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**RESEARCH ARTICLE**

# FORENSIC AGE ESTIMATION BASED ON THE SKELETAL GROWTH ASSESSMENT: A COMPREHENSIVE REVIEW

***,[1]Domnic Marera and [2]Nyaribo Cyprian**

[1]Department of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, College of Health Sciences, University of KwaZulu-Natal, Westville Campus, Private Bag X54001, Durban 4000
[2]Department of Human Anatomy, School of Health Sciences, Egerton University, P.O Box 536, Egerton - 20115

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**ABSTRACT**

Forensic age estimation is a scientific process in a forensic medicine which aims to determine in the most precise way possible, the chronological age of a person of an unknown or doubtful age involved in medical or legal proceedings such as unregistered children, asylum seekers, immigrants, marriage, sporting events and criminals. With the current concerns of migration trends, criminal activities and ethical legal dilemma, forensic medical team and anthropologist have tried to come up with several ways to determine the biological profile of living individuals. The skeleton and dentition has been used for age estimation for years, but with the new technological advances such as digital x-rays, computer tomographic imaging and ultrasound machines, age estimation has been made simple, faster and near accurate. This article reviews the use of bones for age estimation, with emphasis to various methodologies of bone assessment, limitations of this modalities and possible recommendation that may accurately bring to precision, the current methods of age estimation in the future.
**Sources and selection of data:** comparison between old and new literature was reviewed and information was obtained from search engines such as the PubMed and Google scholar.



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## INTRODUCTION

Rapid changes in globalization and industrialization has led to a sudden increase in cross border migration, criminal activities, refugee influx and large population especially children without official biological profile (Angenendt, 1999). As a result, the demand for age estimation among the living has steadily increased in forensic medicine. Not long after Wilhelm Conrad Röntgen discovered x-rays in 1895, the first descriptive literature on the assessment of skeletal maturity as a measure of biological profiles and processes were published (Roche and Sunderland 1959). In this modern era, bone age assessments have been established in forensic medicine and anthropology and has also been used in the diagnosis of growth disorders and to predict the prospective adult height (Angenendt 1999). Currently, there is no single medical test or group of tests that absolutely and accurately determine the exact chronological age of a human being, whether dead or alive (Ritz-Timme *et al*., 2000).

***Corresponding author: Domnic Marera,***
*Department of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, College of Health Sciences, University of KwaZulu-Natal, Westville Campus, Private Bag X54001, Durban 4000*

A number of indicators are available to estimate the age in young people right from childhood to early adult period, but age estimation becomes less accurate with increasing years due to complete maturation and ossification of most bones(Scheuer and MacLaughlin-Black, 1994).

### The need for skeletal age assessment

The application of skeletal assessment in forensic age estimation during legal proceedings has become an important aspect of forensic medicine (Schmeling *et al*., 2008). The African Society of Forensic Medicine stated that in Africa, clinical pathology has been widely embraced but little has been done to encourage the use of bone ossification process to examine the chronological age of living persons, due to insufficient studies and reluctance in its adoption (Olze *et al*., 2004). The uncertainty of age may arise due to several circumstances within or without our reach. In some countries such as Afghanistan, calendars are banned and in Somalia only 3 percent of children are registered (Benson and Williams 2008). The chaotic circumstances surrounding the time of birth, such as war, hunger and natural disasters may contribute to a lack of registration of the birth or loss of registration papers. Children may be separated from the parents and therefore making the determination of age uncertain. Other possibilities may include an adopted child or administrative errors like poor record keeping. Recording the name, sex, parentage, time and place of a child's birth may seem to be easy, butin Africa, due to pooraccess and maintenance of vital statistics such as birth records, only half of the children under five years old have their births registered. In sub-Saharan Africa, 64% of births are unregistered while in Eastern and Southern Africa only 48% of births were recorded by 2011 (Berst *et al*., 2001). Lack of biological profiles has made children more vulnerable to abuse such as recruitment into fighting forces, being exposed to hazardous forms of work, early marriages and adult criminal proceedings. Any person whether a child or adult in conflict with the law have a right to be treated in a manner which takes into account the needs of his or her age. With this in mind, the need for accurate age estimation is necessary to protect the young, identify the unknown individual and to provide justice in accordance with the correct age of the individual (Berst *et al*., 2001).

**Methods of age estimation based on skeletal assessment**

As early as the 1930s, several authors have developed different assessment methods while trying to increase the accuracy and reliability in their application, but few have done inter- country profiling, while African countries still lags behind in this new field of forensic medicine (Schmeling *et al*., 2000). The use of ultrasound and multiple detector computed tomography (MDCT) are new techniques introduced in this field, while x-ray techniques have been used for long and its accuracy improved. Below is a critical comparison of different methods of bone age assessment

**The Gilsanz and Ratibin Atlas**

In 2005, Vicente Gilsanz and Osman Ratibin produced idealized and artificial images specific for age and sex standards of skeletal maturity by thoroughly analyzing the size, shape, morphology and density of ossification centers in hand radiographs of healthy children. They generated images that included the typical characteristics of development for each of the ossification centers(Mughal *et al*., 2013).

**The Greulich and Pyle Atlas (G & P)**

Using this atlas as a standard, bone age is calculated by comparing the left wrist radiographs of the subject with the nearest matching reference radiographs provided for different ages. The Greulich-Pyle standards are the most commonly used method for bone age assessments throughout the world (Greulich and Pyle 1959). However, it was compiled solely from data from Caucasians who lived in the 1930s making it more irrelevant to other population groups.

**Automatic Skeletal Bone Age Assessment**

The first semi-automated system for bone age estimation was developed by Michael and Nelson. This system was able to automatically segment the bones in a hand radiograph, however, large scale tests demonstrated that the system was not reliable when hand bones are fused (Giordano *et al*., 2010). A computerized automatic system of bone age assessment would in theory be a solution,

**The use of Ultrasound**

Sonography-based techniques may be a possible alternative to conventional methods for the assessment of skeletal age. The ability of ultrasound to determine a reliable skeletal age has been proved by Hans (Ogata and Uhthoff 1990) in 2004. The results were highly correlated with conventional skeletal age evaluation using the Gand Pmethod. Although this method is still in its initial stages and needs further refinement, it has obvious advantages as compared to x-ray, such as objectivity, lack of ionizing radiation and easy accessibility(Ogata and Uhthoff 1990).

**Assessment of the cranium**

The most commonly studied aspect of cranial sutures is the degree of their obliterations as an indicator of age. Cranial sutures generally fuse with increasing age, however, there is considerable variability in closure rates and patterns (Masset 1989). This variability leads to the question of the value of cranial suture closure as a method of estimating age. In addition, the standard methods established for scoring cranial suture closure are often criticized for subjectivity and a lack of quantitative analysis (Masset 1989).

**Assessment of the hip bone**

It has been observed that the ossification of iliac crest apophysis is not uniform, resulting in discrepancies when used for bone age calculation (Eikvil *et al*., 2012). This is why it is not used as a replacement of bone age calculation from hand radiographs. Newer methods are being developed to compute bone age from iliac radiographs, but further studies are needed to compare different grading systems to make the iliac apophysis relevant (Eikvil *et al*., 2012).

**Assessment of the bones of the foot**

Age estimation in the living using the maturational changes within the skeleton of the foot do not appear to be commonly used (Davies and Parsons 1927)although foot became important in forensic anthropology due to the long duration with which it can be preserved. If encased in a shoe, the foot can survive intact after other body parts have been lost due to taphonomic influences, explosions, or plane crashes. The foot–ankle atlas of Hoerr (Davies and Parsons 1927)was the most accurate atlases to be developed from the data collected from the Brush Foundation Study.

**Assessment of the clavicle**

In order to establish a reliable age indicator in the period when all epiphyseal plates of other bones have already been inactivated, medial clavicle as the bone with the longest period of growth became the object of various investigations. However, the lack of population-specific method often made it unreliable in some regions (Schmeling *et al*., 2008).

Table 1 below provides a summery of common methods used in bone age assessment from different countries and the types of bones used during the study.

**Table 1. The Common methods of bone age assessment as applied by different authors in the literature**

| Authors | Year | Country of study | Type of bone |
|---|---|---|---|
| Osteological series | | | |
| Gill (Gill and Le Roy 1942) | 1942 | USA | Tibia and fibula |
| Scheuer (Scheuer and MacLaughlin-Black 1994) | 2002 | UK | Fetal bones |
| Vu (Vu *et al*., 2001) | 2001 | China | Skull |
| Cattaneo (Cattaneo 2009) | 2009 | Italy | ileum |
| Brown (Brown *et al.,* 2013) | 2013 | Ghana | Clavicle |
| Radiological series | | | |
| Tanner (Tanner 2012) | 2012 | UK | Hand and wrist |
| Ohtani (Ohtani 2002) | 2002 | Japan | Proximal femur |
| Schmeling (Schmeling *et al.,* 2011b) | 2011 | Germany | Clavicle |
| Whitaker (Whitaker *et al.,* 2002) | 2002 | USA | Foot |
| Gandini (Gandini *et al.,* 2006) | 2006 | Italy | Cervical vertebra |
| CT and MDCT series | | | |
| Robinson(Robinson *et al.,* 2008) | 2008 | UK | Lower limb |
| Brough *et al.* (Agathangelidis *et al.,* 2013) | 2013 | USA | Clavicle |
| Ferrant *et al.* (Ferrant *et al*., 2009) | 2009 | France | Coxal bone |
| Computer Automated series | | | |
| Tanner *et al.* (Tanner and Gibbons 1994) | 1994 | USA | Hand and wrist |
| Pietka (Pietka *et al*., 2001) | 2001 | Poland | Phalanges |
| Giordano (Giordano *et al*., 2010) | 2010 | Italy | Carpal bones |
| Ultra sound series | | | |
| Khalid *et al.* (Khalid *et al*., 2013) | 2013 | USA | Hand |
| Kellinghaus *et al.* (Kellinghaus *et al*., 2010) | 2008 | Germany | Clavicle |
| Bilgili *et al.* (Bilgili *et al*., 2003) | 2003 | Turkey | Hand |

## Limitations of age estimation using bone age assessment

From the above discussion, several researches have tried to come up with the best ways of estimating the age of a living subject, but none so far have come up with an accurate and undisputed methodology of determining the exact age of an individual. Even with the ultra-modern technology available, no medical test or anthropological approaches have developed methodologies that can absolutely and accurately identify the exact chronological age of an individual, whether living or dead. Thus, there will always bean uncertainty related to the age estimated, and addressing reasons for these uncertainties may form the basis to finding a solution.

The limitation that nearly all the bone age assessment studies point to is the lack of benchmark data relating to populations from different countries. Wang (Wang and Puram, 2004) stated that due to the lack of reference data and no clear evidence of definitive interracial differences, an average from minimum and maximum values of several results should be taken, with some margin of error in either direction. However, some other studies (Einzenberger 2003) question the extent to which differences exist between population groups. Furthermore, most methods of age determination have arrived at a 90-95% confidence interval of about two years around the estimated age due to variations affecting bone growth such as racial, socio-economic and nutritional factors (Einzenberger 2003).

It should also be noted that the Greulich and Pyle atlas was not only based on a population of teenagers and young adults over 70 years ago, but comprised only Caucasian children from the United Kingdom. More recently, racial differences have been shown in Middle Eastern, Asian and Black American populations with bone age disparities between 6 to 12 months depending on the age when the children were assessed(Schmeling A *et al*. 2008). This confirms the need of a population specific study based on geographical and racial setting other than using a single study as a universal standard. Although, the mechanics of using Greulich and Pyle atlas to estimate age has been a starting point, how relevant is an atlas of healthy, middle-class UKteenagers of the 30s to present-day African teenagers?, It's only one of many questions surrounding this technique

Individual methodological errors and uncertainties may also limit the use of skeleton for age estimation. For example, methods based on chronological stage assessment of age will typically have a larger uncertainty around stage borders and overlapping issues. Measurements performed by the observers during data collection may vary both between and within observers, and this is also the case for the perception of development stages, therefore, if the same x-ray is assessed either by the same or different observers the assigned bone age may vary (Schmeling Andreas *et al*., 2011a). It has been noted that there is greater error with observation based assessments compared to the computer generated assessments of bone studies for age estimation (Schmeling Andreas *et al*., 2011a). A number of studies have investigated these effects and in summary have demonstrated an average intra-observer error of between 2 and 9 months and an average inter-observer error between 1 and 12 months (Büken *et al*., 2007). However, these were average errors and the error range in these studies was 0 to over 2 years. Combining both the intra- and inter-observer variation, differences of over 12 months frequently occur (Büken *et al*., 2007).

## Future direction

From the papers reviewed in this article, it is obvious that there is significant progressin assessment of bone age estimation, but a number of challenges still exist with the current methods of chronological age assessment with greater opportunities for improving these important part of forensic medicine. The main gap is the lack of research and documentation of population specific standards for developing countries and consideration of socio economic standards during such studies.

With the current technological advancement in the field of forensic medicine and anthropology, there is need for a computerized and automated benchmark data relating to populations from different countries. These systems may be fed with different age assessment parameters, for example several images or histograms of different bones may be programed in a system so that it may combine these data to achieve precise and accurate age of an individual. Hence, maybe developing an automated system for bone age assessment based on hybrid methodologies can be useful to cover this problem and to achieve a better output.

It would also seem proper that due to great variations in results from various bone age estimation methods, population specific pilot studies should be carried out using various techniques on normal healthy children. These results should be compared in order to select and/or develop the best methodology that accurately represents the growth pattern and correlates best with chronological age of the subject in question. Subsequently, large scale researches should be planned to develop national guidelines of bone age assessment that take into consideration the racial, socioeconomic and genetic drifts of a given population.

**Conclusion**

Although, several studies have shown that bone assessment is of significant value in estimating the age of a population, Statistics tell little if, nothing about an individual subject whose age needs to be verified, therefore a multifactorial approach including clinical and mental examination may be necessary to get reliable if not accurate, the age of living person. The use of bone for age assessment is increasingly becoming more popular in forensic medicine due its ease of access and simple methodology, however skeletal, unlike a chronological year, is not constant at all stages of development, and maturation levels can differ within and between individuals.

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