

Anthroporadiology

Martin Obert *

Department of Neuroradiology, University Hospital Gießen, Germany

This editorial is written by a scientist and hobby artist who entered the field of anthropology seven years ago. My science background is rather scattered over different disciplines. It began with studying chemistry at the University of Bielefeld, Germany. It continued with research based on the concept of fractal geometry at the Department of Physics and Astronomy at the University of Missouri, Columbia, USA. I was fascinated by the beauty and the complex symmetry of the images in the world of Benoit B. Mandelbrot. I was astonished that there exist well-defined methods in mathematics that can be used to describe highly irregular images. Up to that time I admired pictures from fine arts that capture my attention emotionally. Thus, images have more than a simple attraction – I admit, it is rather an addiction. Images are a language for me that I use to express myself. In my free time, I like to draw portraits from friends and oil paintings related to the post-impressionism style of the last century. The fractal concept opened to me the opportunity to connect science methods – mathematics, image analysis – with fine arts – or images in general. Therefore, I fit perfect in the radiology area, where I currently run an experimental computer tomography system, which is explicitly used for research.

Anthropology entered my life when Marcel Verhoff visited my office, a professor from the Forensic Department of our local university. He taught me how difficult it is to estimate the age at death of humans of unknown identity, to differentiate between man and women, when only some bone fragments are left over, and how important answers of these questions can be for relatives, who definitively want to know if this recently found bone belongs to the brother who is missing for years. I learned from him that there is no unique method that allows unambiguous aging with a small error bar of the prediction accuracy of subjects of unknown age. He also pointed out how much expertise is needed to judge the different parameters to narrow an age range of an age at death estimate. Verhoff introduced me also into the old ideas from Broca (1861) that closure of cranial sutures might correlate with age - with the hypothesis that the older a subject, the higher the degree of ossification, the more the sutures are closed. So far the degree of closure was described by visual inspection from e.g. the top view onto the sagittal suture. It was easy to convince me that a three-dimensional view - based on computed tomography images - into a suture, might offer advantages over the classical methodology.

Computed tomography is a nondestructive tool in Physical Anthropology. A fundamental property is that the grey-levels in an image are linearly related to the attenuation of x-ray radiation of the investigated material. When a computed tomography system is frequently and carefully calibrated, and when one sticks to an identical set of scan parameters, preserved in a protocol applied in all scans of a study, one can obtain data sets that can be relatively easy compared. Image quality is correlated with radiation dose: the higher the dose, the better the image quality. The application of ionizing radiation is ethically uncritical when we investigate human remains. So we get easily a high image quality of bones.

We started our first Anthroporadiology project and Verhoff suggested scanning skullcaps taken from regular autopsies. Thus, to decide to start a project and to perform projects are two different pairs of shoes. Verhoff came from the Forensic Department with the first

calotte – perfectly cleaned and packed in a plastic bag - and positioned it on the specimen holder of the scanner. Next time, a technician from the dissecting room brought the skullcap and I had to position it on the specimen holder. It was difficult for me to touch the bone. Careful positioning is half of the scan. So I had to try to line out the skull's frontal – occipital axis perfectly parallel to the direction of the movement of the scanner table. After some time it became easier for me to perform the positioning. It was less difficult if it was a skullcap of a 95 years old person. It was difficult when it was a skull of my age. Then it was so apparent that it is sometimes just chance who lies on the table in the dissection room and that this skullcap could be my skullcap. It is still very difficult for me to position children's skulls on the scanner table. I learned that computed tomography images of children taken in the context of child abuse can be burnt into ones brain – coming up in dreams for weeks and months.

We did set up a scale that allowed a visual classification of the degree of ossification of a suture. As usual in radiology, a human takes look at the image data and performs the diagnoses or the classification according to a previously defined scale. To perform the visual inspection, the image data were displayed on an image analysis workstation. Today's workstations are very valuable for physical anthropological bone investigations. One can view the three-dimensional data set in the form of sectional images, which enables a look at the details inside a bone. In three-dimensional views, a bone can be arbitrarily rotated. Volume rendering images can be easily produced that enable a look at the bone surface. Bone parts can be cut off digitally if they hinder the view to a position of special interest. There is an “undo button” that nearly everybody would like to have in an operating or dissecting room. Length and volumetric measurements are possible, to mention only a few quantitative descriptors.

We thought that it would be a good idea to let a medical student perform the analysis so that she or he might try to get a doctoral degree, helping in this study. To be honest, we have not been really aware of the amount of the literally ten thousands of images that we easily produced with our high-resolution computed tomography device – even if we investigated only 164 male and 85 female skulls in our first study. The student was sitting in front of the workstation from early in the morning till late at night. He sat right next to me and took precisely the notes about the degree of ossification of the sutures as careful and concentrated as a human can perform such an analysis. It was soon clear that he could take only a look at a small fraction of images of the complete study, even if he would sit in front of the screen of the workstation for months. I felt a little bit guilty - how I could hand out

*Corresponding author: Martin Obert, Department of Neuroradiology, University Hospital Gießen, Germany, E-mail: Martin.Obert@radiol.med.uni-giessen.de

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such a job. Consequently, we decided to try to set up an image analysis program that is capable to classify the degree of ossification of a suture automatically. One advantage of such an analysis system is that a computer is able to perform calculations on thousands of images within a short timeframe. Clearly, there are many more benefits: A computer may run day and night without the production of a radiologist's pay ticket, the automatic classification is based on a well-defined algorithm, which leads to reproducible results so that no inter observer studies have to be performed.

I said that I feel guilty that a student had to perform the time consuming manual investigation, which often would be described as mindless and boring. On the other hand I admit that I always perform such a manual analysis, where I look for hours at my image data, before I try to develop an image analysis algorithm. The same is true for me when I paint. Before I create the portrait of a person, I look for hours at a photograph of that person. Then I start to paint – finishing the face in sometimes less than an hour. I am unable to describe what happens during the hours when I look or visually inspect – but it is certainly not “mindless”. I consider this “manual” step therefore definitively as necessary.

Despite the advantages of computational images analysis methods, to preserve optimism is sometimes difficult in age at death estimates. The result concerning the correlation between suture obliteration and age was rather unsatisfactory for the studied adult male and female skulls: we found that suture closure does not correlate with age. We had only sparse data in the age range from 0 to 20 years old children and adolescents that inhibited to investigate this age range seriously.

Despite this frustrating result, we decided to continue the aging project. One reason made this decision easy, which is based in the reusability of the scanned images. Once you have digital data, you can run and check an arbitrary amount of hypothesis on this data that have to be expressed and encoded only in image analysis algorithms.

The next hypothesis, which we tried out, took again advantage of the well-defined grey-level scale in computed tomography, which enables quantitative image comparisons of different skulls. What we wanted to compare was a radiological defined bone-density, based on this grey-level scale. Our assumption was that skull density might depend on age. The finding of this investigation was half as frustrating as the suture closure project. We found that the density of adult male skulls is independent of age. Otherwise, the skull density of adult females decays slightly as function of age. This sex difference was unexpected and astonishing for us. That the female bone density decays from an age range related to menopause is eventually easy to understand - but our data seemed to suggest that this decay begins already at an age of approximately twenty years. It became again completely frustrating when we calculated the width of the error bars of the accuracy of the prediction of age at death of subjects of unknown age. Although we found a density correlation for the adult female skullcaps as function of age, it was only a very weak correlation of a largely scattering dot cloud. The age at death prediction had an accuracy – if this word may be used – of plus or minus twenty-five years at reasonable confidence levels.

We checked in an additional investigation if it was necessary to use our experimental high-resolution computed tomography system, or if the findings can be reproduced with a standard clinical tomography system, which is available everywhere. We were able to reproduce the

findings, so the use of a standard system is sufficient. We next used computer simulations to get an idea of the magnitude of the correlation coefficients that one needs to get prediction accuracies that are of practical relevance in anthropology or forensic medicine. We learned by these simulations that we needed absolute correlation values larger than 0.9 to get error bars of only a few years. It is unreasonable to expect useful prediction accuracies with absolute correlation coefficients of 0.6 – the magnitude we found in our skull density analysis. Here, the scattering of the bone density is simply too large. We expanded our digital skull collection to approximately 330, which did not change the principle conclusion with respect to the age prediction accuracy. Other hypotheses will be evaluated that are no longer listed here, since I can line out the principle behind this essay already now.

Anthropologists are experts in anatomy and perfect in descriptions of the human skeleton. Their applied manual methods will change in the future. The exclusive time of the analog meter stick and ruler is basically over. Radiological digitization of human bone collections, storage of the data in data bases and making the images available for everybody over the internet, development of software that automatically compares millions of images to investigate various hypotheses, implementation of image analysis tools that can be combined with neural networks that will perform automatically classifications, applications of computer simulations to check the statistics behind hypothesis – all this will change the anthropologist's workday – increasing our knowledge tremendously. The anthropological methods are at hand - the radiological methods also. The software has to be developed according to the fantasy of anthropologists by many scientists from different disciplines.

For the newcomers from image analysis or physics it may be eventually difficult in the beginning emotionally to participate in Anthroporadiology projects. This is based on our normal anxiety to die. I think that this fear is an important source of motivation beside our curiosity in anthropological research. Since there is hardly any place where one can talk about these feelings, I wanted to use this editorial to mention this aspect too. For a further reading on this subject I would like to recommend the brilliant books written by Irvin D. Yalom.