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# New Method for Diagnosis of the Sex and Age-at-death of an Adult Human Skeleton from the Patella

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**Abstract** The diagnosis of sex and age-at-death from the adult human skeleton is very important in the field of physical and forensic anthropology for the identification of a human body. Three studies of the diagnosis of the patella reporting an accuracy of approximately 85% have been published; however there is no study about diagnosis of the age-at-death on the basis of morphology of the patella. The purpose of this study is to calculate the discriminant function for sex in recent Japanese skeletons and develop a new method for age estimation by analysis of the patella. In this study, 283 recent Japanese skeletal materials (183 males and 100 females) were used. The correctly classified percentages of the discriminant functions with all the variables reached at 85%. However, the age estimation by analysis of the patella was not as reliable as that by the analysis of pubic symphysis or cranial sutures. It can be said that the age estimation by analysis of the patella is rather vague; therefore its usage should be limited for a vague estimation of age, and age-at-death evaluated by this method may be expressed as young (score 0), middle-aged (score 1), and old (sores 2 and 3).

**Key words:** Patella, Discriminant analysis, Recent Japanese, Age estimation, Sex diagnosis.

## Introduction

The diagnosis of sex and age-at-death from the adult human skeleton is very important in the field of physical and forensic anthropology for the identification of a human body. There are many studies on the metric or non-metric diagnoses of sex or age-at-death from bones.

In practice, whether or not these methods can be utilized primarily depends on the preservation of a skeleton. For example, the morphology of the pubic symphysis is widely used as an indicator of age-at-death (White, 2000). However, since the os pubis is rarely preserved in archaeological or forensic specimens, this excellent method can not be utilized in many cases. Even if some of the methods of assessment of sex or age-at-death are utilized, the discrepancy is observed between the results of the different methods used.

This problem can be addressed by developing many methods of diagnosing the sex or age-at-death by analyzing various parts of a skeleton. This will increase the possibility of diagnosis the sex or age-at-death. Further, a more reliable diagnosis could be achieved by utilizing many of the available methods and performing a comprehensive assessment by using these results.

There are three studies concerning diagnosis of the sex by analyzing the patella (Introna *et al.*, 1998; Bidmos *et al.*, 2005; Dayal *et al.*, 2005). These studies determined sex as the discriminant functions calculated using six metric variables from three populations as the Italians (40 males, 40 females; Introna *et al.*, 1998), South Africans of European descent (60 males, 60 females; Bidmos *et al.*, 2005), and South Africans of African descent (60 males, 60 females; Dayal *et al.*, 2005). The correctly classified percentages in these studies reached over 80%. Thus, it was concluded that the discriminate functions with the measurements values of the patella can be utilized for diagnosis of the sex.

However, the sample sizes of these studies were limited to below 120 individuals. Moreover, these methods could not be applied in Asian populations because of statistically significant difference between ethnical populations in the metrical data of the patella was reported by Dayal *et al.* (2005).

There is no study about diagnosis of the age-at-death by the analysis of the morphology of the patella. Woo *et al.* (1986) used rabbit medial collateral ligament to demonstrate that young rabbits were more subjected to ligament avulsion at its attachment to the bone, whereas older rabbits were more likely to suffer midsubstance tearing of ligament or bone fracture. This indicated that the stiffness of the inter-connection between the collagens of ligaments and bones increases with age. Yamada *et al.* (2004) investigated age-related changes of elemental contents at the insertion tendons in humans and showed that the composite elements such as Ca and Mg increased significantly with aging suggesting that age-related bone changes can be observed at the sites of ligament-to-bone or tendon-to-bone attachments.

Osteoarthritis frequently occurs at knee joints. It has been suggested that the degenerative changes caused by osteoarthritis are related to aging (Aufderheide and Rodriguez-Martin, 1998). Degenerative changes of the patella can be recognized as eburnation on the articular facet and severe osteophytes around the articular cartilage. There is the possibility that these degenerative changes may cause the morphological changes with increasing age, especially at the attachment of the quadriceps femoris muscle and the margin of the articular facet.

The purpose of this study is to calculate the discriminant function for sex in recent Japanese skeletons and develop a new method for age estimation by analysis of the patella.

## Material and Methods

The 283 recent Japanese skeletal materials (183 males and 100 females) used in this study belong to the University Museum of the University of Tokyo and the Department of Anatomy, Chiba University School of Medicine; the Graduate School of Social and Cultural Studies, Kyushu University; and Shinshu University school of Medicine. The sex and age-at-death of these samples, which were collected between 1880s and 1960s, were recorded. Figure 1 showed the distribution of the skeletal, which ranged from 14 to 83 yearsold.

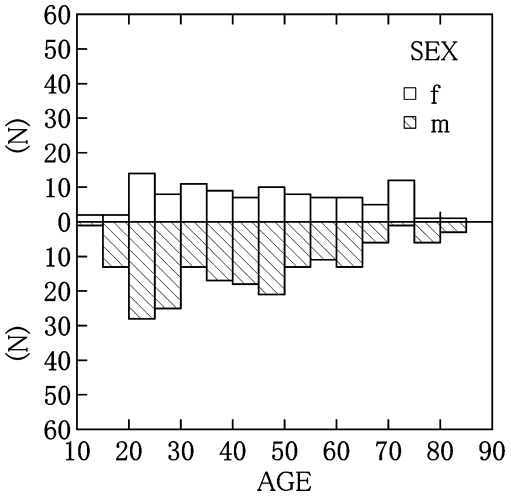


Fig. 1. Distribution of the recent Japanese skeletal samples.

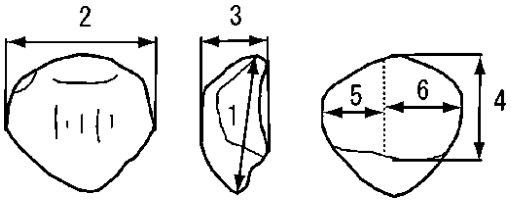


Fig. 2. Definitions of patella measurements.

For the discriminant analysis, six measurements, whose definitions were followed Martin's measurements (Baba, 1991), were used (Fig. 2). Both right and left patella were measured.

In order to devise a method for estimating the age-at-death, the existence of the bone lipping at the attachment of the quadriceps femoris muscle and the existence of the regressive marginal osteophytes at the margin of the articular facet were observed. The composite score method, which was used for estimating the age-at-death by the

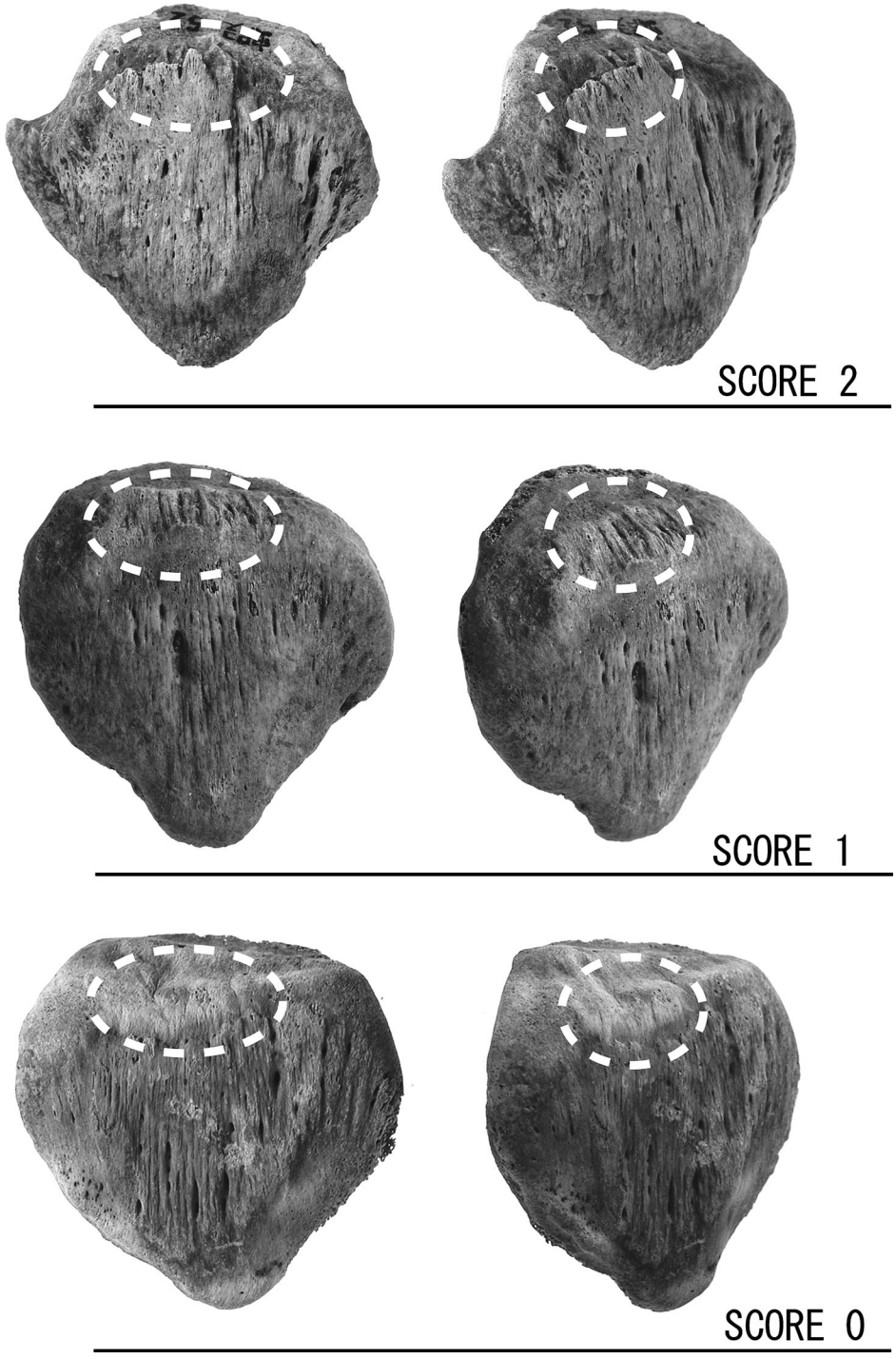


Fig. 3. Definition of the morphology of lipping at the attachment of the quadriceps femoris. These patellae were on the right side. The left side of each picture was shot in the frontal views and the right one was in the frontal-lateral view. The status of bony lipping was examined on the area surrounded by the dot line. SCORE 0 indicates no lipping, SCORE 1 indicates weak lipping with jaggy, SCORE 2 indicates remarkable lipping.

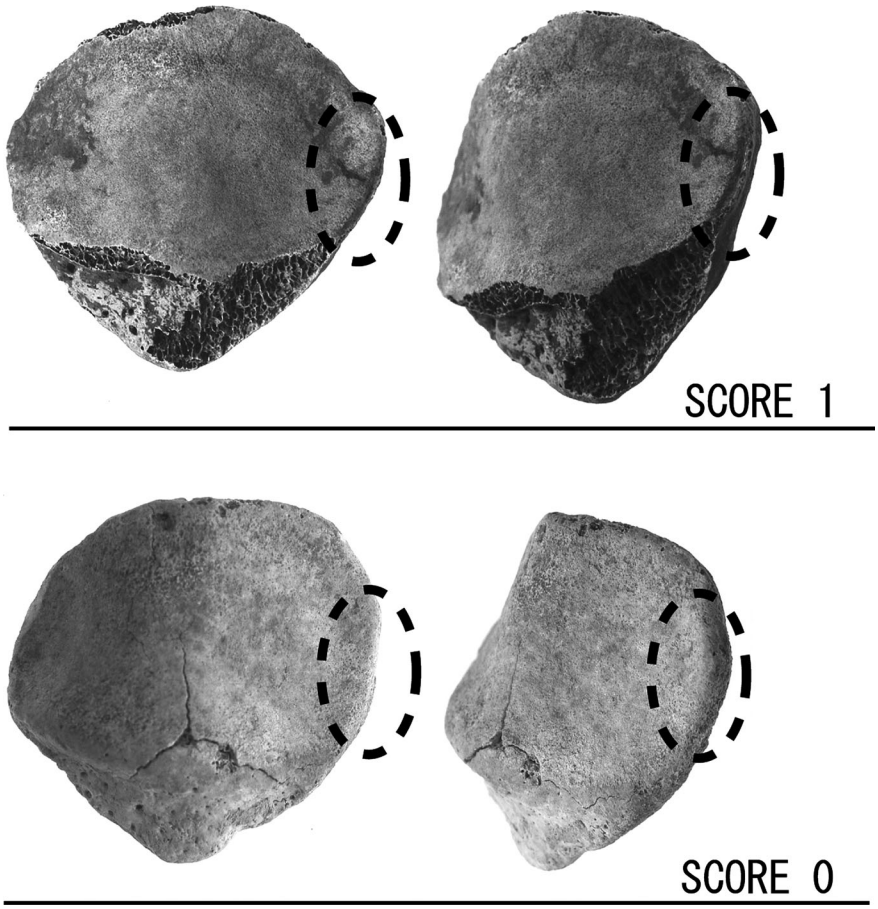


Fig. 4. Definition of the morphology of the dual edge of the margin of the articular facet. These patellae were also on right side. The articular margin surrounded by the doted line showed no dual edge of the bottom picture and the dual margin of the top one.

cranial suture method (Meidle and Lovejoy, 1985) and the auricular surface method (Buckberry and Chamberlain, 2002), was used in this study. The lipping at the attachment is formed through a gradual degenerative transition from no lipping to the remarkable lipping. This transition can be divided conveniently into three stage; no lipping, weak lipping with jaggy on the surface of the attachment of the quadriceps femoris muscle, and the remarkable lipping observed as outgrowth of greater than 1 mm from the smooth surface of the attachment of the quadriceps. Scores of 0, 1, and 2 were assigned for these three stages (Fig. 3). Strictly speaking, the regressive marginal osteophyte can only be observed in individuals that suffered from osteoarthritis of the knee. If this serious regressive marginal osteophytes were counted, the average age of the existence of this lipping would deviate to over 60 years (Lawrence, 1963). However the dual edge of the margin of the articular facet can be observed in the individuals of approximately 30 years who have no symptom of osteoarthritis, and the real marginal osteophytes can be regarded as the bony extension of the outer edge of this dual one in individuals with osteoarthritis. Thus, the articular margin without the dual edge was assigned the score 0 and that with the dual edge, score 1 (Fig. 4). The composite score is defined as the sum of the scores of these morphological

characteristics and the mean age and standard deviation of each composite score was used for estimating the age-at-death.

Statistical analysis was carried out using the one-sample Kolmogorov–Smirnov test was conducted for all variables in each sex to test for any deviations from the normal distribution. The distribution of all variables of each sex did not differ from the normal at a statistically significant level. The Kolmogorov–Smirnov test, however, resulted in rejection of a normal distribution in almost all composite scores in both sexes at the 1% significance level. Therefore, non-parametrical tests were performed for aging parameters.

The one-sample *t*-tests and the Wilcoxon signed rank tests were performed for the side differences. All variables showed no statistically significant side differences at the 5% level. Therefore, only the results of the right side have been reported in this paper.

The two-sample *t*-test and the Mann–Whitney's U test for sexual differences were performed. Subsequently, discriminant analyses were performed, and the discriminant functions, Wilk's lambda, and the correctly classified percentages were calculated.

In the analysis of the composite score for estimation of the age-at-death, the Mann–Whitney's U test was used in order to determine whether the adjacent scores were significantly different. If statistically differences were observed, the mean age of the composite score can be safely used for estimating the age-at-death.

For evaluating these methods, the 26 recent Japanese skeletal materials (15 males and 11 females) were investigated subsequent to the abovementioned analyses. Thus, the data of this independent sample were not included in developing the diagnosis methods of sex and age-at-death by analyzing the patella. All this samples were stored in Chiba University School of Medicine. For the test of diagnosis of sex, the measured values were applied to the discriminate functions. For test of estimation of the age-at-death, the mean errors between the estimated and real ages (inaccuracy and bias) were calculated (Lovejoy *et al.*, 1985; Sakaue, 2006). The inaccuracy was calculated as the |estimated age real–age| /*n*, showing the average magnitude of absolute error. Bias was calculated as the |estimated age–real age| /*n*, expressing tendency for either over- or under-estimation of age.

In this study, statistically significance was set at 5%. All statistical analyses were performed using the statistical software package SYSTAT 10.2.

## Result and Discussion

*Diagnosis of the sex*

Descriptive statistics of all variables are presented for each sex in Table 1. Results of the six measurements are shown in Table 1. All the variables showed statistically significant sexual differences with the two-sample *t*-test.

The results of the discriminant analyses are

Table 1. Basic statistics of the six variables of the patella for sex diagnosis in recent Japanese.

| | Male | | Female | |
|---|---|---|---|---|
| | Mean | (S.D.) | Mean | (S.D.) |
| Maximum Height | 41.1 | (2.7) | 36.6 | (2.1) |
| Maximum Breadth | 43.5 | (3.0) | 39.1 | (2.5) |
| Maximum Thickness | 19.4 | (1.5) | 17.7 | (1.3) |
| Articular Height | 30.9 | (2.2) | 28.3 | (1.7) |
| Breadth of the Medial Facet | 21.5 | (1.8) | 19.3 | (1.5) |
| Breadth of the Lateral Facet | 27.5 | (2.2) | 24.5 | (2.1) |

The sample size is 283 individuals (183 males, 100 females).
There is no statistically significant differences between the right and left.
All varibales have statistically significant differences between sex.

Table 2. Summury results of discriminat analyses for sex from the mesurements of the patella.

| | Function No. 1 | Function No. 2 | Function No. 3 | Function No. 4 |
|---|---|---|---|---|
| Maximum Height | 0.258 | 0.294 | 0.282 | |
| Maximum Breadth | 0.044 | 0.161 | 0.141 | |
| Maximum Thickness | −0.167 | −0.078 | | 0.061 |
| Articular Height | 0.037 | | | −0.205 |
| Breadth of the Medial Facet | 0.182 | | | −0.326 |
| Breadth of the Lateral Facet | 0.143 | | | −0.210 |
| constant | −17.578 | −16.926 | −17.052 | 17.323 |
| Wilk's Lambda | 0.525 | 0.545 | 0.546 | 0.587 |
| Correctly classified (%) | 85.0% | 85.0% | 85.0% | 84.0% |

Table 3. Sexing accuracy for recent Japanese with using three discriminat functions published in other ethnic populations.

| | Italian | (correctly %) | South Africans white | (correctly %) | South Africans black | (correctly %) |
|---|---|---|---|---|---|---|
| Male | 146 | (79.8) | 117 | (63.9 ) | 117 | (63.9) |
| Female | 79 | (79.0) | 96 | (96.0 ) | 96 | (96.0) |
| Total | 225 | (79.5) | 213 | (75.3 ) | 213 | (75.3) |

The most accurate function (83.8%) with "maximum width" and "Maximum Thickness" in Italian was reported in Introna *et al.* (1998), the most accurate function (85.0%) with "all six variables" in South African of European decent was reported in Bidmos *et al.* (2005), the most accurate function (85.0%) with "maximum breadth", "maximum height" and "maximum thickness" in South Africans of African descent was reported in Dayal *et al.* (2005).

presented in Table 2. The correctly classified percentages of the discriminant functions with all the variables was 85%, which is almost comparable to the result of the best functions obtained in previous studies (83.8% in Italians (Introna *et al.*, 1998), 85.0% in the South African black (Dayal *et al.*, 2005), and 85.0% in the South African white (Bidmos *et al.*, 2005). Surprisingly, the correctly classified percentages were approximately 85% in all the functions in this study. In previous studies, the maximum length and breadth were consistently the variables exhibiting the maximum difference between the sexes (Dayal *et al.*, 2005; Bidmos *et al.*, 2005). This was confirmed to be the same percentage of the function No. 3 as those of functions No. 1 and No. 2 in this study.

Table 3 shows the result of application of the best discriminant functions in previous studies to the recent Japanese skeletal samples of this study. The correctly classified percentages of these functions were under 80%. This means that the discriminate power of the discriminant function of the patella developed for one ethnic population will reducel when applied to another ethnic population.

It can be said that this method for diagnosis of the sex from the patella with the discriminant functions can be practically applied to Japanese skeletal specimens.

*Diagnosis of the age-at-death*

Table 4 shows the mean age and standard deviation of each composite score, and Figure 5 shows the box plot of composite score for the sexes. It is clear that the variation in each score was very wide even at the younger score (0 or 1) and all the standard deviations exceeded 10.0. In the Suchey–Brooks system for age estimation by analysis of the pubic symphysis, the standard deviations at younger phases as phase I (the mean age in male, 19.0) and phase II (the mean age in male, 25.3) was lower as 2.5 and 4.9 respectively in recent Japanese male (Sakaue, 2006). Even the

Table 4. Basic statistics for each composite score in the recent Japanese and Mann–Whitney's U tests.

| Composite score | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | N | Mean | (S.D.) | | N | Mean | (S.D.) | |
| 0 | 98 | 32.5 | (14.6) | * | 52 | 31.8 | (11.8) | * |
| 1 | 37 | 43.2 | (13.6) | * | 12 | 48.8 | (13.6) | * |
| 2 | 29 | 50.1 | (13.2) | * | 18 | 58.8 | (11.3) | |
| 3 | 19 | 57.2 | (15.8) | | 18 | 60.7 | (12.7) | |

"*" means statistically significant between Phases or Sexes at 5% level.

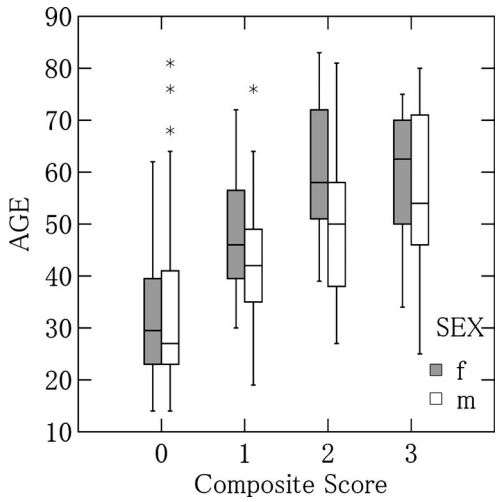


Fig. 5. Box plot of the composite score for estimating age-at-death evaluated by analysis of the patella.

highest value of the standard deviation in the Suchey–Brooks system was 12.1 at phase VI (the mean age in male, 58.4). In the age estimation method with cranial sutures developed by Meindl and Lovejoy (1985), the highest value of the standard deviations was 12.6.

Age differences between scores 0 and 1 and between scores 1 and 2 were statistically significant, but differences between scores 2 and 3 did not reach statistical significance in both sexes.

These results indicated that the age estimation by analyzing the morphological variations of the patella were not as reliable as that by analyzing the pubic symphysis or cranial sutures. Judging from no significant difference between score 2 and 3, the number of scores in this method was only 3 in practice. Therefore, it can be said that age estimation by analysis of the patella is rather vague, therefore, its usage should be limited for the vague estimation of age-at-death in term of three classes: the young (score 0), the middle aged (score 1), and the old (score 2 and 3).

*Test of the method*

The results of the test by using 26 recent Japanese skeletal materials are presented in Table 5. All the female samples were correctly classified and the 4 male individuals were incorrectly classified, and the percentage of correctly classified specimens was 84.6%. Therefore, the diagnosis of sex with the patella is considered to be an effective method. The mean inaccuracy of the analysis was 8.6, which is higher than that reported in Suchey–Brooks systems used to assess recent male Japanese (5.6). The mean bias was slightly positive at 0.7, but this value is incidental. Since an error of over 10 years was obtained in determining the age-at-death of 9 individuals, diagnosis of the age-at-death by analysis of the patella cannot be considered effective.

In summary, the discriminant functions of the patella was effective for the diagnosis of the sex in Japanese skeletal samples, the method of age-

Table 5. The result of the application of the new metods to the recent Japanese.

| Sample No. | Sex | Age | Discriminant scores | Estimated age | Bias | Inaccuracy |
|---|---|---|---|---|---|---|
| 1 | f | 71 | −1.976 | 48.8 | 22.2 | 22.2 |
| 2 | f | 20 | −1.452 | 31.8 | −11.8 | 11.8 |
| 3 | f | 41 | −1.848 | 31.8 | 9.2 | 9.2 |
| 4 | f | 32 | −1.501 | 31.8 | 0.2 | 0.2 |
| 5 | f | 23 | −0.854 | 31.8 | −8.8 | 8.8 |
| 6 | f | 20 | −1.410 | 31.8 | −11.8 | 11.8 |
| 7 | f | 31 | −1.898 | 31.8 | −0.8 | 0.8 |
| 8 | f | 43 | −3.187 | 48.8 | −5.8 | 5.8 |
| 9 | f | 68 | −0.659 | 60.7 | 7.3 | 7.3 |
| 10 | f | 64 | −1.963 | 60.7 | 3.3 | 3.3 |
| 11 | f | 33 | −2.224 | 48.8 | −15.8 | 15.8 |
| 12 | m | 39 | ***−0.487*** | 32.5 | 6.5 | 6.5 |
| 13 | m | 63 | 0.272 | 43.2 | 19.8 | 19.8 |
| 14 | m | 51 | 2.014 | 32.5 | 18.5 | 18.5 |
| 15 | m | 20 | ***−0.096*** | 32.5 | −12.5 | 12.5 |
| 16 | m | 28 | 2.337 | 32.5 | −4.5 | 4.5 |
| 17 | m | 40 | 1.144 | 43.2 | −3.2 | 3.2 |
| 18 | m | 39 | 0.608 | 32.5 | 6.5 | 6.5 |
| 19 | m | 52 | 0.229 | 43.2 | 8.8 | 8.8 |
| 20 | m | 41 | ***−1.230*** | 43.2 | −2.2 | 2.2 |
| 21 | m | 17 | 0.565 | 32.5 | −15.5 | 15.5 |
| 22 | m | 30 | ***−0.535*** | 32.5 | −2.5 | 2.5 |
| 23 | m | 56 | 1.003 | 50.1 | 5.9 | 5.9 |
| 24 | m | 30 | 2.220 | 32.5 | −2.5 | 2.5 |
| 25 | m | 45 | 0.672 | 32.5 | 12.5 | 12.5 |
| 26 | m | 27 | 2.512 | 32.5 | −5.5 | 5.5 |
| Average | | | 84.6% | | 0.7 | 8.6 |

The bold-itallic characters mean the misclassified socres of sex.

at-death estimation developed in this study was not very accurate. Nevertheless, this method could be used for obtaining a vague estimate of the age-at-death, and this is the only method that can be used for age estimation by analysis of the patella.

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