conclusion (2).

Comparison of antemortem and postmortem radiographs is one of the most common identification procedures in forensic anthropology. Features depicted on roentgenograms often used as individualizing markers for positive identification include normal anatomical variation, signs of medical surgical intervention, pathological changes, and indications of healing processes. The reliability of these markers for forensic purposes depends on their uniqueness and stability over time (3).

The trabecular bone architecture that can be seen on radiographs is sometimes used as an individualizing forensic marker; however, its dependability for positive identification has not been previously established, since it was not known how unique the pattern is and how much it changes over time. Nevertheless, the trabecular pattern is potentially the best radiographic marker for forensic purposes since its presence doesn't depend on a rare event such as pathology, or trauma. As long as an antemortem radiograph is available, the postmortem radiograph of the corresponding area will provide enough data for verification or rejection of identification (4).

The aim of the present research was to investigate the effect of age-related bone degenerative changes in the trabecular architecture of the appendicular skeleton, and the reliability of this marker on radiographs for positive identification of human remains.

Materials and Methods

A sample of 305 radiographs of the root of the hand taken from 103 postmenopausal women was digitally analyzed. The radiographs used came from the archives of the Jerusalem Osteoporosis Institute where they were taken as part of a larger research project on osteoporosis carried out during the years 1982–1988. The participants in this project were examined annually for bone mineral status (5). The mean age of the women whose radiographs were included in the present research was 66.7 years (Table 1). They were all in good health, although 25.2% of them had been diagnosed as suffering from mild postmenopausal osteoporosis based on radiographic examination of the lumbar spine (Lumbar Spine Index 2) and 21.3% of severe postmenopausal osteoporosis (Lumbar Spine Index 3-4) (6,7) (Table 2).

The technique utilized to evaluate the reliability of the trabecular bone as a forensic identification marker is called radiographic absorptiometry or photo densitometry. This method was first devised in the early 1960's for quantitative detection of bone mineral changes (8). The density of the bones was obtained from standardized radiographs analyzed with an optical densitometer. This technique generally fell into disuse as lower radiation exposure methods such as Single and Dual photon absorptiometry were devised for diagnosis of osteoporosis (9).

Today, advances in computerized graphics permit digital quantification together with image enhancement and noise reduction of the image, allowing an accurate analysis of the trabecular bone architecture depicted on radiographs.

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[1] Division of Identification and Forensic Sciences, Israel Police Headquarters, Jerusalem, Israel.

[2] The L. Greenberg Institute of Forensic Medicine, Tel Aviv, Israel.

[3] Laboratory of Physical Anthropology, Hadasah School of Dental Medicine, the Hebrew University, Jerusalem, Israel.

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TABLE 1—*Age distribution at the time of the radiographic examination.*

Age	No.	Mean	S.D.
40–45	7	43.4	1.6
46–50	16	46.8	1.4
51–55	12	51.7	1.5
56–60	18	57.4	1.4
61–65	65	62.2	1.3
66–70	45	66.6	1.5
71–75	91	71.9	1.3
76–80	33	77.1	1.4
80+	18	81.0	0.9
Total	305	66.7	1.4

TABLE 2—*Degree of osteoporosis by age. The degree of osteoporosis was established by visual examination of lumbar spine radiographs [LSI, (6)].*

Osteoporosis (LSI)	Frequency	%	Mean Age
0	124	40.7	67.8
1	39	12.8	62.0
2	77	25.2	66.2
3	46	15.1	68.4
4	19	6.2	64.3
Total	305	100	66.7

Radiographic absorptiometry assumes that changes in optical density, when measured from roentgenograms on a gray scale ranging from 0 to 254, are inversely proportional to bone density (9).

In the present study, the radiographs were digitized and measured using a computerized image analyzer. This is a PC-based system which includes a view table, a CCD computer-controlled video camera and control card, and a computer with appropriate software developed by ''Galai'' technologies and especially adapted for this research.

After encoding and preprocessing the radiographic images, a reference horizontal line was selected along the ultradistal end of the radius. The gray-level value of each pixel along the line was recorded, thus producing a profile of the trabecular bone pattern (Fig. 1). This profile, also known as a densitograph or line map, transects distinct trabeculae. The vertical fluctuation (on the Y-axis) of the line maps reflects the varying density along the bone while the horizontal direction (on the X-axis) of the graph indicates the distance with the system adjusted to represent 1 mm of the film per pixel.

Differences in relative intensity between radiographs of the same bone produce graphs whose initial position on the vertical axis differs. This does not affect the analysis since the measurements are carried out along the horizontal axis (10).

The line maps obtained from the radiographs were statistically analyzed. The stability of the trabecular bone pattern was tested by comparing the line maps of the radiographs of the same individual taken at different times (between 1 to 6 years apart), while the uniqueness of the trabecular pattern was tested by comparing the line maps of the three radiographs of each individual with the correspondent radiographs of all other individuals.

The analysis was conducted with a PC-based statistical package called ''Statistix.'' Pearson's coefficients were calculated for all pairs of line maps.

Results

The correlation coefficients between pairs of radiographs of the same individual taken at different times ranged between 0.99 and 0.72 (Fig. 2, Table 3). Higher correlation coefficients were observed in those individuals with low degrees of osteoporosis, as assessed from lumbar spine roentgenographs. While the correlation coefficients observed were never below 0.80 in individuals classified as normal or slightly osteoporotic, 31.8% of the subjects classified as suffering from mild to severe osteoporosis had correlation coefficients below 0.80; the lowest correlation was 0.72 (Table 4).

A total of 13 908 pairs of correlation coefficients were calculated between pairs of line maps of different individuals. The Pearson's correlation coefficients ranged from -0.99 to 0.62; most correlation coefficients fell between -0.40 and 0.40, with only 5.13% of the correlation coefficients being higher than 0.50 (Table 5). Lower correlation coefficients indicate that the shape of the line maps is very different, while negative correlation coefficients imply that the line maps are in opposite directions (Fig. 3).

No overlap between correlation coefficients of same and different individuals was detected, thus a cutting point at the level of $r = 0.72$ can be established for identification of human remains by means of trabecular bone pattern. In other words, if ''known'' or antemortem and ''unknown'' or postmortem radiographs from an unidentified decedent are compared in order to determine identity, a positive identification will be established when the correlation coefficient of the known and unknown line maps is higher than 0.72.

The effect of the radiographic conditions (kilovoltage and milliamperage per second) on the reliability of trabecular identification has been already reported (4). The correlation coefficients of line maps of the same bone radiographed under varying conditions are always higher than 0.73, while the correlation coefficients of line maps of different bones taken under the same conditions are always below 0.60. Thus the radiographic settings do not affect the reliability of the technique.

Discussion

The underlying hypothesis of this research was that despite age-related bone loss (11), there are distinct features of the trabecular bone of the appendicular skeleton which remain stable through time and that there is great individuality in the trabecular pattern.

The main mechanisms of microarchitectural disruption associated with aging are either a decrease in trabecular plate thickness produced by a low bone turnover and reduced bone formation at the cellular level, or perforation of plates and removal of whole trabecular units, due to high bone turnover and an excess of bone loss over bone formation. Although Silva and Gibson in 1997 (12) suggest that both mechanisms are concomitant, the findings of the present study support the notion of a low trabecular bone turnover as reflected by the lack of change in the microarchitecture of the trabecular mesh over time.

The stability of the trabecular bone assessed from radiographs of older, osteoporotic women, which are postulated as having the greatest extent of bone mineral loss, can be extrapolated to younger women and to males who have less bone mass loss (13).

The present study substantiates the scientific reliability of the trabecular bone pattern as a forensic marker for personal identification. Although this marker has been implemented for more than 30 years (14), the results of this research provide quantifiable criteria to be presented in courts of law in a way easier to judge. The equipment required to quantify the correlation between various

FIG. 1—*Radiograph of left hand and wrist with densitograph produced by the image analyzer.*

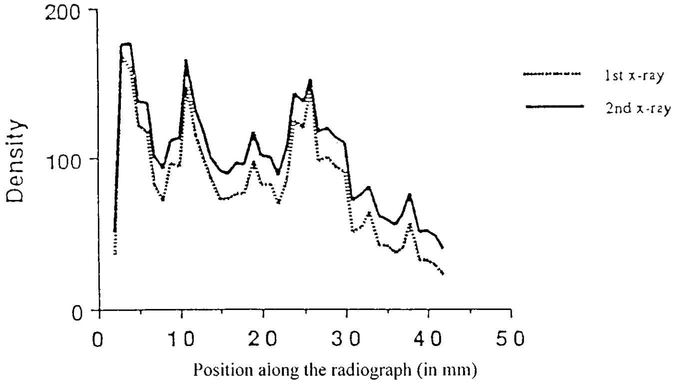

FIG. 2—*Densitographs of radiographs of the same individual taken at different times (4 years apart)* (r = *0.99).*

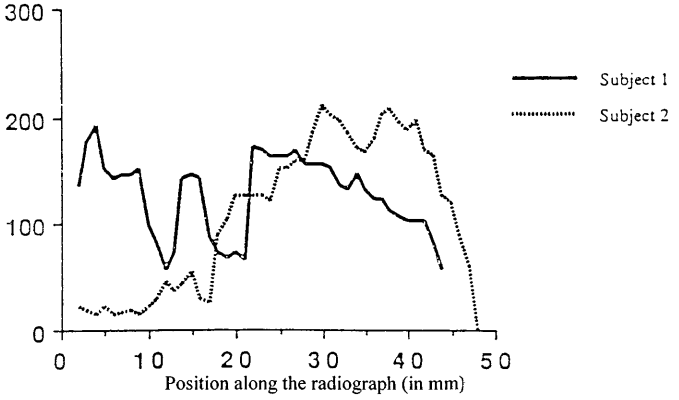

FIG. 3—*Densitographs of radiographs of different individuals* (r = *−0.96).*

TABLE 3—*Pearson's correlation coefficients between radiographs of the same individual taken at different times.*

	1st and 2nd X-ray		2nd and 3rd X-ray		1st and 3rd X-ray	
Correlation	Freq.	%	Freq.	%	Freq.	%
0.99–0.95	47	44.8	54	51.5	49	49.5
0.94–0.90	27	26.7	23	23.3	24	23.7
0.89–0.85	16	16.2	11	10.7	17	15.5
0.84–0.80	7	6.7	7	6.8	6	6.2
0.79–0.75	2	1.9	2	1.9	3	1.0
0.74–0.70	4	3.8	6	5.8	2	4.1
Total	103	100	101	100	101	100

TABLE 4—*Pearson's correlation coefficients by degree of osteoporosis (LSI).*

LSI/Corr.	0	1	2	3	4
0.72–0.79	0	0	0	9	10
0.80–0.85	1	6	3	8	3
0.86–0.90	3	9	15	11	1
0.91–0.95	21	36	27	4	0
0.96–0.99	77	23	45	4	3
Total	102	74	76	36	17

TABLE 5—*Pearson's correlation coefficients between pairs of line maps from radiographs of different individuals.*

X-ray/Corr.	−0.9 to −0.5	−0.49 to 0	0.1 to 0.62	Total
1st X-ray	208	1742	3303	5253
2nd X-ray	251	1710	2134	4095
3rd X-ray	152	1378	3030	4560

densitographs, i.e., a computer, a video camera and a graphics program, is common and can be found in most modern laboratories.

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Additional information and reprint requests:
Tzipi Kahana, Ph.D.
The L. Greenberg Inst. of Forensic Medicine
67 Ben Zvi Rd.
P.O. Box 49015
Tel-Aviv 61490, Israel