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Sex determination based on a thoracic vertebra and ribs evaluation using clinical chest radiography

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ABSTRACT

Our aim was to investigate whether sex can be determined from a combination of geometric features obtained from the 10th thoracic vertebra, 6th rib, and 7th rib. Six hundred chest radiographs (300 males and 300 females) were randomly selected to include patients of six age groups (20s, 30s, 40s, 50s, 60s, and 70s). Each group included 100 images (50 males and 50 females). A total of 14 features, including 7 lengths, 5 indices for the vertebra, and 2 types of widths for ribs, were utilized and analyzed for sex determination. Dominant features contributing to sex determination were selected by stepwise discriminant analysis after checking the variance inflation factors for multicollinearity. The accuracy of sex determination using a combination of the vertebra and ribs was evaluated from the selected features by the stepwise discriminant analysis. The accuracies in each age group were also evaluated in this study. The accuracy of sex determination based on a combination of features of the vertebra and ribs was 88.8% (533/600). This performance was superior to that of the vertebra or ribs only. Moreover, sex determination of subjects in their 20s demonstrated the highest accuracy (96.0%, 96/100). The features selected in the stepwise discriminant analysis included some features in both the vertebra and ribs. These results indicate the usefulness of combined information obtained from the vertebra and ribs for sex determination. We conclude that a combination of geometric characteristics obtained from the vertebra and ribs could be useful for determining sex.

1. Introduction

Shape and size of the skull, pelvis, and humerus have often been used for sex determination in forensic medicine [1–8]. However, skeletal bones are not always complete in forensic cases due to conditions within the burial environment, and only parts of bones are found occasionally [9]. In such cases, it is desirable to discriminate personal information, such as age, height, and sex, from the bones available. Some reports have shown that features of vertebrae and ribs, including the 1st and 2nd cervical vertebrae, 12th thoracic vertebra, all lumbar vertebrae, and the 1st and 4th ribs, could be useful for sex determination [9–18]. On the other hand, no study has reported whether sex can be determined from a combination of anatomical information extracted from a thoracic vertebra and ribs.

Our study focuses on evaluation of chest radiography (hereafter referred to as chest image), the most common examination performed at many hospitals and medical centers. It is easy to collect a large number of clinical chest images. We attempted to determine sex in a Japanese population by using clinical chest images. The hypothesis of this study is that size and shape of a bone may not be changed by death. Although previous studies have used computed tomography (CT) images for sex determination [3–5,12–14,16,17], chest images are thought to be potentially useful since they can be reconstructed from three-dimensional CT data. Our aim is to examine whether sex can be determined from geometric information obtained from large numbers of thoracic vertebrae and ribs in various age groups.

2. Materials and methods

All chest images in our database were obtained using a computed

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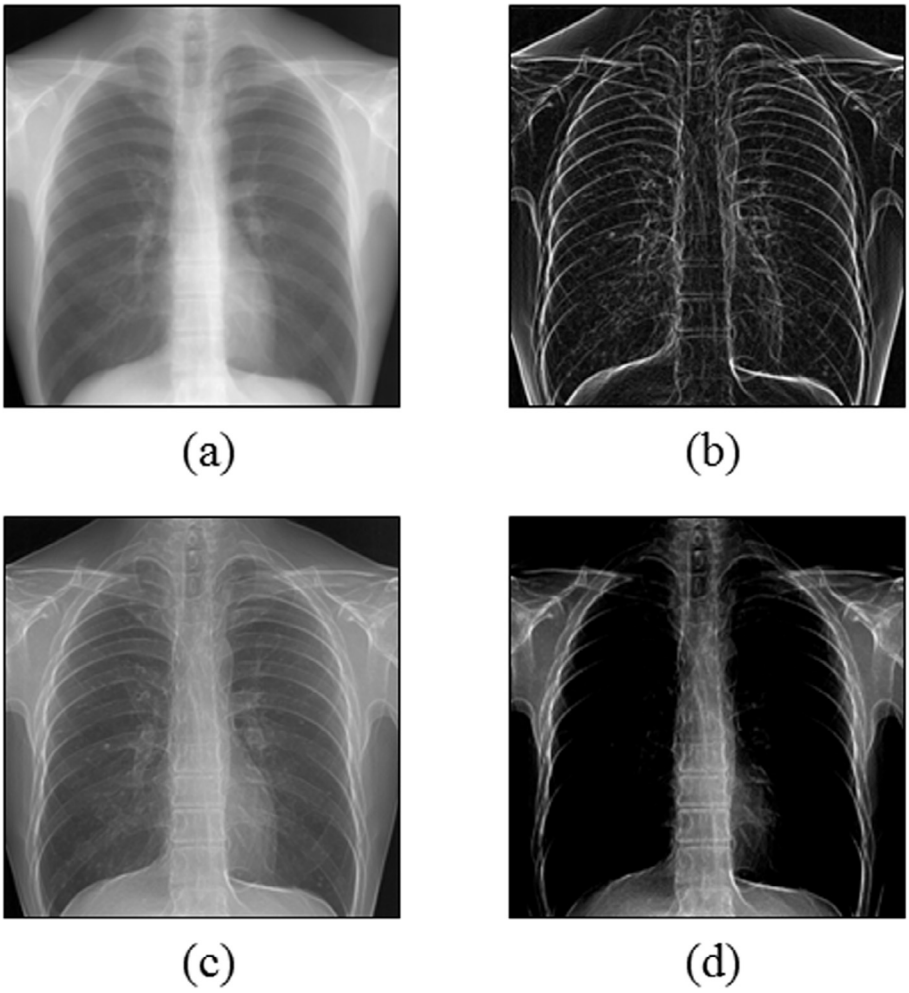

Fig. 1. Examples of image pre-processing for measurements of widths, heights, and diagonal lengths of the 10th thoracic vertebra on a chest radiograph. (a) original chest image; (b) edge-enhanced image using Sobel filter; (c) sharpened image by adding (b) to (a); (d) sharpened image after adjustment of the window width and level. On the other hand, no pre-processing has been done for measurement of the widths of the 6th and 7th ribs.

radiographic system (FUJIFILM Medical Corporation, Tokyo, Japan) at the lung cancer screening program in Iwate Prefecture, Japan [19]. The matrix size and pixel size of the images were 512 × 512 and 0.69 mm, respectively. Six hundred normal chest images were randomly selected from our database and included images from patients of six age groups (20s, 30s, 40s, 50s, 60s, and 70s). Each group included 100 images (50 males and 50 females).

We used the 10th thoracic vertebra, 6th rib, and 7th rib for sex determination. Visual assessment of the 10th thoracic vertebra was easy due to the low overlap with the trachea or diaphragm compared to other vertebrae. In addition, the lower thoracic vertebrae are often preserved well in archaeological skeletal assemblages and forensic contexts due to their weight-bearing function and relative density [13]. Measurement of the rib widths was also easy due to the low overlap with the clavicle or diaphragm. Moreover, these anatomical structures were less affected by geometric distortion and magnification owing to their close proximity to the center of the X-rays during chest imaging.

Image processing was performed to facilitate visualization of the measurements of the vertebra lengths as shown in Fig. 1. A total of 14 indices were used in this study. Twelve among 14 indices were obtained from the 10th thoracic vertebra on a chest radiograph (Fig. 2). Seven linear measurements of the vertebra were performed on chest images displayed on an electronic display device using an image processing software (ImageJ, National Institutes of Health, USA). Then, 4 ratios and an area were obtained from the 7 measurements. Fig. 3 shows a procedure to measure the widths of the 6th and 7th ribs on a chest image. The reproducibility of these measurements appears to be substantial (interclass correlation coefficient, r = 0.803) [20].

Sex determination was performed as follows. First, a Student's *t*-test was applied for comparison of male and female at each index. Differences between the sexes were considered statistically significant when p values were less than 0.05. If the index showed statistically significant difference, accuracy of sex determination was evaluated by using a linear discriminant analysis (LDA). Second, the accuracies in all age groups were evaluated by using a stepwise discriminant analysis for (1) a thoracic vertebra, (2) ribs, and (3) the combination of both as shown in Fig. 4. A stepwise discriminant analysis is a statistical method to select effective variables contributing to discrimination. We sought to distinguish male from female by means of discriminant equations obtained from the analysis. Multicollinearity of various features was checked by the variance inflation factor (VIF) before applying the stepwise discriminant analysis. The VIF indicates how a variable can be predicted by another one. A VIF value of 10 or more indicates multicollinearity in the data. Finally, the accuracies in each age group were also evaluated by applying the stepwise discriminant analysis. All statistical analyses were executed by using JMP® 11 (SAS Institute Inc., Cary, NC, USA) and R version 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Table 1 shows the descriptive statistics for 14 indices and accuracies of sex determination by using the linear discriminant analysis (LDA) for the indices that demonstrated significant differences. Ten indices in males, except for X_{middle}/X_{upper}, X_{middle}/X_{lower}, Y_{center}/Y_{left}, and Y_{center}/Y_{right}, were significantly higher than those in females. If we use $X_{middle}{\cdot}Y_{center}$, an index corresponding to the area of the vertebra, the accuracy of sex determination was the highest, with 85.0% (510/600).