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Note

Age estimation in youths and young adults

A summary of the needs for methodological research and development

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Abstract

The aim of this paper is twofold. The first is to give an overview over the current state of the art and research challenges in the age estimation in youths and young adults. This implies a summary of the methods used for age estimation. The second is to give some national and European research programs and funding opportunities, and some international organizations in relation to the field of age estimation.

Keywords	Age estimation methods, national and European research programs and funding, organizations
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1 Age estimation: Current state and research challenges

1.1 Introduction

Immigration authorities in several countries are confronted with a challenge in the age assessment of young asylum seekers. These are cases where applicants are unaware of their exact date of birth, are travelling without appropriate identity documents or bring documents of uncertain provenance. In some cases it is suspected that the asylum seeker claims to be a minor to increase his or her chance to obtain a residence permit or other benefits. In other cases unaccompanied minors may claim to be adults to evade a stricter regime for minors. Generally, there are significant legal differences with respect to rights and obligations of minors and adults. Children under 18 years of age are often given special care and support that adults do not receive. The minors are cared for, educated, and given protection according to the United Nations Convention on the Rights of the Child (1989).

The European Migration Network (see section 3.3) reports that some minors arriving in EU are subject to trafficking for the purpose of sexual exploitation, for illegal labour or for domestic labour. In many cases of trafficking the children are reported to be older than their chronological age. When the given age is doubted by the legal authorities in the country, age estimation is performed. No age estimation method or group of methods today can determine the exact chronological age of a child. Age estimation methods which are both safer and more precise may be beneficial to child victims of trafficking.

The estimation of age raises ethical and political issues. It should strongly be avoided that asylum seekers under 18 years of age are misclassified and hence treated as adults, and it may have serious consequences if adults are wrongly assessed as minors and placed together with children in asylum centers. Hence, it is very important, both for the asylum seekers and for the authorities, that the age estimates are as correct as possible. The problem is particularly complex as it concerns individuals and their legal protection. The present methods and procedures have raised ethical questions related to both the applicants, the examiners and for the contracting authority.

In the European countries there is currently no consensus on which methods to use for age assessment. A majority of countries assess age based on a medical examination of bone and/or dental development, physical appearance and interviews, while a few states rely on non-medical assessments only (IGC Workshop, 2011). The various countries also use different margins of precision for each method and different approaches for combining results when several methods are used.

The human body grows and matures with age, especially in children and adolescents. Therefore, the main idea behind the medical methods is to compare measurements of physical maturity of the body with age. However, due to individual variation in the timing of skeletal and dental development, the results of any method are subject to uncertainty when applied to a single individual. There are also issues related to the relevance and representativeness of the available reference populations. There exist several methods and a fairly substantial literature on the field. However, there are few summarizing studies regarding optimal methods of age estimation. The different methods are associated with varying degrees of uncertainty and precision, and this is not always well understood.

There will always be biological variation and uncertainty associated with age estimates. From a statistical-methodological point of view, there are reasons to believe that a combination of different measurement methods, and a more conscious use of relevant statistical methodology, may provide more reliable estimates and better quantification of associated levels of uncertainty. When the uncertainty is known, the acceptance level of the error rates is a political decision, as there are no methods by which the age of asylum seekers can be estimated 100% precisely.

1.2 Research objectives

The long-term research objectives are to develop, validate, and facilitate for application of the most accurate methods for age estimation of children and adolescents. These are methods which give more objective and repeatable measurements, i.e., more consistent results. This research must be within practical and financial constraints, and respect recognized ethical standards.

Properties and shortcomings of the various existing methods must be reviewed systematically to achieve this objective. Also the opportunities provided by combining different methods must be examined. A systematic review of studies of reference populations is necessary. New and complex reference data, where age is known, should be collected through international collaboration, and the possibilities for exploiting better existing reference data should be investigated. If one is to reach the objective in full, multinational collaboration among immigration authorities as well as researchers should be established.

The long-term research challenges require collaboration between different scientific disciplines, and may be broadly classified into:

- *What data should be collected and how to collect these?* What features are best correlated with age, and how can they be measured objectively, accurately and efficiently? For measurement of skeletal and dental development, alternatives to X-rays are also desired, e.g., magnetic resonance imaging (MRI) or ultrasound (US). For socio-psychological evaluation there seems to be no standard procedures.
- *How can data be interpreted more effectively and consistently?* Are there good alternatives to visual interpretation of images, e.g. by using computer aided image analysis? Is it possible to develop accepted procedures and standards for the interpretation of measurements of socio-psychological development?
- *How can the results from measurements of physical properties be used more effectively to assess age and describe the associated uncertainty level* in a way that allows for easy interpretation by executive officers, who are not experts in either medicine, psychology or the applied methods.
- *How can better reference populations for the different methods and groups of people be developed?* What new data sets will be required and how can existing data sets best be used?

1.3 Research topics

Based on the current state-of-the-art of methods for age estimation, with a focus on medically based approaches, the research challenges are further specified as follows:

1. *Reference datasets*. In general reference datasets and atlases for more populations are needed. A better definition and understanding of variations in reference datasets relative to a

population also seems to be needed. In addition, reference datasets for combinations of methods are currently non-existent and could be very helpful. This is also the case for reference data based on newer modalities (US, MRI), as studies indicate that different image technologies seem to visualize skeletal development differently.

2. *Modality-specific reference studies*. Newer imaging modalities such as ultrasound and MRI have the advantage of using radiation-free imaging technologies. Initial studies indicate that these modalities can be used in age estimation. Still, one cannot always observe the exact same things with the different modalities, and modality-specific development stages may need to be defined. Hence, more studies and refinements of these methods are needed.
3. *Combination of methods*. More research is needed to define more precisely the best standard approach for age estimation based on a combination of different methods. There is a need both for identifying the best combination of methods and for finding the best approach for combining them and arriving at age estimates and associated uncertainties.
4. *Quantification of uncertainty.* More studies are needed into the problem of understanding and properly quantifying the uncertainty associated with age estimates. The use of standard error as a measure of accuracy has been criticized by diverse authors, and for approaches based on regression analysis recent papers propose the use of Bayesian probability as an alternative. More studies with respect to these items are desirable.
5. *Automation of interpretation*. More automated software solutions can help reduce the intra/inter observer variability and make measurements more objective and repeatable. Collaboration between radiologists and IT experts is needed to improve and develop methods for more automated interpretation of the data and include these in practical software solutions.

1.4 Overview of methods used for age estimation

Black et al. (2010) define the four ''pillars'' of age estimation as: social and psychological evaluation, external estimation, skeletal estimation, and dental estimation. In the following we have focused on the latter three pillars. The first pillar is only briefly described below through the words of Sue Black et al.

1.4.1 Social and psychological evaluation

This requires evaluation by a properly trained clinician or social work practitioner. The aim of this process is to assess the mental, and not the physical, maturation of the subject. The practitioner will interrogate areas of the person's life history in relation to recall of events and form an opinion as to the nature of the response both at the time of the events under discussion and the current attitude towards pivotal episodes in their past. Given the often traumatized nature of the individual being interviewed, it is essential that this is a slow process that builds trust and forges a bond between the individual being investigated and their assessor so that as objective a view as possible is achieved. It may be that on completion of this process there is deemed no need to progress to a physical estimation of age. From: Black et al. (2010), Chapter 14: Key practical elements for age estimation in the living.

1.4.2 Physical examination

This includes measurements such as body height and weight, body type and body mass index, as well as visible signs of sexual maturity. In addition a general physical examination should be

performed to describe any signs of a pathological condition which may interfere with the maturation rate.

Of the forensic methods recommended for age determination, assessing age on the basis of physical traits is the least precise. Evaluating sexual maturity has the greatest margin of error and should be used for age determination only in conjunction with an evaluation of skeletal maturity and tooth development. There are also few studies analyzing the progression of these parameters with chronological age in different populations. The physical examination is still considered crucial to reveal pathological conditions that can affect the physical maturation (Schmeling et al., 2011).

1.4.3 Skeletal age

Skeletal age is determined from the development stage of bones. These approaches estimate development stages from the fusion/maturation of specific bones.

- ***Hand*** (wrist) is most common. Criteria for evaluating hand radiographs include the form and size of bone elements and the degree of epiphyseal ossification. A given image is either compared with standard images of the relevant age and sex (radiographic atlas) to determine the development stage, or the degree of maturity is determined for individual bones (single bone method) and combined to calculate an overall maturity stage. For the first approach the Greulich and Pyle atlas has become the standard reference, while for the second approach the Tanner-Whitehouse approach (exists in three editions) is the main reference. In principle, it would be expected that the Tanner-Whitehouse method would be more reliable. However, this has not been demonstrated in practice and it is also more cumbersome to use and more costly in terms of time. On average the skeletal development of hand bones is complete at the age of 17 years in girls and at the age of 18 years in boys.

- ***Clavicle*** (collar bone). Evaluation of the progress of ossification of the cartilage at the sternal end of the clavicle is suggested to estimate the age of persons who are assumed to be older than 18 years, because all other developmental systems under examination have completed their growth by this time. Traditional classification systems differentiate between four stages of clavicle ossification (stage 1: ossification center not ossified; stage 2: ossification center ossified, epiphyseal plate not ossified; stage 3: epiphyseal plate partly ossified; stage 4: epiphyseal plate fully ossified), while Schmeling et al. (2004) divide the last stage into two additional stages (stage 4: epiphyseal plate fully ossified, epiphyseal scar visible; stage 5: epiphyseal plate fully ossified, epiphyseal scar no longer visible). If the fusion of epiphyses is complete and an epiphyseal scar is visible, it can be assumed, in the case of women, that the person is at least 20 years old, and, in the case of men, that the person is at least 21 years old. Total fusion of epiphyses with disappearance of the epiphyseal scar was first noted in both sexes at the age of 26 years at the earliest.

- ***First rib.*** Analysis of the ossification of the first rib has only recently been suggested for age estimation in the living. Garamendi et al. (2011) propose this as an approach that may be used in addition to analysis of the clavicle ossification as it can be analyzed from the same set of X-ray images. Using digital thorax X-rays the ossification of the costal cartilage of the first rib was graded according to the four stages defined by Michelson (1934) and analyzed in relation with known age and sex of the subjects. Following this all subjects with the final Stage 3 of ossification were above 25 years of age, and there is no published study in which a subject being younger than 21 years of chronological age has a first rib ossification in a Stage 3. The results suggest that the first rib ossification might become an additional

method for age estimation in subjects around 21, but more research on more populations is needed to confirm this (Garamendi et al., 2011). Earlier studies indicate that respiratory stress seems to be the main cause of ossification of the first rib. Hence persons exposed to recreational and labor respiratory stress, may have a more advanced development than others.

- ***Cervical vertebrae*** (vertebrae of the neck). Thevissen et al. (2012) have investigated the development of the cervical vertebrae as seen from cephalometric radiographs (in combination with the development of the third molars). This is another approach which has only recently been suggested for age estimation in the living. Several grading systems were compared, and the two most accurate were used in combination with third molar development stages (Gleiser and Hunt, 1955). For the younger age groups (below 14) a considerable gain in accuracy was observed when combining the different approaches. However, for the older age groups (late third molar development stages) no or a negligible gain in accuracy was observed. Thevissen et al. (2012) do however recommend the approach as an addition to third molar information when the root of the third molar is less than ¾ developed, also because the cephalometric radiographs requires a lower radiation dose than hand wrist and chest radiographs.

- ***Hip (iliac crest***). Skeletal age can be determined by the appearance of the iliac apophysis of the pelvis. The apophysis appears laterally on a pelvic X-ray, and moves towards the spine as a person approaches adulthood. Risser's sign is a measure of the growth left in the spine, where 5 stages have been defined. The stages 1-5 typically appear from age 14-16 for girls and 15-18 for boys. Like the former two approaches, this has also only recently been suggested for age estimation in the living. In a pilot study by Schmidt et al. (2011) the applicability of ultrasound examinations for the evaluation of apophyseal ossification of the iliac crest was analysed. With reference to the sonographic staging of clavicular ossification, the maturation stages of the iliac crest apophysis of 23 male and 16 female subjects, aged 11-20 years, were determined. Ossification stage I occurred in the male subjects at a minimum age of 15.7 years. Ossification stage II was diagnosed in boys at a minimum age of 14.1 years and in girls at a minimum age of 11.7 years. The earliest observation of ossification stage III was at a chronological age of 16.2 years in males and 15.2 years in females. The earliest age of occurrence of ossification stage IV was at least 18.0 years in male test persons and at least 17.1 years in female test persons. They conclude that the approach can be a valid and efficient method, but larger studies are needed.

- ***Knee***: fusion of growth plate maturation of the knee. Dedouit et al. (2012) have developed an original magnetic resonance imaging (MRI) staging system for epiphyseal fusion of growth plate maturation of the knee and evaluated its reliability and validity for age assessment in the age group 10-30 years. Five original MRI stages were defined. They report on high correlation with age and good intra and inter-observer consistence, but here much more studies are needed to verify the approach.

1.4.4 Dental age

Skeletal methods present some drawbacks in view of the variability in bone maturation, which is influenced by nutrition and other environmental factors. For dental development the calcification rate is more controlled by genes than by environmental factors, eliminating the uncertainty related to nutrition (Garn et al., 1965).

Dental age is in most practical cases estimated from the development of the teeth either by eruption of teeth or by grading the development of tooth crown and roots on radiographs. Today orthopantomograms, which give a panoramic view of all the teeth, are most commonly used and introduction of digital pictures have reduced the exposure x-ray radiation. The developmental stages of the selected teeth are described from initiation (crypt stage) to completion (closure of the dental root apex). When the roots of all teeth are all fully developed (around 20 years), other degenerative changes in teeth have to be considered.

1.4.4.1 Estimating age from tooth development

The developmental stages of the teeth are decided by a trained dentist who compares the teeth development as seen on radiographs with a set of developmental stages. The predefined stages are presented with examples of radiographs, sketches and/or descriptions in words. Over the years, various authors have proposed classifications to grade the dental formation

Two major grading systems exist:

- Gleiser and Hunt (1955) described tooth development in 15 stages. These were presented in sketch drawings and tables (Moorrees, Fanning and Hunt, 1963), and have been used with slight modification in several later studies.
- Demirjian et al. (1973) described the tooth development in 8 stages. These stages are illustrated with x-ray pictures, a detailed description of each stage and sketch drawings.

Development of children's teeth is covered in several separate studies. Most studies cover the age span 3-16 years. In most of these studies the wisdom teeth are excluded:

- Demirijan's principle:
    - Demirjian et al. (8 stages, 1973, 1976)
    - Solari et al. (10 stages, 2002)
    - Willems et al. (2001)
- Moorrees, Fanning and Hunt diagrams:
    - Moorrees, Fanning and Hunt (13-14 stages, 1963)
    - Haavikko (12 stages, 1970-1974)
    - Anderson, Thompson and Popovich (13-14 stages, 1976)
- Others:
    - Nolla (11 stages, 1960)
    - Liliequist and Lundberg (8 stages, 1971)

Studies on the development of wisdom teeth cover the dental development in the age group ~ 15 – 23 years:

- Gleiser and Hunt (1955) stages:
    - Kullman et al. (7 stages - only dental root, 1992)
    - Liversidge (15 stages, 2008)
    - Köhler et al. (10 stages, 1994)
- Demirjian stages;
    - Mincer et al. (1993)
    - Roberts et al. (2008)

- Others
    - Harris and Nortje (5 stages, 1984)
    - Engström, Engström and Sagne (1983)

The developmental stages of tooth crowns and roots are converted to dental age with the use of tables. Most methods give tables with the mean age of the various developmental stages, but some use the mean age for entering the stages. Estimated chronological age may be calculated as the mean of all the "tooth" ages. Data has been collected from various populations for a range of age groups.

Demirjian's method (Demirjian et al. 1973, Demirjian and Goldstein 1976) is the most widespread and represents a sort of constant comparison for all researchers. This method was based on the principle of Tanner et al. (1962) for estimating the maturity of the hand and wrist. It does however only cover the age span 3-16years and because of the limited number teeth and developmental stages in the higher age groups, this method has to be used with caution in children older than 12 years. Several studies have shown that the Demirijan's method underestimate age (Liversidge et al. 1999, Leurs et al. 2005, Eid et al. 2002).

For the age groups around 14-20 years, the third molars (wisdom teeth) will often be the only teeth still under development. Separate tables for development of wisdom teeth in the lower jaw (mandibular third molar) are most commonly used. At the same time, the timing of third molar development shows higher variability than the other developing teeth (Liversidge, 2008).

1.4.4.2 Other approaches

As described above the commonly used methods for dental age estimation are based on determination of development stage. One reason for this is the simplicity of these approaches. Mörnstad et al. (1994) and later in several studies by Cameriere et al. (2006), a different approach have been taken by measuring the developing tooth on radiographs and published a mathematical formula for calculating dental age on developing teeth. The method is based upon measuring the completeness of apical development via a computer method, and rather than classifying this into stages a regression formulae deriving age directly from the measured ratios is proposed. Cameriere and co-workers have over the past few years expanded on this method. Evaluations indicate a similar to slightly improved performance compared to that of using development stages, but the approach requires detailed measurements in the X-ray images and is therefore more time consuming. (Thevissen et al., 2011). When the teeth and their roots are fully developed (after the age of about 20 years), age estimation from the teeth becomes even more difficult. Kvaal et al. (1995) have suggested one of the few existing methods for these cases. It is based on ratios between the pulp and tooth length as measured on dental x-ray films combined in a regression formulae. The estimates in 20year age group tend to be overestimated by this method. Very accurate age estimation from these measurements is difficult, and the standard error reported for these estimates are about 9 years.

1.4.5 Imaging technologies

Typically, X-rays have been used to acquire the imagery needed for the different analyses, and in some cases CT. A disadvantage of both X-ray and CT imaging is the fact that the technique uses ionizing radiation. An argument against the use of radiation, especially with a different intention than diagnosis or therapy, is that any radiation may be harmful. The benefit to the asylum seeker must outweigh the radiation risk. Radiation dose is of particular concern in pediatric radiology. New studies indicate that ultrasound can be an alternative radiation-free approach. Ultrasound has the advantage over other methods in that it is relatively inexpensive

and widely available. It can also easily be applied by using portable systems. Another radiation-free approach is MRI, but here the equipment is more costly, larger and not so widely available.

Hand/wrist: The traditional approach is based on stage assessment from X-ray images, but experiments using alternative image modalities have been carried out. For use in age estimation of football players in age-related tournaments, MRI of the wrist has been investigated as a tool. A grading system of six grades for fusion was designed (Dvorak, 2007). In another study on football players performed by FIFA (George et al., 2012), MRI and X-ray wrist images acquired from the same person on the same day were investigated. Their results indicate that from x-rays the degree of distal radial fusion will seem more advanced than in MRI images. Ultrasound is another radiation-free approach that has been investigated. Bilgili et al. (2003) do this on the age group 0-6 years, applying an approach derived from the GP atlas. In this study interpretations based on the GP atlas with ultrasound and with radiographic images were found to be highly correlated. Mentzel et al. (2005) apply the ultrasound based BonAge system (see sec 5.5) for age estimation in the age group 6-17 years, reporting correlation with the manual Greulich&Pyle approach. Another study using BonAge **(**Xu et al., 2008) does however report lower correlation, especially for the older age groups. Khan et al. (2009) arrive at a similar result, concluding that US assessment should not yet be considered a valid replacement for radiographic bone age determination

Clavicle: Experiments have been carried out for CR, CT and MR images of the clavicle, using the same five ossification stages for all modalities. Age estimation is feasible for all modalities, but modality-specific reference studies are needed. Ultrasound has also been applied for age estimation from the clavicle, but here the traditional classification had to be modified. Four stages have been defined, where the earliest occurrence for development stage 4 was observed at age 19 for women (Quirmbach 2009, Schulz 2008). Schulz et al. conclude that the age intervals observed for the ossification stages are consistent with the known data from radiological and computed tomography assessments, but the results should be confirmed in a larger number of cases and with analysis of observer variability

Iliac crest: As reported in the previous section, Schmidt et al. (2011) have presented a pilot study analyzing the applicability of ultrasound examinations for the evaluation of apophyseal ossification of the iliac crest. Their conclusion is that the approach can be a valid and efficient method, but that larger studies are needed.

Knee: As reported above Dedouit et al. (2012) have developed an MRI based staging system for epiphyseal fusion of growth plate maturation of the knee and evaluated its reliability and validity for age assessment. They report high correlation with age and good intra and inter-observer consistence, but more studies are needed to verify this.

These studies have indicated that the exact same change cannot always be observed with the different modalities, and often modality-specific development stages need to be defined. Even in cases where the same stages are observed, different modalities seem to visualize the phenomena differently so that the development stage as observed with one modality may seem more or less advanced when observed through another modality. Finally, many of these approaches are in their infancy and for those where more than one study has been performed, the results are diverging. Hence, more experience with these approaches seems to be needed in addition to modality-specific reference data.

	Age range	X-ray	CT	MR	US
Dental stages	→ ~19	X			
Hand/wrist	→ ~18	X		X	X
Clavicle	→ ~25	X	X	X	X
First rib	→ ~25	X	X		
Cervical vertebrae	→ ~18	X			
Iliac crest	→ ~18				X
Knee	→ ~18			X	

1.4.6 Manual vs. automatic approaches

Determination of development stage is traditionally achieved through manual analysis performed by medical experts. For manual approaches, there is however always some variability related to subjectivity and there will be inter- and intra-observer differences. Approaches based on stage assignment, may add to this, as estimates are not continuous and assignment around stage borders can be difficult. For bone age, the Tanner-Whitehouse approach is therefore expected to be more reliable, as it is based on several stage estimates rather than one. However it is more cumbersome and costly to use, and in practical applications it has therefore not been shown to give an improvement which is sufficiently significant. Similar arguments apply also for the estimation of dental age.

It is believed that automatic image based methods can help to overcome these problems. Still, few such solutions exist, and more work in this area is needed. However, a few systems performing such analysis have been introduced, all of them intended for analysis of bone age from the hand/wrist:

- BoneXpert. (Visiana, Denmark)
  http://www.bonexpert.com/ (Thodberg 2009,Thodberg and Sävendahl 2010, Martin et al. 2009).
  BoneXpert is a software product that determines bone age (skeletal maturity) automatically from a digital hand X-ray. Method: The outlines of the bones are found through automatic image analysis based on active appearance models. From this bone age is estimated for each bone and validated. The results can then be adjusted to conform to either the Greulich-Pyle method or the Tanner-Whitehouse. The automated method can analyze images of all ethnicities within a bone age range of 2.5–17 years for boys and 2–15 years for girls. Evaluations (performed in cooperation with the developers) indicate similar performance as the manual approaches for these age groups, but no truly independent evaluations have been found.

- Maturos 4.0. (Le Groupe Français d'Auxologie, Clinique du Val D'Ouest, France)
  http://www.auxologie.com/maturation_squelettique/maturos.php
  This is not a fully automatic tool like the BoneXpert, but rather an interactive tool to support the bone age assessment. The user examines selected bones from the hand-wrist radiograph, and for each of them the software displays typical pictures for comparison and assessment of the degree of maturity. The software also automatically proposes the three most appropriate stages. Then each degree is shown on the screen in three forms: a reference radiograph, a picture and a descriptive text. After completion of evaluation, the software calculates a percentage of attainable maturity that can then be converted into "bone age". Santos et al. (2011) present an evaluation of the approach compared to that of

the classical approach using the GP atlas. Between 12 and 15 years the bone age with the MT program is closer to the chronological age, whereas in older ages the GP Atlas method is more trustworthy. At the ages with legal consequences in Portugal (16 and 18 years) the GP Atlas method is most accurate. Around 16 years old, they find that there are doubts in relation to the accuracy of both methods, but GP Atlas seems to perform better.

- Sunlight BonAge system (BeamMed Ltd., Israel. Former: Sunlight Medical Ltd.). http://www.beammed.com/products/bonage
  Ultrasound based system for assessment of bone age based on the skeletal development of the hand. It is intended for skeletal age evaluation for children and adolescents with growth abnormalities. The approach is based on Greulich and Pyle method and uses a proprietary algorithm and gender- and ethnicity-based reference curves to produce a skeletal age result in years and months. Studies that have compared the estimates to that of the Tanner-Whitehouse approach on radiographic images obtained for children in the age group 5-15 years, conclude that the method is quick and accurate (Shimura et al., 2005). Studies comparing the results from the device to that of Greulich and Pyle grading applied to radiographic images for the age group 6-17 years arrived at a similar conclusion (Mentzel et al., 2005). A third study (Xu et al., 2008) performed on the same age group did however arrive at the conclusion that the results from the system and from the radiographic analysis were not highly correlated, especially not for the older age groups.

1.4.7 Reference databases

Both the dental and the skeletal approaches typically compare the imaged teeth or bones to a reference database of descriptions, sketches or images of development stages. From the determined development stage, a table linking development stage to age is used to find the age estimate. Various atlases typically describe the development stages through images or sketches and/or textual descriptions. The development stages as such are population independent, but their relation to age (through look-up tables) may not be. Development stages also have the weakness of not giving continuous estimates and assignment around stage borders can be difficult.

1.4.7.1 Population variations in skeletal age

Schmeling et al. (2011) report from several studies which all seem to indicate that socio-economic status affects skeletal development more than ethnicity: Studies evaluated so far seem to suggest that there is a genetically determined element to skeletal maturation which does not appear to depend on ethnicity and may be exploited under optimum environmental (i.e. high socioeconomic status), whereas a less favorable environment may lead to retardation of skeletal maturation.

1.4.7.2 Population variations for dental age

For third molar mineralization and eruption a few comparative studies exist, comparing African, Mongoloid and Caucasoid populations. Here differences are observed, where the different stages of maturation occurs at earlier ages for the African population, somewhat later for the Caucasoids and latest for the Mongoloid population. The observed differences are assumed to be related to differences in palatal dimensions between these populations, as inadequate space can cause delay in third molar development, where the largest dimensions are observed for the Africans and the smallest for the Mongoloids. Hence, ethnicity seems to have more to say for dental age than skeletal age, but there is not full consensus on this in the research communities (Liversidge et al. 2006, Liversidge 2012). Schmeling et al. (2011) do

however conclude that population-specific reference data should be used when evaluating third molar eruption for age estimation.

1.4.8 Combination of methods

A combination of several methods is generally recommended to arrive at better estimates. In most cases this is done by achieving an age estimate from each method separately. Then experts draw the final conclusions based on these estimates. A few studies have instead looked into approaches for simultaneous age estimation from different methods based on e.g. combined regression models (Bassed et al. 2011, Suma et al. 2011, Thevissen et al. 2012).

There is however (as also pointed out by Schmeling et al., 2011) a need for more research to define the best approach for age estimation based on simultaneous use of different methods, which methods should be combined and how. There is also a need for a satisfactory way to scientifically determine the margin of error when combing methods, and there is a need for studies based on data from different methods that are acquired simultaneously from a single reference population.

1.4.9 Uncertainty

Age estimation aims to define in the most accurate way the chronological age of a person for which the age is unknown. However, the term "estimation" defines the real limits inherent to this expertise. There is today no medical test or a group of tests that will absolutely and accurately let us know the exact chronological age of a human being. There will always be an uncertainty related to the estimate, and correctly expressing this uncertainty is just as important as the actual estimate.

The uncertainties in age estimation are related to:

- *Individual biological variations*. There will always be a large variation in development between individuals of the same chronological age.
- *Reference datasets*. If incorrectly constructed, the reference standards can contribute to error. The human body exhibits natural variation and so reference standards may not always express the full extent of human variability in aging. Similarly, the reference materials may not be evenly distributed across all age classes. Reference datasets often come with estimates of standard deviation, but these refer to the reference dataset and not to a population. Finally, reference datasets may be population dependent and reference data are not available for all populations (Liversidge et al., 2006).
- *Inter-/intra-observer variations*. Measurements performed by the observers may vary both between and within observers, and this is also the case for the perception of development stages.
- *Methodological errors and uncertainties*. This will be method dependent. As an example, methods based on stage assessment will typically have a larger uncertainty in the stage assignment around stage borders.

Where possible it is important to find approaches that can help reduce the uncertainty. However, the variations due to reference data, observers, and methods will never be zero and the natural variability will always be there. Hence, it is important to understand, quantify and communicate the uncertainty in the best possible way.

2 Research programs and funding

Below is a list of both national and European research programs and funding opportunities in relation to the field of age estimation. This list is by no means complete.

2.1 The Research Council of Norway: VAM

The Welfare, Working Life and Migration (VAM) program is probably the most relevant program within the Research Council of Norway (RCN). The VAM program seeks to generate new knowledge of high scientific merit on the foundations, operation and processes of the welfare society. Research topics for the program are ageing, consequences of increased wealth, international migration, family and society, economic growth and organization of working life, and the support for, organizing and governing of the welfare society.

Research activity under the program will promote the further development of the welfare society by fostering and developing:

- Research that is empirically based, theoretically advanced and methodologically sound;
- Research that develops new perspectives with regard to inter- and multidisciplinarity, theoretical framework and empirical methods;
- Research that is internationally oriented and comparative;
- Research that promotes long-term knowledge development for use in policy formulation and public administration.

We have sent a letter to the Research Council of Norway with a request to include age estimation in the VAM program. It is highlighted that international cooperation is essential but also some national support and coordination is required. A note corresponding to chapter 1 in this paper was enclosed to the letter. This note was presented for The European Asylum Support Office (EASO) by Eivind Hoffmann in September 2012. The Ministry of Justice, The Norwegian Directorate of Immigration (UDI) and The National Identity and Documentation Centre (NID) give their support and describe the social impact in an enclosed letter.

2.2 EU's Seventh Framework Programme

The Seventh Framework Programme (FP7) bundles all research-related EU initiatives together under a common roof playing a crucial role in reaching the goals of growth, competitiveness and employment. FP7 runs from 2007 to 2013. In July 2012 the program announced the largest number of calls for proposals ever. The calls target both innovation and a range of societal challenges, building a bridge to **Horizon 2020**, the next funding program for EU research from 2014-2020 (see section 2.3).

The broad objectives of FP7 have been grouped into four categories:

- Cooperation - Funds collaborative projects between research teams
- Ideas – Funds excellent individual investigators in cutting-edge frontier research through European-level competition
- People – Funds training, mobility and career development of researchers
- Capacities – Enhances research and innovation capacity throughout Europe

Most relevant in the current context is probably the **Cooperation** category that supports all types of research activities carried out by different research bodies in transnational cooperation.

The aims are to gain or consolidate leadership in key scientific and technology areas. The Cooperation program is sub-divided into ten distinct themes: health; food, agriculture and fisheries, and biotechnology; information and communication technologies; nanosciences, nanotechnologies, materials and new production technologies; energy; environment (including climate change); transport (including aeronautics); socio-economic sciences and the humanities; security; space.

"Socio-economic Sciences and Humanities" and "Security" seem to be the most relevant themes.

2.2.1 Socio-economic Sciences and Humanities

Research in the theme "Socio-economic Sciences and Humanities" (SSH) contributes to an in-depth, shared understanding of the complex and interrelated socio economic challenges confronting Europe. It provides answers to questions related to, e.g., sustainability, environmental challenges, demographic change, migration and integration, quality of life and global interdependence. Emphasis is given to the following seven areas:

1. Growth, employment and competitiveness in a knowledge society
2. Combining economic, social and environmental objectives in a European perspective
3. Major trends in society and their implications
4. Europe in the world (covering among others migration, poverty, crime and conflict)
5. The citizen in the European Union
6. Socio-economic and scientific indicators
7. Foresight activities, such as the future implications of global knowledge, migration and ageing

Link to overview of activities and contacts for FP7 in the Norwegian Research Council:
http://www.forskningsradet.no/no/Temaoversikt_og_Forskningsradets_kontakter/1253952628126

2.2.2 Security

The objectives of the Security theme are to develop technologies and knowledge needed to ensure the security of citizens from threats such as terrorism and (organized) crime, natural disasters and industrial accidents while respecting fundamental human rights; to ensure optimal and concerted use of available and evolving technologies to the benefit of civil European security; to stimulate the cooperation of providers and users for civil security solutions; improving the competitiveness of the European security industry and delivering mission-oriented results to reduce security gaps.

Security related research is an important building block for supporting European freedom, security and justice. It will also contribute to developing technologies and capabilities in support of other European Community policies in areas such as transport, civil protection, energy, environment and health.

Emphasis will be given to the following activities:

- **Increasing the security of citizens** - technology solutions for civil protection, bio-security, protection against crime and terrorism;
- **Increasing the security of infrastructures and utilities** - examining and securing infrastructures in areas such as ICT, transport, energy and services in the financial and administrative domain;

- **Intelligent surveillance and border security** - technologies, equipment, tools and methods for protecting Europe's border controls such as land and coastal borders;
- **Restoring security and safety in case of crisis** - technologies and communication, coordination in support of civil, humanitarian and rescue tasks;
- **Improving security systems integration, interconnectivity and interoperability** - information gathering for civil security, protection of confidentiality and traceability of transactions;
- **Security and society** - socio-economic, political and cultural aspects of security, ethics and values, acceptance of security solutions, social environment and perceptions of security;
- **Security research coordination and structuring** - coordination between European and international security research efforts in the areas of civil, security and defense research.

2.3 Horizon 2020

Horizon 2020 – The EU Framework Programme for Research and Innovation - is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. Running from 2014 to 2020 with an €80 billion budget, the EU's new program for research and innovation is part of the drive to create new growth and jobs in Europe.

International cooperation will be an important cross-cutting priority of Horizon 2020. In addition to Horizon 2020 being fully open to international participation, targeted actions with key partner countries and regions will focus on the EU's strategic priorities. Through a new strategy, a strategic and coherent approach to international cooperation will be ensured across Horizon 2020.

Horizon 2020 will raise the level of excellence in Europe's science base and ensure a steady stream of world-class research to secure Europe's long-term competitiveness. It will support the best ideas, develop talent within Europe, provide researchers with access to priority research infrastructure, and make Europe an attractive location for the world's best researchers.

2.4 European Science Foundation

The European Science Foundation (ESF) provides a common platform for its Member Organizations in order to advance European research and explore new directions for research at the European level.

Through its activities, the ESF serves the needs of the European research community in a global context. It carries out an array of activities, ranging from organizing scientific exploratory workshops to providing science policy advice. ESF provides a platform for Member Organizations to develop joint strategic operations and synergy among themselves.

The ESF represents all scientific fields. To promote high quality science at a European level the wide ranging portfolio is managed of activities under eleven disciplinary headings: humanities; life, earth and environmental sciences; medical sciences; physical and engineering sciences; social sciences; marine sciences; materials science and engineering; nuclear physics; polar sciences; radio astronomy and space sciences.

2.5 NORFACE

NORFACE - New Opportunities for Research Funding Agency Cooperation in Europe - is a partnership between fifteen research councils to increase co-operation in research and research policy in Europe. It started in January 2004. The fifteen partners involved are the research

councils for the social sciences from Austria, Canada, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, The Netherlands, Norway, Portugal, Slovenia, Sweden and the United Kingdom. NORFACE formalizes this existing working relationship and provides a framework and a vision for a durable multi-national strategic partnership in research funding and practice.

http://www.norface.net/

2.5.1 NORFACE Research Programme on Migration

In 2008-2009 NORFACE introduced a transnational research program with the theme Migration in Europe - Social, Economic, Cultural and Policy Dynamics. The program is jointly funded by the national research councils – among them Research Council of Norway - and the European Commission. It was launched in June 2009 and will run for a maximum of four years.

The Programme on Migration aims to build a new synergetic body of research, which will contribute to our theoretical understanding and knowledge in the area of Migration Research. The four main objectives of the program are:

- To advance globally excellent theoretical and methodological disciplinary, inter-disciplinary and comparative research on migration which builds synergetically on a pan-European basis;
- To take advantage of and develop the informal laboratory of experience, knowledge and data which migration in Europe currently presents;
- To motivate and support excellence and capacity building for research on migration on a cross-national basis throughout the NORFACE countries and beyond;
- To develop understanding and promote research-based knowledge and insight into migration for issues of societal, practical and policy relevance, with theoretical foundations but worked on jointly with relevant users and experts.

Three main themes are emphasized: migration; integration; cohesion and conflict.

http://www.norface-migration.org/

2.5.2 NORFACE-II Support Action

From September 2011 the NORFACE partnership continued in the shape of the NORFACE-II Support Action. The NORFACE-II Support Action aims at further deepening and strengthening the established transnational cooperation and is now in the phase of planning for a new multidisciplinary transnational research program with the theme "Welfare State Futures". This new cooperation has been brought about with the aid of the European Union's Seventh Framework Program. The project will last until March 2013.

The new NORFACE work plan (2011-2013) consists of three work packages: Joint Research and Related Activities and Initiatives; Exploiting Data & Research Infrastructure in the Social Sciences; Governance and Management of the NORFACE-SA Network, and Output, Dissemination and Impact.

3 Organizations and networks

Below is a list of some international organizations related to the field of age estimation. This list is by no means complete.

3.1 AGFAD

AGFAD = Study Group on Forensic Age Diagnostics of the German Association of Forensic Medicine.

Due to cross border migration in the European Union, an increase in the number of foreigners without valid identification documents could be noticed in many European countries. These developments led to an increasing demand for forensic age estimation of the living.

During the "10th Lübeck Talk of German Forensic Doctors" a superregional analysis of the present state of the forensic age diagnostics took place. On this congress the foundation of a study group containing forensic doctors, dentists, radiologists and anthropologists was proposed to develop guidelines to support expert opinion with the goal to harmonize different approaches concerning expert opinions and to assure the quality of the expert opinions. The interdisciplinary "Study Group on Forensic Age Diagnostics" was constituted on March the 10th in the year 2000 in Berlin.

At the foundation meeting it was concluded, that age diagnostics of corpses and skeletons also belongs to the tasks of the study group.

Up to now the study group has 123 members that come from Germany, Austria, France, Great Britain, the Netherlands, Belgium, the United States of America, Switzerland, Spain, Azerbaijan, Norway, Denmark, Israel, Portugal, Greece and Italy.

http://agfad.uni-muenster.de/english/start.htm

3.2 EASO

The European Asylum Support Office (EASO) is an agency of the European Union which plays a key role in the concrete development of the Common European Asylum System. It was established with the aim of enhancing practical cooperation on asylum matters and helping Member States fulfill their European and international obligations to give protection to people in need. EASO acts as a center of expertise on asylum. It also provides support to Member States whose asylum and reception systems are under particular pressure.

EASO will support Member States in their efforts to implement a more consistent and fair asylum policy, for example by helping to identify good practices, organizing training at European level and improving access to accurate information on countries of origin.

3.3 EMN

The objective of the European Migration Network (EMN) is to meet the information needs of Union institutions and of Member States' authorities and institutions by providing up-to-date, objective, reliable and comparable information on migration and asylum, with a view to supporting policymaking in the European Union in these areas. The EMN also serves to provide the general public with such information.

3.4 IGC

The full name of IGC is Inter-Governmental Consultations on Asylum, Refugee and Migration Policies in Europe, North America and Australia.

IGC is an informal, no decision-making, collaboration in the area of asylum and migration. The member states are Australia, Belgium, Canada, Denmark, Germany, Finland, Ireland, Italy, the Netherlands, Norway, Austria, Spain, the United Kingdom, the United States, Sweden and Switzerland.

The IGC is organized through diverse workgroups on subjects as return, asylum, data, country of origin information, and smuggling.

http://www.gdisc.org/index.php?id=156

3.5 UNHRC

The United Nations Human Rights Council (UNHRC) is an inter-governmental body within the United Nations system responsible for strengthening the promotion and protection of human rights around the globe and for addressing situations of human rights violations and make recommendations on them. It has the ability to discuss all thematic human rights issues and situations that require its attention throughout the year. It meets at the UN Office at Geneva.

UNHRC has recommended EU authorities to unify methodology applied in age estimation to ensure the protection of children and the defense of immigrants Human Rights in Member States (Schmeling et al., 2011).

http://www.ohchr.org/EN/HRBodies/HRC/Pages/HRCIndex.aspx

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