55th Annual Society for the Study of Human Biology Symposium
in association with the
British Association for Biological Anthropology and
Osteoarchaeology

Age Estimation

St Catherine’s College, Oxford, England
9-11th December 2014
Tuesday 9th December

14.00  Welcome

14.10  **Controversies in dental age estimation**
       Helen Liversidge

14.40  **Appearance of third molars as a diagnostic test for age of majority**
       Tim Cole

15.10  **Censoring data for age estimation reference data sets**
       Graham J Roberts*, Fraser McDonald and Victoria S Lucas

15.20  **Tea / coffee and poster session 1**
       Authors of odd numbered posters should stand by their poster

16.00  **The history of using tooth microstructure to estimate age and to explore human growth in a comparative primate context**
       M. Christopher Dean* and Helen Liversidge

16.20  **Forensic age estimation from the teeth: are only third molars relevant?**
       Bianca Gelbrich*, Alexander Hirsch, Karl-Heinz Dannhauer and Götz Gelbrich

16.40  **Clinical age estimation of living subjects from 2003 to 2013. London and the UK**
       Victoria S Lucas*, Fraser McDonald and Graham J Roberts

17.00  **Dental age estimation of subjects with isolated cleft lip palate**
       Anastasia Mitsea*, Kety Karayianni, Kostas Tsiklakis, Romina Carabott and Cath Adams

17.20  Discussion

17.40  Close

17.45  Reception (Sponsored by Informa, publisher of Annals of Human Biology)

*Student competition entrant
*Presenting author
Wednesday 10th December

Morning Session

9.00  Morning Announcements

9.10  Seeing without touching: osteological ageing methods and new imaging techniques
      Niels Lynnerup

9.50  Fusion of automatically estimated skeletal and dental age from a large reference database
      Martin Urschler*, Sabine Grassegger, Thomas Ehammer and Darko Stern

10.10 Machine learning based automatic bone age estimation for MRI images of the left hand
      Darko Stern*, Sabine Grassegger, Thomas Ehammer and Martin Urschler

10.30 Tea / coffee and poster session 2
      Authors of even numbered posters should stand by their poster

11.10 New approaches to estimate adult age-at-death using modern imaging technologies
      Chiara Villa*, Jo Buckberry, Cristina Cattaneo and Niels Lynnerup

11.30 Assessing the effects of pregnancy on ageing from the pubic symphysis: incorporating living people into biological profile research by combining medical imaging and participant interviews
      Janamarie Truesdell*

11.50 Age estimation based on MRI of the third molars: transferring 2D staging into 3D staging
      Jannick De Tobel*, Elke Hillewig, Koenraad Verstraete

12.15  SSHB AGM

13.00  LUNCH

* Student competition entrant
* Presenting author
Wednesday 10th December

Afternoon Session

14.00  Awarding of the Tanner Medal by SSHB Chair Sarah Elton.

Can maturity indicators be used to estimate chronological age?
Noël Cameron

14.40  How body size can change the ways we evaluate adult skeletal age estimations
Catherine E Merritt

15.00  Ranges in human growth diversity and estimating ages
Fernando V. Ramirez Rozzi

15.20  Tea / coffee and poster session 3
Authors of odd numbered posters should stand by their poster

16.00  The effect of factors other than age upon skeletal age indicators in the adult
Simon Mays

16.20  Skeletal size, robusticity and body mass, influences on age-related metamorphosis of the os coxae articulations
Vanessa Campanacho*, Andrew T. Chamberlain, Pia Nystrom and Eugénia Cunha

16.40  A method for estimating age of Scandinavian medieval sub-adults based on long bone length
Charlotte Primeau*, Laila Friis and Niels Lynnerup

17.00  The role of epiphyseal scars in skeletal age estimation
Catriona Davies*, Lucina Hackman and Sue Black

17.20  Discussion

17.40  Close

19.00  Symposium Dinner at St Catherine’s College

*Student competition entrant
*Presenting author
Thursday 11\textsuperscript{th} December

Morning Session

9.00 Age estimation is always a Bayesian pursuit
Lyle W. Konigsberg

9.40 Obtaining appropriate interval estimates for age when multiple indicators are used: Evaluation of an ad-hoc procedure
Steffen Fieuws, Guy Willems, Sara Tangmose Larsen, Niels Lynnerup, Jesper Boldsen, Patrick Thevissen\textsuperscript{+}

10.00 The meaning of means
Jo Buckberry

10.20 Tea / coffee and poster session 4
Authors of even numbered posters should stand by their poster

10.40 Combining different methods of forensic age estimation: how to calculate the likelihood that a certain age limit has been passed over?
Bianca Gelbrich\textsuperscript{+}, Carolin Frerking, Sebastian Schwerdt, Eve Tausche and Götz Gelbrich

11.00 Which is the appropriate range of age for reference samples in forensic age estimation?
Bianca Gelbrich, Andreas Schmeling, Andreas Olze, Rüdiger Lessig, Karl-Heinz Dannhauer, Matthias Lehmann, Alexander Hirsch and Götz Gelbrich\textsuperscript{+}

11.20 People smugglers, statistics and bone age
Tim Cole

11.40 Summary of the Symposium
Sigrid Kvaal

12.10 Panel Discussion

12.40 Closing Remarks

\textsuperscript{*}Student competition entrant
\textsuperscript{+}Presenting author
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*Student competition entrant

*Presenting author
Stephen D. Ousley* and Melanie Boeyer

14 A Reappraisal of Developing Permanent Tooth Length as an Estimate of Age in Human Immature Skeletal Remains
Hugo F.V. Cardoso, Laure Spake**, and Helen M. Liversidge

15 Estimating Subadult Age from Diaphyseal Dimensions: Addressing Non-linearity and Heteroscedasticity
Kyra E. Stull† and Stephen Milborrow

16 Born dead or alive. Methodological considerations for using the neonatal line in enamel as a histological landmark to determine durations of developmental periods before and after birth
Carsten Witzel

17 Life in the lines: Interpreting stress and life history events from primate teeth
Simone A. M. Lemmers**, Barthélemy Ngoubangoye, Anaïs Herbert, Pam Walton, Wendy Dirks, Joanna M. Setchell

*Student competition entrant
**Presenting author
Controversies in dental age estimation

H Liversidge

Queen Mary University of London, Institute of Dentistry, London.

The aim of this study was to discuss several controversies in age estimation from developing teeth. Do we need to use population- or sex-specific reference data? Does the age range, sample size and method of analysis of reference data impact on estimated age? Are the effects of malnutrition and secular trend important? Materials and methods include assessment of developing permanent mandibular teeth from archived dental radiographs (N=9427) from UK, Nigeria, Senegal, South Africa, Japan, Malaysia, New Zealand, Australia and Canada, longitudinal data from 25 males and 25 girls from Nolla (1952) and data from Sudan (Elamin and Liversidge 2013). Average age of selected individual tooth stages was calculated and compared between ethnic groups and males and females. Results show that population differences in dental maturity were small and the age variation for each tooth stage within each group was considerable. Sex differences were also small, except for canine and third molar roots. Estimating dental age is always done at the individual level and small group difference have little effect on estimated age in the light of the large standard deviation. Increasing the sample size tenfold did not reduce the standard deviation of mean age of individual tooth stages. These findings show that accuracy and precision of age estimation are hampered by the large age variation in dental maturity. Conclusion: Population specific and sex specific dental maturity reference data do not reduce the age variation in tooth formation and are unlikely to improve accuracy or precision of age estimation.
Appearance of third molars as a diagnostic test for age of majority

T J Cole

UCL Institute of Child Health, London, UK

**Background:** Dental imaging is used in many countries for administrative or forensic assessment of developmental age, e.g. in persons subject to immigration control.

**Aim:** To consider the evidential value of a mature third molar for identifying age of majority (18 years).

**Methods:** Using data from the literature relating dental stage to age, the lower left third molar is considered in terms of the mean age of attainment of the adult appearance (stage H), and the diagnostic test performance of the adult appearance to predict the age of majority.

**Results:** The mean age of attainment of a mature third molar is around 20 years, but varies appreciably between countries. Stage H has fairly high specificity but low sensitivity to detect the age of majority, and about 40% of assessments are wrong.

**Conclusions:** The case for using third molar development to assess the age of majority is weak, and where it is used as evidence it should be challenged on the grounds that the evidence is of poor quality.

*Student competition entrant
*Presenting author
Censoring Data for Age Estimation Reference Data Sets

Graham J Roberts†, Fraser McDonald, and Victoria S Lucas

King’s College London Dental Institute

Introduction: Few investigators indicate the method(s) by which data for Age at Attainment (AaA) of Tooth Development Stages (TDS) has been managed to exclude incorrect, extreme, and inappropriate values. This applies particularly to Third Molars because the final stage of tooth development is unbounded in its upper border.

Material and Methods: Plus or Minus 3sd. For AaA of Reference Data Sets each of the preliminary data sets were subjected to standard statistical routines to derive the mean and standard deviation of the data array for each TDS. An expression within Microsoft Excel filtered out values above or below 3 standard deviations. This resulted in reduced n-tds counts.

Appropriate Censoring Stage H. The data array for stage H is censored, in its upper boundary, at the maximum age for Stage G.

Results: Plus or Minus 3sd A detailed study of TDSs showed that of 256 data arrays within the DARLiNG Reference Data Set a total of 226 (88.25%) gave results that were within the upper and lower limits of +/- 3 standard deviations.

Appropriate Censoring Stage H. The upper region of the data were top heavy with ‘older’ subjects. Once censored the mean value for AaA for LL8Hm reduces from 22.04 years to 19.67 years

Conclusions: Censoring ensures appropriately configured AaA for Tooth Development Stages.

*Student competition entrant  
†Presenting author
The history of using tooth microstructure to estimate age and to explore human growth in a comparative primate context.

M. Christopher Dean¹ and H. M. Liversidge²

¹Cell and Developmental Biology, University College London, Gower Street, London WC1E 6BT
²Institute of Dentistry, Queen Mary University of London, Turner Street, London E1 2AT

Background: For more than 300 years it has been clear that tooth tissues form in a layered manner. There are some occasions (either forensic, archaeological or paleoanthropological) when it is useful to use the incremental growth markings in teeth to estimate age.

Aim: The aim was to demonstrate how an estimate of age can place dental and skeletal growth in the past into a more reliable comparative context.

Methods: Using a comparative model that describes the major differences between chimpanzee and modern human dental development we asked what aspects of dental development best distinguish chimpanzees, early hominins and modern humans from each other. When an age estimate is available for an early hominin it was possible to ask what the probability of sampling an individual that lived in the past would be from a population of living humans.

Principal observations: Later stages of molar development in early hominins are the most distinct from those observed in chimpanzees. In great apes, early hominins, and modern humans, brain growth is more than 95% completed by the time M3 crown formation is complete. This is also true for somatic growth in early hominins and in living great apes but it is not the case in modern humans where body mass and stature lag behind what appears to be the typical hominoid growth pattern.

Conclusions: When an estimate of age is available, meaningful comparisons can be made between individuals that lived in the past and large samples of modern humans and of non-human primates.
Forensic age estimation from the teeth: Are only third molars relevant?

Bianca Gelbrich¹*, Alexander Hirsch², Karl-Heinz Dannhauer³, Götz Gelbrich⁴,

¹University Hospital Leipzig, Germany
²Dental Practice Hirsch, Leukersdorf, Germany
³University Hospital Leipzig, Germany
⁴University of Würzburg, Germany

Background: Mineralization of the permanent dentition, except of third molars, is complete in more than half of the children before the fourteenth birthday. Therefore, only the mineralization stages of third molars can contribute in proving that a subject has passed over a legally relevant age limit. Here we examine whether not mineralization, but presence or absence of the other teeth may nonetheless play a role in age estimation for criminal proceedings.

Methods: We analyzed data of 678 children aged 6 to 14 years. Mineralization of teeth was recorded according to Nolla’s scheme (similar to Demirjian’s, but using 10 stages).

Results: Agenesis of any tooth except third molars was found in 46 subjects, and 39 subjects (5.8%) had at least one missing second premolar. Missing of a second premolar was associated with a delay of third molar mineralization by 0.77 stages on Nolla’s scale (95% CI 0.33 to 1.22 stages, P=0.001). Subjects with agenesis of a second premolar were on average 9.8 months older (95% CI 2.9 to 16.6 months, P=0.005) than those with complete second premolars and the same mineralization stages of third molars.

Conclusion: Agenesis of second premolars is associated with delayed mineralization of third molars and hence possibly implies a higher age to be estimated in such subjects. Persistence of the delay of third molar mineralization beyond the age of 14 years needs to be shown in other data. If this is confirmed, age estimation formulas should account for missing second premolars (with the necessity to exclude extractions).

*Student competition entrant
*Presenting author
Clinical Age Estimation of Living Subjects from 2003 to 2013. London and the UK

Victoria S Lucas*, Fraser McDonald, Graham J Roberts

King’s College London Dental Institute

Introduction: Since 2003 the number of requests for Age Estimation, usually of asylum seekers, has increased from 2 to 3 a year to over 90. The majority of requests are from lawyers acting for Age Disputed Asylum Seekers (AS). If an AS is under 18 years s/he is designated a child. This results in improved benefits such as foster care and education.

Subjects, Materials and Methods: Archives of the DARLInG [Dental Age Research London Information Group] were explored to compare “Putative Age v. Estimated Dental Age”.

Results: The total DAE requests was 415. These were partitioned by the PA minus DA difference. Of these 46 (11%) were within 3 months of the claimed age. A further 44 (10.2%) had a putative age between 3 months and 8 years greater than the estimated age. Some 325 (78.3%) were provided with an estimated age greater than 3 months, and up to 7 years greater than was claimed by the client.

Discussion: Approximately 11% were assigned an age similar to the age claimed. That is to say, 46 individuals were within the ± 3 months that the DARLInG team considered to be an appropriate Dental Age Estimation.

Conclusion: Dental Age Estimation (DAE) is an accurate method of Age Estimation and provides support to Social Workers where the age of the subject is disputed.

*Student competition entrant
*Presenting author
Dental age estimation of subjects with isolated cleft lip palate

Anastasia Mitsea*, Kety Karayianni, Kostas Tsiklakis, Romina Carabott and Cath Adams

Oral Diagnosis and Radiology Clinic, Forensic Odontology Unit, School of Dentistry, University of Athens, Greece

The development of 3rd molars in CLP (Cleft Lip Palate) individuals is interesting since they are located outside the cleft area. Moreover there are not a lot of available data. The null hypothesis is that CLP is not related with 3rd molars development.

Objective: To study the 3rd molars development, and assess dental age in CLP individuals, based on 3rd molars, according to Demirjian method.

Materials and Methods: In this retrospective, blind study, two observers studied orthopantomographs of 79 subjects, (40 CLP and 39 control subjects). These Orthopantomographs were taken as a part of treatment planning of CLP individuals. The chronological age for each subject was compared to the dental age using the concordance correlation coefficient. Differences in means were tested for statistical significance using the standard ANOVA paradigm.

Results: The null hypothesis in not valid. There is not a significant difference between developments of antimere 3rd molars in both jaws concerning CLP individuals. There is delay of 3rd molars crown formation in CLP individuals. The discrepancies between chronological and dental age based on 3rd molars, in both CLP and non CLP individuals seemed not to be different in a statistical significant level.

Conclusion: Lower 3rd molars in CLP individuals present a better correlation with chronological age than the uppers. The applicable DAE (dental age estimation) method seemed to not to be inappropriate to apply in the current sample. Further research is needed. Bigger sample could be collected and other DAE methods could be tested.

*Student competition entrant
*Presenting author
Seeing without touching: osteological ageing methods and new imaging techniques

Niels Lynnerup

University of Copenhagen

3D segmentation of CT-based imagery allows for the virtual recreation of morphological skeletal characteristics used for age determination. First stages in the research of applying these techniques have often focused upon 3D visualisation of the features used in the well-known age-determination techniques, e.g. using the auricular and pubic symphysis. In a further stage, age-related changes have been attempted quantified directly by CT using CT-scan-based study samples of known age. Thus, such age-determination methods do not necessarily rely on methods developed on dry bones. An example might be quantifying subcortical trabecular bone changes. However, such methods are still visual, i.e. a visual and comparative appraisal is made. In the future, it may be expected that more methods will incorporate the digital information from a CT-scan, and not just the purely morphological, visual (reconstructed) data. Such studies may, e.g., apply curvature analyses of joint surfaces. Importantly, the use of CT not only allows for newer and other age-determination methods. It also allows for the collection of much more up-to-date reference samples. The well-known methods dealing with dry bone were developed on specific anatomical collections, e.g. the Terry collection, which means that the age composition of these particular collections may be carried over to the methods. Also, the collections reflect humans living more than 100 years ago. Having an always updated digital database with CT scans means that many methods may now be tested, and new methods developed on this material.
Fusion of Automatically Estimated Skeletal and Dental Age from a Large Reference Database

Martin Urschler¹,²*, Sabine Grassegger², Thomas Ehammer², Darko Stern¹

¹Institute for Computer Graphics and Vision, Graz University of Technology, Graz, Austria
²Ludwig Boltzmann Institute for Clinical Forensic Imaging, Graz, Austria

Bone age estimation (BAE) of living individuals is undoubtedly an important upcoming application in forensic medicine due to the necessity for age assessment of children and young adolescents in the context of migration movements from developing countries to Europe. Established BAE techniques (Greulich & Pyle, Tanner Whitehouse) based on X-ray images involve a severe drawback in the form of radiation exposure, which is prohibited in many countries without diagnostic reasons, and suffer from intra- and inter-observer variability that diminish repeatability and objectivity.

Based on our already presented work on fully automatic age estimation from left hand MRI data sets, which proposes a way to overcome these drawbacks, we aim for investigating the potential increase in accuracy of forensic age estimation by fusing automatically derived skeletal, i.e., left hand and clavicle, and dental age according to the recommendations of AGFAD promoting a multi-factorial age assessment as the valid scientific approach.

Skeletal and dental age will be computed by state-of-the-art machine learning techniques that automatically localize the age relevant structures from training data and derive the features discriminating age implicitly. With these trained models, novel data can be assessed automatically regarding chronological age. In order to train powerful models, a large amount of MRI data needs to be collected. This is not possible for a single group and should be performed jointly, starting on a European scale. This work is intended as a discussion basis to set up such a joint effort.

*Student competition entrant
¹Presenting author
Machine Learning Based Automatic Bone Age Estimation for MRI Images of the Left Hand

Darko Stern¹*, Sabine Grassegger², Thomas Ehammer², Martin Urschler¹,²

¹Institute for Computer Graphics and Vision, Graz University of Technology, Graz, Austria
²Ludwig Boltzmann Institute for Clinical Forensic Imaging, Graz, Austria

Legal medicine applications have recently seen an increased demand in bone age estimation (BAE) of living individuals, especially for age assessment of children and young adolescents without proper identification documents in the context of asylum seeking procedures.

Established BAE techniques (Greulich & Pyle, Tanner Whitehouse) based on X-ray images involve the exposure to radiation, which is ethically questionable especially when applied to children, therefore X-ray scans are prohibited in many countries without diagnostic reason. Moreover, BAE techniques employ visual comparison to an image-based atlas, thus suffering from intra- and inter-observer variability that diminish repeatability and objectivity.

BAE based on MRI removes the drawback of ionizing radiation while novel, more powerful and reliable automatic methods from medical image analysis and machine learning promise the possibility to improve the repeatability and accuracy of BAE.

We propose a completely automated method for BAE based on state-of-the-art machine learning techniques to assess a subject’s age from volumetric hand MRI images. We use a Regression Random Forest for both, localizing the bone structures and the epiphyseal gap, and for deriving image features automatically, that discriminate over the age range between 13 and 19 years.

On our database of 214 male Caucasian subjects, we are able to estimate the subjects age with a mean difference of 0.74±0.70 years compared to the chronological age, which is in line with radiologist results using established radiographic methods. We see this work as a promising first step towards a novel MRI based bone age estimation system, with the key benefits of lacking exposure to ionizing radiation and higher accuracy due to exploitation of volumetric data.

*Student competition entrant
*Presenting author
New approaches to estimate adult age-at-death using modern imaging technologies

Chiara Villa\textsuperscript{1*}, Jo Buckberry\textsuperscript{2}, Cristina Cattaneo\textsuperscript{3} and Niels Lynnerup\textsuperscript{1}

\textsuperscript{1}Laboratory of Biological Anthropology, Department of Forensic Medicine, University of Copenhagen, Denmark
\textsuperscript{2}Biological Anthropology Research Centre, Archaeological Sciences, University of Bradford, UK
\textsuperscript{3}LABANOF, Forensic Anthropology and Odontology Laboratory, Department of Human Morphology, University of Milan, Italy.

Age-at-death estimation of unidentified human skeletal remains or badly decomposed corpses is one of the most important steps in constructing a biological profile. Since technologies such as Computed Tomography (CT) and laser scans are becoming more widely used in routine forensic investigations, the development of dedicated methods seems appropriate. Application of the traditional methods to 3D virtual bones gave contradictory results, thus, different approaches and features were considered utilizing the digital nature of the CT and laser scanning data. First, a new method was developed evaluating the trabecular bone changes in the symphyseal and auricular surfaces on post-mortem CT scans of cadavers. Age-at-death could be evaluated with a low inaccuracy and that old adults (\textgreater{}60 years) could be discriminated with better accuracy than with the traditional methods. Secondly, the geometrical changes of the diagnostic surface features (i.e. ridges and furrows, transverse organization, porosities) were quantified calculating the curvature variation of 3D models from CT and laser scans of the pelvic surfaces. Highly significant correlations were obtained from 3D models of the Suchey-Brooks pubic bone casts and of the “auricular surface recording kit” of the Buckberry and Chamberlain method; lower correlations associated with large individual variability were found using bones from the Terry Collection (Smithsonian Institution). The results obtained were encouraging: it could be demonstrated that the operator subjectivity can be reduced and that a mathematical approach has the potential to adequately express the morphological feature of the surface.

\*Student competition entrant
\*Presenting author
Assessing the Effects of Pregnancy on Ageing from the Pubic Symphysis: Incorporating Living People into Biological Profile Research by Combining Medical Imaging and Participant Interviews

Janamarie Truesdell*

School of Anthropology and Museum Ethnography, University of Oxford

One of the major restricting factors in biological profile research continues to be the limited availability of data representing current populations. By incorporating the medical imaging of living volunteers, this study sought to investigate a new methodology for contemporary data collection allowing for both unlimited sample size and the inclusion of life history information provided by the subjects themselves.

Anecdotal evidence has long associated pregnancy with the disproportioned inaccuracy of ageing from the female os pubis. However, as previous studies have exclusively utilised physical post-mortem specimens, both lifestyle and birth history has been basic and of debatable accuracy (as, by necessity, it is/was gathered from secondary and tertiary sources such as medical records and/or family and friends). By working within the NHS and the Oxford University Hospitals system (OUH), the author obtained access to all patients receiving any and all scans involving the pubic symphysis. Questionnaires detailing demographics, body type, diet, activity level, sports history, and smoking and alcohol consumption were then completed by both sexes, with an additional pregnancy history page given to females. All participants then signed consent for both their scan(s) and questionnaires to be included as part of this project. The scans were then 3D volume rendered and a modification to the Suchey-Brooks Method for Ageing the Os Pubis was applied to determine whether male, nulliparous females, and parous females could be distinguished from each other with any significant reliability. Additional patterns between life history and symphyseal change were also investigated.

*Student competition entrant
*Presenting author
Age estimation based on MRI of the third molars: transferring 2D staging into 3D staging.

De Tobel J*, Hillewig E, Verstraete K.

Ghent University, Belgium.

Purpose: To prospectively evaluate the use of 3T MRI of the third molars in age estimation.

Materials and methods: In 52 healthy participants aged 14 – 26 years, MR images in three planes of all third molars were evaluated by two observers. In sixteen of them, MRI findings could be compared with findings on panoramic radiographs. Three staging methods were applied: Demirjian (1973), Köhler (1994) and Olze (2010).

Results: The Olze method could not be applied, while both others could. In upper third molars the palatal root was considered decisive on MRI. In lower third molars this was the distal root. The majority of upper third molars (59.4%) was not assessable on panoramic radiograph, while all of them were on MRI. For assessable upper third molars the evaluation on radiography was more difficult than on MRI (P < 0.001). Lower third molars were assessable on both imaging techniques, with no difference in level of difficulty. Inter- and intra-observer agreement for evaluation was higher in MRI than in panoramic radiographs. In both imaging techniques lower third molars showed greater inter- and intra-observer agreement than upper third molars. MR images in the sagittal plane proved to be essential for staging. Axial and coronal images contributed to the staging only in a few cases, when the molar was tilted or when the apex was unclear on sagittal images.

Conclusions: In age estimation, 3T MRI of third molars can be valuable. Some considerations are however necessary to transfer known staging methods to this 3D technique.

*Student competition entrant
*Presenting author
Can maturity indicators be used to estimate chronological age?

Noël Cameron

Centre for Global health and Human Development, School of Sport, Exercise and Health Sciences, Loughborough University, UK

Indicators of skeletal maturity were first defined by William Greulich and Idell Pyle in 1950 as “those features of individual bones that…occur regularly and in a definite and irreversible order (which) mark their progress towards maturity.” That definition of “maturity indicators”, and their later description, was not related to the passage of chronological time but to the progression of the individual from an immature to a mature state. Indeed, the use of a timescale of development caused considerable problems in translating biological maturity into a developmental or maturational scale. Because progress was determined by developmental rather than temporal landmarks the ability of such landmarks to reflect the passage of time was both variable and inconsistent. One year of maturational time does not equate to one year of chronological time. Maturity indicators were discrete events in a continuous process, or indeed in a series of processes (skeletal, sexual, dental, etc.), that highlighted the problems of uneven maturation within the individual, the independence of maturational processes, sexual dimorphism and the relationship of maturity to size. Chronological age determination was never the aim of maturational assessment and thus its widespread use as an age determinant poses considerable interpretive challenges to the human biologist.
How body size can change the ways we evaluate adult skeletal age estimations

Catherine E Merritt

Department of Anthropology, University of Toronto

Studies consistently assess the life expectancy of past populations as 30 to 35 years of age. This interpretation of the archaeological record has significant implications for our understanding of fertility and death rates, mortality curves, and overall population health. One factor that is rarely considered is the body size, as past populations were typically shorter and lighter than current populations. Similarly, modern populations have shown a substantial increase in stature and body mass over the past forty years, with obesity rates in North America at almost 35%. These changes in human body size call for the reassessment of age estimation methods developed on skeletal collections from the 20th century and their application to past and modern populations.

The most common age estimation methods are the Suchey-Brooks pubic symphysis method, the Lovejoy et al. auricular surface method, and the İşcan et al. rib method. This study applied these methods to 764 skeletons from the Hamann-Todd and William Bass Collections. Individuals ranged from 1.30m to 1.93m and 24kg to 99.8kg.

The joint surfaces of obese individuals show increased surface texture degeneration and osteophytic lipping compared to all other groups, while underweight individuals show fewer age markers. Physical activity and mechanical loading may be factors. High lean muscle mass slows the rate of bone remodelling, providing a potential protective effect against skeletal aging.

These findings suggest a higher presence of older adults in the paleodemographic record, and that the effect of obesity on skeletal markers may be an important consideration for forensic anthropologists.

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Ranges in human growth diversity and estimating ages

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Human life-cycle characterizes by the long period of growth and the presence of growth spurt at adolescence. The understanding of how we became humans relies thus on methods of estimating age and the knowledge of human biology. Different average adult stature among human populations reveals that patterns of growth differ. Any study on growth requires estimating individual age only way to compared equivalent stages in fossil hominids and/or modern humans populations.

Based on a 8 year longitudinal study in around 550 Baka pygmies of known age we established the patterns of somatic growth as well as life history variables. Without departing of the human life-cycle, Baka pygmies show some characteristics which reveal the range of growth diversity in modern humans. Probably one important contribution of studies based on absolute chronology as this one is that the presence of some ‘particularities’ in works on growth based on estimating age are not due to problems in methodology but they reveal a real observation of human growth diversity.

*Student competition entrant
*Presenting author
The effect of factors other than age upon skeletal age indicators in the adult

Simon Mays

English Heritage

**Context:** Estimation of adult age from skeletal remains is problematic due to the weak and variable relationships between age indicators and age.

**Objectives:** to assess the proportion of variation in age indicators that is associated with factors other than age and to attempt to identify what those factors might be.

**Methods:** the paper focuses on frequently used adult bony age markers. A literature search (principally using Web of Science) is conducted to assess the proportion of variation in age indicators typically associated with factors other than age. The biology of these age markers is discussed, as are factors other than age that might affect their expression.

**Results:** Typically about 60% of variation in bony age indicators is associated with factors other than age. Inherent metabolic propensity to form bone in soft tissue, vitamin D status, hormonal and reproductive factors, energy balance, biomechanical variables and genetic factors are among those that may be responsible for this variation, but empirical studies testing this are few.

**Conclusions:** Most variation in adult skeletal age markers is due to factors other than age; dry bone study of historic documented skeletal collections and high resolution CT scanning in modern cadavers or living individuals is needed to help identify these factors.
Skeletal size, robusticity and body mass, influences on age-related metamorphosis of the *os coxae* articulations

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It is theorized that age at death estimation inaccuracy, for adult skeletons, may be caused by genetic and environmental factors producing bone degeneration variability between individuals. The establishment of age at death estimation methods from the analysis of the pelvic articulations’ metamorphosis started at the beginning of the 20th century, however a better understanding of the factors affecting bone degeneration processes is still in its infancy. The main aim of the present study is to determine if skeletal robusticity, stature and body weight affect age-related changes at the pubic symphysis, iliac auricular surface and acetabulum in male and female adults from the Coimbra and William Bass donated skeletal collections. Three measures of degeneration were studied, ranging from particular (each trait), components (weighted linear combinations of traits), to general (composite score: sum of all the scores across all traits). Spearman’s rho results range from low to high correlation between age and criterion, suggesting other factors, besides age, may influence pelvic articulations’ metamorphosis. Logistic regression analysis showed that body mass variables only affect some criteria, with weight and stature having the greatest effect, and conversely robusticity having the least effect on bone degeneration. The results also showed a different pattern between samples, possibly because the effect of body mass variables on bone degeneration is random, or is due to differences in body mass and age distribution between populations, with the American population being on average taller, heavier and older than the Portuguese sample.

*Student competition entrant
*Presenting author
A method for estimating age of Scandinavian medieval subadults based on long bone length.

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When working with archaeological subadults it is necessary to age individuals as close as possible to their chronologic age for later analyses for growth, demography and disease frequency etc. The preferred method for aging archaeological subadult skeletons is by dental examination. Where no teeth are present, the remaining methods are to evaluate fusion of skeletal elements, epiphyseal union or diaphyseal length. However with archeological samples the fragile skeletal elements and epiphyseal fusion may be damaged or eroded due to taphonomic processes or excavation methods. Hence, the remaining method for age estimation is to compare the diaphyseal length with published growth tables in order to obtain a skeletal age. Using data for estimation of age from a different population is not advisable as there will be a lack of correlation between populations due to ethnicity, demography, diet, time period, health and environment.

This study therefore develops a set of regression equations on the basis of dental age to evaluate the skeletal age from the length of the long bones, when dental material is not available. These regression equations are population specific for subadults from the Danish medieval period. A sample size of 184 archaeological subadults was included, aged from birth to around twenty-one years. Individuals were aged according to their dental information. Regression formulae were constructed for aging according to their diaphyseal lengths. This study indicates that with the regression formulae developed here, estimation of age can be done with reasonable results on Scandinavian subadults from the medieval period.

*Student competition entrant
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**The role of epiphyseal scars in skeletal age estimation**

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Within the process of human identification, it is imperative that all methods used to assess the age of an individual and the criteria on which these methods are based have a strong evidential basis. Despite their application in several approaches to skeletal age estimation, the relationship between chronological age and the obliteration of epiphyseal scars has not been tested. This may lead to a significant error in estimated age. A study of the persistence of epiphyseal scars in females and males between 20 and 50 years of age was undertaken in five anatomical regions and the aim of which was to assess the relationships between the level of persistence of the epiphyseal scar and chronological age, biological sex and side of the body; and thereby evaluate the validity of the inclusion of the obliteration of epiphyseal scars in methods of skeletal age estimation. This study showed that the level of persistence or obliteration of epiphyseal scars varies between anatomical regions with remnants of epiphyseal scars found in 78-99% of individuals. Although a proportion of this variation may be attributable to the biological sex of the individual, the overall relationship between chronological age and the level of persistence or obliteration of the epiphyseal scar was found to be of insufficient strength to support a causative link. This study therefore indicates that the obliteration of the epiphyseal scar should not be considered as a maturity criterion in methods of skeletal age estimation.

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*Student competition entrant
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Age estimation is always a Bayesian pursuit

Lyle W. Konigsberg

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Konigsberg and Frankenberg (1992) argued in favor of maximum likelihood estimation for characterizing the age-at-death distribution for a sample. However, they did not consider estimation of individual ages-at-death or ages in the living which is a problem with an inherently Bayesian flavor. I show using examples from fetal long bone growth, dental formation, and traditional osteological age “indicators” how the estimation of individual ages-at-death or ages in the living follow from Bayes Theorem. Each example is framed by the following steps. First, the probability of observing particular age indicators conditional on an exact age is obtained from a reference sample with known ages. Second, a reasonable prior distribution for age is used. In cases where the analyst wants the data to “speak for themselves” this prior could be a uniform age distribution with reasonable upper and lower bounds. Finally, the product of the probability function from the first step and the prior from the second step is formed and divided by its integral to get the full posterior density of age. This posterior density can then be used to give highest posterior density intervals which have a more straightforward interpretation than traditional confidence intervals. Although the integration in the final step can be difficult, it can be approximated using Markov Chain Monte Carlo (MCMC) methods. I give some examples of MCMC for age estimation using the open source package OpenBUGS (http://www.openbugs.net/).
Obtaining appropriate interval estimates for age when multiple indicators are used: Evaluation of an ad-hoc procedure

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When an estimate of age is needed, typically multiple indicators are present as found in skeletal or dental information. There exists a vast literature on approaches to estimate age from such multivariate data. Application of Bayes’ rule has been proposed to overcome drawbacks of classical regression models, but becomes less trivial as soon as the number of indicators increases. Each of the age indicators can lead to a different point estimate and a prediction interval. The major challenge in the combination of multiple indicators is not the calculation of a combined point estimate for age, but the construction of an appropriate prediction interval. Ignoring the correlation between the age indicators results in intervals being too small. Boldsen et al. (2002) presented an ad-hoc procedure to construct an approximate confidence interval without the need to model the multivariate correlation structure between the indicators. The aim of the present presentation is to bring under attention this pragmatic approach and to evaluate its performance in a practical setting. To illustrate and evaluate the method Köhler et al.(1994) third molar scores are used to estimate the age in a dataset of 3200 males subjects in the juvenile age range. The approximate confidence interval after applying the correction are smaller than those obtained with a single age indicator, but larger than the one inappropriately relying on the conditional independence assumption.

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The classic position paper ‘Farewell to Palaeodemography’ revealed that age-at-death profiles (as computed from skeletal markers) mimic the age structure of the reference population used to develop a given method. Despite this, mean ages are still commonly used when estimating the age of an individual. In addition, error and bias (calculated from the mean age estimate of the reference population) are utilised when methods are tested on different known-age populations. In many cases, age estimates based on mean ages will produce results that over-age younger adults, and under-age older adults. These problems are compounded when we use the resultant age estimates to categorise skeletons into groups such as young adult, middle adult and older adult, especially when they are associated with specific age ranges (e.g. 18-25; 26-45; 46+). The use of numbers in conjunction with ordinal categories hides the fact that ‘middle adults’ are merely those who are clearly not very young (all bones are fused), but equally are not obviously very old, when in reality an individual might be a young adult who aged quickly, or an older adult who is ageing more slowly. This leads to the misconception that few individuals lived to a great age in the past, with the majority dying in the middle decades. The reality is that we can identify biological age groups that have some relationship with chronological ages, but that precise estimates of chronological age are still difficult to obtain. This demonstrates that, although there is a clear correlation between chronological age and biological age, the two are distinct and might not exhibit a fully linear relationship.

This paper will explore the meaning of ‘mean age-at-death’ and its (mis)use in anthropology, highlighting key questions. Should we make better use of full age ranges when testing methods? Are ‘most likely to be’ but ‘would not exclude’ age ranges appropriate? Are biological ages more appropriate? How well do biological ages reflect stages in the life-course?
Combining different methods of forensic age estimation: How to calculate the likelihood that a certain age limit has been passed over?

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\textit{Background:} Forensic age estimation in legal context is requested to provide the likelihood that some relevant age limit has been passed over. When estimating age from a single biological structure, knowledge of the distribution of the estimation errors (differences between estimated and true age) allows quantifying this likelihood. When exploring several biological structures (due in the forensic setting), this likelihood largely depends on the correlation of the estimation errors. For example, if the lower third molars are accelerated, the upper third molars will be probably accelerated, too. Therefore, knowing the stage of the lower teeth, the upper will not add much certainty about the age. On the other hand, if estimation errors of dental and skeletal age were uncorrelated, each one would add independent information to the other.

\textit{Methods:} We examined Demirjian stages of third molars and age estimated from the left hand (Thiemann-Nitz) in 242 subjects aged 7.8-19.1 years.

\textit{Results:} Estimation errors from both methods were uncorrelated (r=0.05, 95% CI –0.08 to 0.18, \( P=0.44 \)). Thus, over- or underestimation of age by the two methods can be assumed to occur independently.

\textit{Conclusion:} Likelihoods estimated from left hand X-ray and panoramic image can probably be multiplied. E.g., if left hand and third molars say a subject is aged above 14 years and the risk of error is 0.01 and 0.02, respectively, the joint probability of error is 0.0002, i.e. 1:5000. Statistical independency of dental and skeletal age estimation errors importantly facilitates quantifying the error resulting from combined methods.

*Student competition entrant
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Which is the appropriate range of age for reference samples in forensic age estimation?

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Background: When estimating age from a biological structure that reaches some end stage, a reasonable upper bound $A_{\text{max}}$ for the ages of subjects in reference samples must be chosen. E.g., for Demirjian’s staging of third molars, the estimated age $A_H$ for stage H will depend upon $A_{\text{max}}$. When $A_{\text{max}}$ is too high, $A_H$ may arbitrarily increase at the disadvantage of subjects being assessed. Forensic age estimation might be questioned because of arbitrariness. A well-founded convention to objectively determine $A_{\text{max}}$ should be established.

Methods and Results: For given data, we propose setting $A_{\text{max}}$ at the maximum of ages of subjects who were classified into the second highest developmental stage (e.g., Demirjian stage G). The reference sample should consist of all subjects of age $A_{\text{max}}$ or younger. We explain that (1) a lower choice of $A_{\text{max}}$ would lead to a bias towards too small estimates and (2) a higher choice of $A_{\text{max}}$ might violate the principle “in dubio pro reo”. For Bayesian methods, no upper bound for the ages of subjects in the sample needs to be set but $A_{\text{max}}$ should be the upper bound for values of the Bayesian prior distribution. We also show why the minimum age in the reference sample is less important. Illustration is provided from a sample of 2958 subjects.

Conclusion: We propose a choice of the upper bound of ages in reference samples that is objective, mathematically reflects of the principle “in dubio pro reo”, and may contribute in improving standards of forensic age estimation.
People smugglers, statistics and bone age

Tim Cole

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The story of how an obscure 50-year-old medical textbook about bone age in children became the subject of statistical controversy in court cases about people smuggling across Australia.

*Student competition entrant
*Presenting author
Poster Presentations: Abstracts

New drawing for tooth development and eruption of one year olds

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The age category of one year olds of our atlas of tooth development and eruption was based on a very small sample skewed for age and the median tooth stages do not progress evenly. The aim of this study was to improve the sample for one year olds. The materials were from documented collections of skeletal remains from five locations (Luis Lopes collection (Portugal), De Froe and Vrolik collection (The Netherlands), Hamann-Todd collection (USA), Belleville’s collection (Canada) and the collection d’anthropologie biologique (France)) and consisted of 64 individuals aged from 1.00 to 1.95 years. Tooth development and eruption was assessed and the median, minimum and maximum tooth stages noted. The median stages for the 35 individuals in the younger half of this group was compared to those in the older half to determine if two drawing were necessary.

Principle findings show that there are major differences in the median of tooth development of six deciduous and three permanent teeth. Moreover, the median of alveolar bone eruption has changed for two deciduous teeth. These differences, however, do not necessitate two separate diagrams for this age group.

We present a new drawing for tooth development and eruption for one year olds.

*Student competition entrant
*Presenting author
Age Assessment of Asylum Applicants performed at the Institute of Forensic Medicine in 2012

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175 (168 male, 12 female) forensic age estimations of asylum applicants were performed at the Institute of Forensic Medicine in Copenhagen in 2012. The forensic age estimations comprise three parts: A physical examination performed by a forensic pathologist, a radiological examination of the left hand and wrist performed by a radiologist as well as a radiological examination performed by a forensic odontologist. A Tanner stage is given at the physical examination and at the two latter an age or an age interval are given respectively.

We here present how the age estimates covary. Overall there was good agreement between the estimates of the separate examinations. When there were discrepancies it was generally seen that the odontological estimate showed a lower age than the respective radiological examination of the hand and wrist. In 131 out of the 175 cases it was estimated that the examined asylum applicant was 18 years or older.
Estimating Age of Mature Adults from the Degeneration of the Ischial Tuberosity

Ceri Falys

University of Reading

The ischial tuberosity has been illustrated to be useful in ageing young adults, however, no studies have investigated what age-related changes occur to the surface post epiphyseal fusion. In this study, changes in the surface topography of the upper portion of the ischium were examined and scored using 615 ischia of individuals of European ancestry (n = 342 males; n = 273 females), with known ages of 40+ years, from four documented skeletal collections: Hamann-Todd, Pretoria, St. Bride’s, and Coimbra. An ordinal scoring method was developed to describe differences in surface topography (i.e., slight or coarse granulation, nodule formation, undulation, and surface breakdown). Four distinct stages of degeneration were identified, resulting in new non-population specific ageing criteria, which is applicable to both sexes. A blind test of 83 individuals, aged 40+ years, from Christ Church Spitalfields, UK found the degeneration stages of the ischium to be 95.0% accurate. These preliminary results display the first evidence of the utility of the ischium in ageing older adult individuals. However, in the current format, these criteria should only be applied to individuals already identified as over 40 years in order to refine the age ranges used for advanced age. The preliminary findings do suggest the ischium has potential to aid age estimates beyond the traditional “mature adult” age category (i.e., 46+ years), and provides several suggestions for future research.
Oral histories: timing diet

Julia Beaumont

Archaeological Sciences, University of Bradford

The stable isotope ratios of carbon (δ¹³C) and nitrogen (δ¹⁵N) in bone and dentine collagen have been used for over 30 years to estimate human palaeodiet. In comparison with faunal bone collagen, and the context of period and geographical location, we can estimate diet, subsistence strategy and even the migration of individuals in a burial population. The duration of breastfeeding and weaning has been investigated using δ¹³C and δ¹⁵N from juvenile tissues because of the potential effect on birth spacing and both maternal and infant health, as well as an indicator of cultural behaviour.

Recent developments in microsampling of dentine have allowed an improvement in the temporal resolution for infant, childhood and adolescent dietary patterns for an individual. However, estimating the age which is represented by each increment of dentine, allowing for natural variation in developmental ages in a population, is an important factor: some of the increments taken from a deciduous tooth can represent as little as three months of life.

Here I present a diagrammatic representation designed to show of the age at which dentine development begins and ends in each human tooth, allowing the targeting of a particular period of life by choosing an appropriate tooth, or the age at death where a tooth is still forming. The use of these aging techniques is demonstrated by two case studies: the dentine profiles an M1 and M2 from the same individual, and the evaluation of a retained deciduous OR supernumerary tooth from an Iron Age female adult.
Estimating age from deciduous root resorption

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The aim of this study was to assess the accuracy of estimating age from fractions of deciduous root resorption. The sample studied was 946 panoramic radiographs from dental patients aged 3-16 years. Deciduous mandibular canine and molar roots were staged into levels of resorption (one quarter, one half and three quarters based on length). Teeth on the left side were assessed where possible. Reliability of root fractions was assessed from duplicate readings and calculated using Kappa. Age was estimated using reference data from Fanning (1961), Moorrees, Fanning and Hunt (1963) and O’Meara and Knott (1967). The difference between dental and chronological ages was tested using t-test. Results show that the average difference ranged from 0.6 to -1.7 year. Some root fractions estimated age accurately (average difference not significant to zero), however the standard deviation was consistently around 2 years. These results reflect the large age variation in root resorption. We conclude that root resorption can be useful to predict age if other age indicators are absent.

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Age- and sex-related changes in the normal soft tissue profile of Northern Sudanese: a three-dimensional cross-sectional study

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Information about age- and sex-related normative values for the nasolabial region in Northern Sudanese subjects is scanty. In the current study normal sex- and age-related nasolabial angles and distances were obtained. The three-dimensional coordinates of seven landmarks on the facial soft tissues were collected using a hand-held laser scanner in 654 healthy Northern Sudanese subjects (327 males, 327 females) aged 4 to 30 years. From the landmarks, five angles and two linear distances were calculated, and averaged for age and sex. Comparisons were performed by factorial analysis of variance. All analysed measurements significantly modified with age in both sexes (p <0.01) except the lower lip to Ricketts' E-line distance. For some angles and both distances, a significant effect of sex was found. Nasal convexity and the interlabial angle became more obtuse with growth, while the nasolabial and mentolabial angles progressively reduced. Females had significantly more obtuse mentolabial angles than males. The maxillary prominence angle progressively decreased during childhood, and increased after adolescence, with larger values in males than in females. The upper and lower lip distances from the Ricketts' E-line were significantly larger in males than in females; for the upper lip, the difference somehow reduced with age. Overall, when compared to literature data for African and Caucasian subjects, several differences were found, pointing to the necessity of ethnic specific data. Measurements collected in the current study could be used for the quantitative description of facial morphology in Northern Sudanese children, adolescents and young adults.

*Student competition entrant
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Deconstructing Expert Judgment: Experience-Based Age Estimates and Their Role in Improving Transition Analysis (ADBOU)

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Since the mid-2000s, members of an international research team headed by Boldsen and Milner have examined over 3,000 modern known-age skeletons on three continents, and have shown that experienced observers can produce highly accurate age estimates with little information being contributed by standard age-estimation features (e.g., the pubic symphysis, sacroiliac joint, and cranial sutures). After training, experienced osteologists can approximate that success, as shown by students such as the first author. Experience-based age estimates tracked by Getz since 2012 show that improvement takes time and is only possible after looking at hundreds of skeletons. Experience-based age estimates have two other limitations: they do not yield quantitatively rigorous estimates of certainty, and they are not appropriate in medicolegal contexts. To address these deficiencies, our research team has identified, defined, and investigated over 100 features believed to contribute to the demonstrated success of expert age assessments. Traits that proved to contain valuable age-related information were further investigated using over 1,000 known-age North American skeletons. Preliminary analyses show that when ages-at-transition for a subset of these features are combined, they collectively provide much-improved age estimates, particularly in the middle and upper parts of the lifespan. By incorporating these features into a modified Transition Analysis procedure (presently based on only standard skeletal features), age estimates that meet the accuracy and precision of experienced observers can likely be produced.

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The Population & Cemetery Simulator

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Since the publication of Wood et al.’s (1992) article on the “Osteological Paradox” and Hoppa and Vaupel’s (2002) “Rostock Manifesto”, many palaeodemographic models have been proposed that focus on the correct estimation of a population’s age profile. The problem of how to assess archaeological and osteological data including all the problematic effects caused by demographic dynamics has not yet been tackled. Moreover, many osteoarchaeologists have just continued to utilize traditional approaches. It is my aim to provide archaeologists with an intuitive and practical demographic software tool.

The Population & Cemetery Simulator (PCS) helps archaeologists to calculate the size and demographic composition of archaeological populations as well as their frequencies of diseases and artefacts. As an agent-based model it can utilize individual mortality and alternatively work with aggregate mortality profiles. The Population & Cemetery Simulator represents an agent-based model with two interfaces. One is designed for straightforward data input, the second interface allows researchers to change internal procedures more substantially without the need to learn a programming language. By utilising the Behaviour Composer developed by the modelling4all team at Oxford, the simulation software draws upon the expertise of an interdisciplinary community.

The PCS was applied in the case of the Neolithic Massacre of Talheim to show that the buried population could have been a complete village community. I will also show how artefact rates and diseases can be simulated in the demographic model.

*Student competition entrant
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Age estimation of sub-adults using the annular ring epiphyses

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Current methods of age determination of sub-adults are numerous but have limitations such as small sample sizes and large age ranges. This study is used to test the method produced by Albert and Maples (1995) and to provide an improved method for sub adult age estimation. The pattern and age of annular fusion was examined for 30 white-European individuals of unknown sex approximately 8-30 years in age. Fusion was separated into four stages. This study also included cervical vertebrae which have not been analysed before. Vertebral ring epiphysis was found to be a good predictor of age in comparison with other methods. The correlation between stages of union and estimated age was 0.926 (p<0.001). The standard deviation was 1.473-2.066 years with 99% confidence level. This study is the first to test Albert and Maples (1995) method on an unknown white-European sample, however alterations may have to be made to separate the descriptions of stage 2 and 3. It also shows how the method can be used on all pre-sacral vertebrae, not just thoracic and the first two lumbar. This aging method provides essential information to lessen the gap for sub-adult age estimation when used in conjunction with other methods.
Magnetic Resonance Imaging and the Age Estimation of Living Juveniles

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The majority of people within the western world, if asked, would be able to prove their date of birth and therefore their chronological age. However, large cohorts with the world's population are unable to tell or provide evidence for their age; or have a desire to convince authorities that they are older or younger than actuality. In Western countries, age is a significant factor in the allocation of public resources, and treatment by the criminal justice system. Current methods for estimating biological age relies on observation of dental and skeletal developments through radiographs. The use of ionising radiation carries a small risk to the individual and therefore, for non-therapeutic reasons, research into the application of alternative techniques would be welcome. This research, currently within its initial year, will utilise both pre-existing MRI and radiographic images obtained from a contemporary Northwest UK population between 8-26 years. It aims to examine current practices in the UK and Europe, and to answer the important question; Can MRI be used to determine the age of a living individual as accurately as radiographs; and to what extent could this be incorporated into the multidisciplinary framework within the criminal justice and immigrations systems in place?

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**Accuracy of estimating age from cervical vertebrae and mandibular molar maturation**

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Shape changes during the maturation of cervical vertebrae reflect the pubertal growth spurt and are a potential method to estimate chronological age, particularly when third molars are mature or absent.

**Aims:** The aim of this study was to assess the accuracy of estimating age by cervical vertebrae maturation (CVM) and mandibular second (M2) and third (M3) molars.

**Materials:** The sample consisted of lateral cephalograms of 75 boys aged 10 to 15 years from the Bolton-Brush and Burlington Orthodontic online collection.

**Methods:** Changes of size and shape of C2 to C6 and molar root stages were assessed. Ages of transition for CVM stages were calculated from raw data of 69 boys (aged 9 to 15 years) in Lamparski (1972). CVM ages were calculated. Dental age was calculated using molar ages from Liversidge (2009). The mean difference between CVM age and dental and chronological ages was calculated.

**Results:** Results for accuracy of age estimation show that the mean difference using CVM was -.86 year (SD 0.75), mean difference using for M2 was -0.32 (SD 0.79) and M3 was 0.52 (SD 1.51).

**Conclusions:** These findings show that mandibular molars were more accurate in estimating age than this method of CVM for these boys. M2 was most accurate, followed by M3 (although SD for estimated age using M3 was almost twice that of M2). We conclude that CVM shape has potential as a method of age estimation particularly for young adults.

*Student competition entrant
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Developing teeth around birth – a case study

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The aim of this study was to estimate age from developing teeth from a dental radiograph of the teeth of a mummified baby. Deciduous teeth were assessed by measuring tooth length and assessing tooth stage. Age was estimated in two ways. Firstly, by using tooth length data collected from Stack’s collection of 196 individuals aged 24 to 88 weeks gestational age (mean 43 weeks, SD 10). Prediction equations were calculated for each tooth type. Secondly, age was estimated using the London Atlas (AIQahtani, Hector and Liversidge 2010). Results from tooth length predictions as well as tooth stages suggest that the age was close to 40 weeks. These findings will be discussed in light of the subsequent histological findings that were carried out for the Coroner’s investigation. We conclude that tooth length and tooth stage assessment contribute to dental age assessment of a neonate.
Patricia: An Online Radiographic Database for Modern Growth and Development

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Much of what we know about human growth and development comes from large-scale longitudinal studies such as the Harpenden Growth Study or the Fels Longitudinal Study. Because of secular trends in earlier maturity, and greater childhood growth and adult stature in the 20th century, clinical standards for normal growth and skeletal development have become outdated. Forensic age estimation in subadults is likewise based on obsolete standards.

In recognition of the need for up-to-date standards for estimating age in modern subadults, the National Institute of Justice awarded a grant (2008-DN-BX-K152) in October 2008 for the creation of a digital radiographic database from clinical and medical examiner settings from around the United States. Subadult radiographs are a tremendous resource because they are ubiquitous; large collections of subadult skeletons are virtually unheard of. The database is known as Patricia (Pediatric Radiology Interactive Atlas). These data can also be used to study normal growth and development in modern children. To date, over 45,000 radiographs from over 12,000 children have been compiled.

Preliminary studies from several body regions using logistic regression models have revealed earlier epiphyseal appearance times with more precise upper and lower bounds for age estimation. Because the demographic data include intrauterine weeks for preterm babies, better estimates for epiphyses that can first appear in utero, such as the distal femur, are possible. These results are consistent with fetal ultrasound studies, and highlight statistical and/or methodological problems with previous studies, such as Elgenmark (1946).

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A Reappraisal of Developing Permanent Tooth Length as an Estimate of Age in Human Immature Skeletal Remains

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Although some studies focus on radiographic tooth measurements for the purpose of age estimation in children, a few studies use isolated teeth using tooth length as a predictor of age. However, the permanent dentition prediction models were hampered with relatively small sample sizes with unequal age distributions, and missing information from the third molar. We wish to re-assess and expand the prediction models for the permanent dentition, by increasing the sample significantly and recalculating the models using classical calibration. We used a sample of 165 known sex and age individuals (68 females and 97 males) from Portuguese and English skeletal collections. Regression models were calculated for each tooth for each sex, and sexes combined. The least prediction error, as measured by the mean standard error (MSE), was found in the incisors and the first molar (Females: I¹=0.51 years, I²=0.50, M¹=0.54, Males: I²=0.52, M¹=0.55). The tooth with the largest prediction error was the third molar (Females: 1.54, Males: 1.85). The combined sex sample showed similar prediction errors for the incisors and first molar, and for the third molar, which showed the largest error. Generally, the incisors, canine and first molar showed the best adjustment in the models and the smallest prediction errors, whereas the third molar was consistently the worst tooth. This study provides prediction formulae that can be easily used in a variety of contexts where an age estimate is required and tooth length can be quickly measured from any isolated tooth without the use of radiographic technology.

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Estimating Subadult Age from Diaphyseal Dimensions: Addressing Non-linearity and Heteroscedasticity

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Historically, subadult age estimation was explored by simple linear regression, which is inadequate because (i) age has a non-linear relationship with bone dimensions, and (ii) the variation in age increases as bone dimensions increase (i.e., the data is heteroscedastic). Recently, subadult age estimation using long bone lengths and breadths were analyzed by taking the cube root of age to minimize heteroscedasticity and using multivariate adaptive regression splines (MARS) to model non-linearity (Stull et al., 2014). The goals of the current research were to estimate age from femur diaphyseal length, to estimate uncertainty in the estimate (prediction intervals), and to compare the presented models with each other and previously published models.

Femur diaphyseal lengths of that were previously collected from Lodox Statscan radiographs were used as the predictor variable. The sample included 1100 South African children between the ages of birth and 10 years. For the first model, femur diaphyseal lengths were used in combination with a power transformation for linearity. Iteratively Reweighted Least Squares was used to estimate conditional variance (and hence prediction intervals). For the second model, MARS was used to estimate age on the same data, but without any associated transformation. Heteroscedastic residual variance was estimated with a separate nonlinear regression of the absolute residuals on the predicted age. The strengths and weaknesses of the presented models are discussed and the results are compared to the model developed by Stull et al. (2014).

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Born dead or alive. Methodological considerations for using the neonatal line in enamel as a histological landmark to determine durations of developmental periods before and after birth

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The neonatal line (NNL) in enamel is an incremental marking characterized by an altered microstructure. Birth stress is thought to be responsible for its formation along the enamel forming fronts of teeth that are forming enamel at birth (all deciduous teeth and M1 normally). It has been successfully employed as a marker to discern stillbirths from individuals born alive in archaeological dentitions as well as in forensic casework. It is argued that in order to achieve a high degree of certainty especially in forensics, more than one tooth per individual should be investigated. This, and the investigation by different microscopic techniques should bring consistent results about the presence or absence of the NNL and its position in the investigated teeth. The duration of developmental periods before and after birth can be deduced from the amount of enamel that is formed internal (before birth) and external (after birth) to the NNL. Measurements related to enamel extension and to enamel apposition as well as direct counts of daily incremental enamel markings could be used. By presenting selected cases different strategies are exemplified and their advantages and problems will be discussed. If preserved with a high enough visibility counting daily incremental enamel markings is thought to yield the best results. However, more work needs to be done in teeth of individuals with known pre- or postnatal age at death and known circumstances of pregnancy and birth process. Effects of systemic disruptions during pregnancy that can mimic the NNL should be studied in particular.
Life in the lines: Interpreting stress and life history events from primate teeth

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Comparative data from modern primates can help us to reconstruct the physiology and behavior of extinct species, including our fossil ancestors. Study of the evolution of primate life history sheds light on the evolution of the timing of events like age at weaning, maturation and first reproduction. Studying the schedule of these events in our own order, the primates, is key to understanding which characteristics are unique to Homo sapiens sapiens. Previous studies have hypothesized that stress caused by weaning can be detected at a micro-level in both enamel and dentin. We are using histological analysis of the teeth of naturally deceased mandrills (Mandrillus sphinx) with known life histories to investigate the timing of accentuated increments in the microstructure of their dentition in relation to life history events. We will test to what extent stress related to life history events is recorded in the dentition and how different events and phases can be distinguished from one another. Our aim is to establish a methodology that can be applied to ‘blind’ material such as the fossil teeth of extinct, wild and/or poorly known primates, contributing to the understanding of the evolution of the life history of our own species and of human and non-human primates in general.

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