Analysis of X-ray Images of Femora for Age at Death Estimation of Skeletal Individuals

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Abstract: This work focuses on an *in silico* analysis of age specific changes of human femora based on X-ray images. Thereby an alternative technique should be found to support classic anthropological methods for individual age estimation. Overall it is achievable to correlate age-related changes in the bone structure with the individual age. With this new approach it is possible to generate grey levels of digital images of specific bone features and correlate categories of grey level variation with the individual age. This method was applied to selected *femora* of an excavation site, that originates from the age of the Roman Empire/early migration period (365-416 AD). The obtained ages (grouping in defined classes) were then evaluated with the results of classical anthropological methods by a confusion matrix.

Keywords: forensic anthropology, age estimation, digital image processing, X-ray imaging

1 Introduction

There are several techniques in terms of analysing human skeletal remains with the aim of generating a biological profile of an individual [Br74, FSS79]. To create such a profile diverse questions can be clarified regarding sex, age, body height, stature, ancestry, degenerative and pathological changes [Fr10, Do08]. In general, the success of selected methods depends on state of preservation of material and the presence of significant bone features [Bi08, GHG14]. Morphognostic and osteometric methods are popular procedures in the anthropology field [Ge02]. In addition to these classical methods new approaches, such as flat panel radiography or digital X-ray image analyses, were established in the last years for an additional information gain. The combination of classical and modern methods is essential in order to obtain even more information to confirm already existing results since the classical methods reach their limits [KGS13, Ca07]. The new application allows an automated *in silico* analysis for an objective evaluation process.

The excavation site in Görzig (Saxony-Anhalt) represents a collection of well-preserved human skeletal remains. It is a small burial ground that originates from the age of Roman Empire/early migration period (365-416 AD). Prior to this study biological profile (sex, age of death, body height, degenerative changes, DNA analyses) of the site was

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determined in previous works by the application of anthropological methods (morphognostic and osteometric) [Kl11, Be10, Je16]. The results for sex determination were subsequently confirmed by extensive DNA analyses. In addition, specific haplogroup markers of Y-chromosome and mtDNA were analysed to obtain more information about the ethnic background [Ha15, Pf14]. With this burial ground it can be shown how important the combination of classical and modern methods is. To prevent subjective bias in classical approaches and to extend the information base, radiographs were used for further analyses [Sc04, BPA10]. Satisfying results for a sensitive and objective new method are shown here by digital analysis of X-ray images from proximal epiphyseal plate of the *femur*. In contemporary X-ray diagnostics the images are stored in a digital format [Fr16]. The age-related changes cause other resonance pattern in the X-ray image and this causes a change in the grey values of the image that can be measured digitally. For this digital measurement it is necessary that the assessed structures, such as the epiphyseal plate, are emphasized. For better feature visualisation different image filters can be used.

2 Materials and Methods

2.1 Samples and Tools

The samples originated from the described excavation site [Be10]. Of the native sample set (75 individuals) *femora* of 14 individuals were screened by X-ray imaging in an initially approach. Due to partly missing counterparts of either left or right femora for some individuals the resulting sample set comprises of 25 *femora*. Utilized image analyses algorithms were implemented using Java and the 3D pixel-intensity plots (3D surface plots) for age estimation were generated by ImageJ [Ra97].

2.2 Image Analyses

For image processing different approaches and analysis filters were used (Tab. 1, Fig. 1).

processing step	operation
preparation	smoothing with 3x3 Gaussian kernel colour space spreading (linear followed by exponential)
analyses	Fourier and Hough transformation Laplacian edge detection and 3D surface plot threshold filter
evaluation	confusions matrix

Tab. 1: Processing phase of filter analyses. For the image analyses the workflow was divided in three steps – preparation, analyses and evaluation. In each step different filters and image processing tools were applied.

The digital radiograph is provided as greyscale JPEG file, distinguishing 256 values of grey. For the purpose of digital analyses of an epiphyseal plate an image area of 70 x 220 pixels was selected, including the epiphyseal plate and the surrounding bone portion. Initial investigations were made to detect the epiphyseal from the unprocessed original image by a Laplacian edge detector [PLW09].

For a better detection of the epiphyseal plate the next step was affiliated with the aim of smoothing through 3x3 Gaussian filter and the colour space stretching from image (linear and exponential) [Jä12]. This step was mandatory to reduce the image noise and to increase the contrast. Although that implicates a blurring of smaller structures, such as fine trabeculae structure, however coarse structures, such as the epiphyseal plate are emphasized. On the basis of the preprocessed image Fourier- and Hough transformation were applied separately. Thereby contours are highlighted between structures. Hough transformations are designed for detection of geometric shapes such as straight lines and are used for binary images (black-and-white images). To allow even better extraction of the epiphyseal plate the contrast was maximized by a threshold filter. The threshold filter was applied on the preprocessed image from the preparation phase (smoothed and spread). Subsequently, a Laplacian edge detection and Hough transformation has been performed with the threshold image again. The 3D surface plot was created from the original image. With the 3D surface plot the colour information of an image is converted into topographical information. The width and length of the image is mapped on the x and y-axis, the intensity of the grey values (between 0 and 255) of the image is mapped on the z-axis.

Finally, after applying the image processing steps (bracing, threshold analyses, Fourier transformation, Laplacian edge detection, 3D surface plot) the evaluation of respective imaging was performed. For filter analysis the original image was scaled into a grid (image size 220 rows*70 columns). First, the smoothed and stretched image was analysed. Afterwards the pixels were accumulated from left to right (vertical, column by column), which have not the grey value zero. Following all non-black pixels were detected from top to bottom (horizontal; line by line). The scaling of the resulting plot is based on the local maxima. Because left-right scanning achieved better results, only this method was applied for further analyses. To obtain a reference value of left-right scans, resulting peaks were analysed in order to determine their width. The smaller the width of the peak, the more the epiphyseal plate can be seen in the X-ray image. Hough lines were further evaluated on the slopes of the straight lines. Overall for the evaluation of two chosen filter options, the Laplacian edge detector and the surface 3D plot are particularly suitable for the age estimation in form of a visual representation. In order to correlate the results of the filter analysis with an individual age, three age classes were introduced -young (< 20 years) - middle (20 - 40 years) - old (> 40 years). This age classes corresponds to individual age estimation by morphognostic methods [MS57]. This classification was based on the peak widths, results of Hough transformation and optical features, as the wide of surface plot peaks or the edge detection image. The older an individual is, the wider are the peaks and the higher the results of Hough transformation. Evaluation of the data was carried out by a comparison of the results with the morphognostic in form of a confusion matrix (Fig. 3).

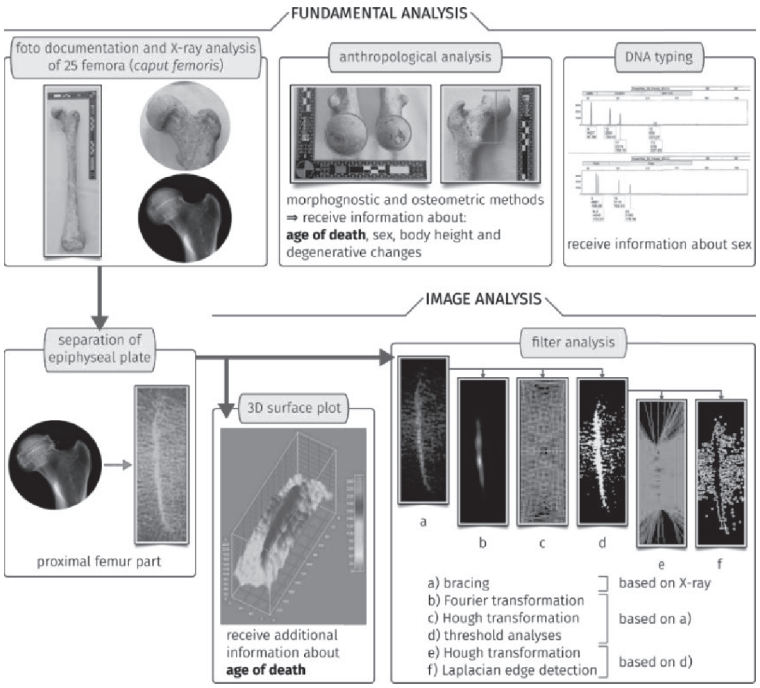

Fig. 1: Workflow for image analysis with different filters. The figure shows an overview of applied methods, including filter analysis. First, the basic analysis - the photographic documentation of all bones – was performed. Hereafter 25 bones were X-rayed. Then the *femora* and other regions were subsequently analysed by conventional anthropological methods. In the second analysis level data from first anthropological level regarding individual age estimation level were complemented by a new image analysis. Here the epiphyseal plate was isolated from this area and analysed by various image processing filters: a smoothing and a contrast stretching filter (a) and a Fourier (b) and a Hough transformation (c). In addition, the contrast has been maximized by applying a threshold filter (d). On the threshold image again a Hough transformation (e) and Laplacian edge detector (f) were applied. Finally the original X-ray image has been converted into a topographic map by a 3D surface plot.

3 Results and Disscusion

The aim of the analysis was to filter out the epiphyseal plate digitally as a supplemental aspect in human individual age estimation. The initial use of the Laplacian edge detector yielded insufficient results. The smoothing alone has shown no visible improvement in comparison with the original image. But the combination of smoothing and contrast stretching (logarithmic and exponential) resulted in a considerable improvement of contrast. The best filtration yielded the threshold at 128. Also through Fourier transformation the epiphyseal plate could be clearly emphasized. The Hough lines were

applied to the original image with no clearly discernible pattern. Unlike the Hough lines applied to the threshold image. At this point a pattern in the field of epiphyseal plate could be differentiated. Reapplying the Laplacian edge detector on the threshold filter detects the epiphyseal plate, but it also shows brighter surrounding structures as an edge. Also the 3D surface plot shows interpretable results (Fig. 2).

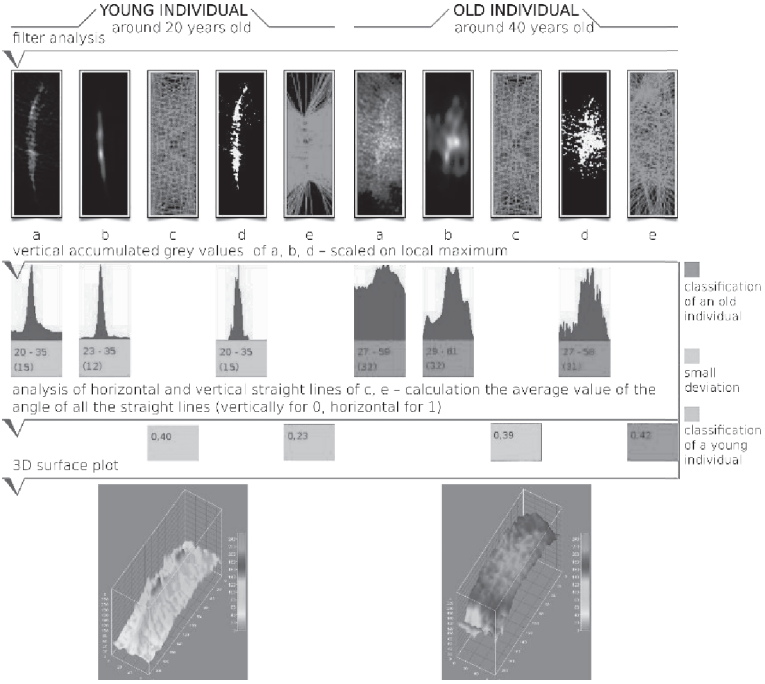

Fig. 2: Comparison of the results of analysis filter between young and old individuals. The figure shows the age comparison between a young (~ 20 years old) and an older (~40 years old) individual. The comparison is based on different scorings of filter analyses and optical evaluating. The applied filters look significantly different. Especially contrast enhancement and Fourier transformation lift the epiphyseal line clearly in the plot of young individual instead of older. In the plot of the older individual, however, no clear epiphyseal plate was detected. It is recognized that the line starts already to merge with the surrounding. The peaks, that arise from the vertical accumulated grey values of the contrast enhancement, Fourier transformation and threshold filter show between younger and older a distinct from each other. Peaks of the younger individuals are narrower and the peaks of the older individual are wider. The peak width is described by the peak score below. The values of the Hough transformation can be evaluated the average value of all these horizontal and vertical straights (↕ 0 and ↔1). The colours of the numbers reflect the comparison between filter analysis, morphognostic analysis and the results of the age assignment. A young individual (< 20 years) is represented with the colour green and the colour red represent an older individual (> 40 years). Yellow represents the transition group. Also the 3D surface plot shows different results. The obtained topologies of young and old individuals distinct from each other. The peaks of young epiphyseal plates are narrow and pointed, peaks of older epiphyseal plates are rather plateau-shaped. That discrepancy can mainly be used for individual age estimation.

Because of the small sample size and the fact that the real age of analysed material is unknown, the filters were initially only divided in three presented age classes. For grading the individuals in the respective age class all results of the particular filters have been merged. Here six bones were associated with a young age, ten bones with a mean age and nine bones with an elderly age. To evaluate the results, these age classes were then compared with the results of the age estimation, which were generated by the morphognostic analyses of the *femur*. For evaluation the results of the filter analyses were divided into three groups (correctly classified, transition group and incorrectly classified) (Fig. 3). Correctly classified bones were assigned both by morphognostic and filter analyses in the same age class. The transition group describes bones that have a small deviation between the results of morphognostic and filter analyses. In cases where no accordance occurred between both methods were thus categorized as false. Fourteen bones of the sample set were classified correctly by stretching, ten belong to the transitional group and one was classified incorrectly. By threshold assessment (128) twenty-one bones were correct and four belong to the transition group. In the Fourier transformation twenty-two bones were properly classified and three bones were assigned to the transition group. With Hough lines from the original image eleven bones were correctly classified and fourteen bones related to the transition group. By threshold assessment, Fourier transformation and the first Hough lines no bone was incorrectly classified. Using the Hough lines from the threshold eighteen bones were properly classified, six bones related to the transition group and one bone was misclassified. The Laplacian edge detection and the application of 3D surface plot were carried out without a filter based classification scenario. With the Laplacian edge detector it was possible to determine whether the edge reflects an epiphyseal plate or not. From the 3D surface plot obtained topologies of young and old individuals differentiate both groups significantly. Peaks of young epiphyseal plates are narrow and pointed. In contrast, peaks of older epiphyseal plates are rather plateau-shaped. That discrepancy can mainly be used for individual age estimation.

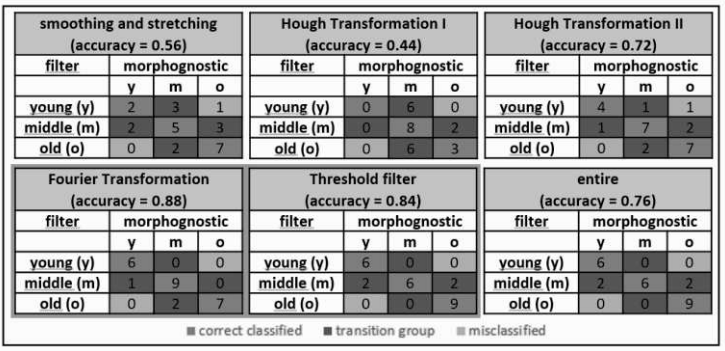

Fig. 3: Confusion matrix of the data set. The matrix represents the comparison between the results of the analysis filters and the morphognostic. It is shown that Fourier transformation and threshold filter provides the best result (green tag). The entire of all filters, is with an accuracy of 0.76 is considerable.

4 Conclusion and Outlook

With the application of digital X-ray images an ancillary impartial method was implemented regarding individual age estimation of skeletal remains. One major objective of this method is thus to minimize the influence of subjective evaluation criteria of classical or conventional anthropological methods. It should be noted that with the analysed sample set of *femora* it is only possible to present the potential and possibilities of this method. Because of the small sample number it is not feasible to draw generalized statements at this point. For generalization it is necessary to correlate the actual results with various skeletal material of known individual age. The particularly object was to recognize the epiphyseal plate by *in silico* method. This was realized by the use of different filters. The application of the threshold value filter and the Fourier transformation generates the best results. Filtering by Hough lines from the original image delivered no expressive results compared to the Hough lines from the threshold image. By the image analysis of the threshold filter, the Fourier transformation and the contrast enhancement the left-right scanning was applied to detect the non-black pixels and visualized in a distinct peak. By characterization of peak width it is possible to separate young and old individuals. Thus, based on the peak widths caused by the epiphyseal plate, an age correlation is apparent. This structural alteration is a meaningful [SK90] feature and can be used for the application of digital filter age analysis demonstrated in this study. In addition to considering *femora*, other epiphyseal regions of the human skeletal can be characterized. Therefore, this new approach offers a variety of applications.

5 References

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