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RESEARCH ARTICLE

AGE ESTIMATION USING CHRONOLOGICAL CHANGES IN THE EPIPHYSEAL ENDS OF THE CLAVICLE

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ABSTRACT

The determination of an individual's age is an important aspect of forensic medicine. The clavicle has the longest period of growth; therefore, it has been investigated by various researchers in order to establish a reliable age indicator when all other epiphyseal age indicators have already been inactivated. Several authors have developed different techniques of age determination using the clavicle, however, there is still no standard system agreed upon with respect to use of the clavicle in age assessment. The use of X-rays has proved that the onset and fusion of the medial epiphysis of the clavicle can be used to determine an individual's chronological age. Thus, the purpose of this review article is to present the different methods of age estimation using the clavicle and to discuss the variations in the time frame of the ossification of the medial clavicular end as reported by previous researchers.

INTRODUCTION

Chronological age is defined as an individual's age from birth and is usually measured in days, weeks and months for young children and in years for older children (Krogman and Iscan, 1986). In many countries, chronological age is a significant part of a person's identity. Therefore, the ability to determine an individual's chronological age is a major component of daily life, however, for vulnerable children, it is important for accessing social support and education (Gonsior *et al.,* 2013).
An individual can be mistakenly treated as an adult or have restricted access to social facilities when his or her age cannot be properly ascertained. In cases where adults are erroneously treated as children, whilst less potentially harmful to the individuals themselves, it has implications for the safety of others. In addition, it could limit the availability of resources to vulnerable children and of those who are in genuine need (Scheuer 2002). Access to accurate and reliable age estimation techniques is undeniably extremely important in these cases where there is no other evidence to support the age claimed by an individual.

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Age estimation using biological indicators is performed on both the living and the deceased, and is done through assessment of biological maturity which is then ultimately translated by the practitioner into an estimation of 'probable' chronological age (Scheuer and Black 2000). In the deceased, there are number of techniques for age estimation that ranges from the very invasive methods such as amino acid racemization to the less invasive procedures such as radiological examination (Cameriere *et al.,* 2012).

However, in the living, invasive age techniques are inappropriate, therefore, non-invasive imaging modalities including radiographs, computed tomography (CT) and magnetic resonance imaging (MRI) are applied to evaluate the changes in biological tissues such as bones and teeth. Age estimation in the living is important in cross-border adoptions, international competitive sports and in crime investigation including child pornography and human trafficking, perpetrators must be brought to justice and determination of whether the person of interest is a minor or not is of paramount importance (Meijerman *et al.,* 2007). One of the most promising methods of age estimation is the radiological study of secondary ossification centers of the clavicle, especially in the living.

Growth and development of the clavicle

The clavicle is a long bone with an epiphysisat either end that permits growth of the bone. It is the first fetal bone to undergo primary ossification, and its medialepiphysis is the last to fuse with the diaphysis (Cardoso *et al.,* 2013). However, other long bones ossify by end ochondral ossification, the clavicle ossifies via both intramembranous and endochondral ossification (Kreitner *et al.,* 1998). The two primary ossification centres of the clavicle appear on the medial and lateral side by the sixth week of development and fuse together about one week later (Cameriere *et al.,* 2012). After the bone matrix is laid down, cartilage appears at the acromial sternal (medial) end of the developing clavicle while mesenchymal cells proliferates at the lateral (Acromial end). Therefore, at this stage, growth continues by a combination of endochondral and membranous ossification in the acromial end and the sternal end of the clavicle, respectively. The medial cartilaginous mass contributes about 80% or more of the clavicular length (Scheuer and Black 2000). The combination of the spatial location of the two ossification centres at either end of the bone and endochondral ossification at these sites gives the clavicle its unique S-shape by the eighth to ninth week of gestation. The bone finally attains its adult form by the eleventh intrauterine week (Krogman and Iscan 1986), and after birth, growth slows down untill puberty (11 to 14 years). From this point, the medial epiphysis starts growing until complete fusion around 30 years (Black and Scheuer 1996). Therefore it is difficult to use the clavicles of children before adolescent period in age estimation, but much easier and more accurate during the adolescent and post-adolescent periods.

Little attention has been given to the lateral clavicular epiphysis in the anatomical literature, while some texts (Kreitner *et al.,* 1998) state that no epiphysis forms at the lateral clavicle, others claim the opposite is true (Scheuer and Black 2000). Existing sources state that the lateral epiphyseal surface of the clavicleis usually small, and tends to be a transitory structure. Its secondary ossification centre appears around 19 or 20 years of age and fuses within months of its formation (approximately 3 months to complete ossification). Its epiphyseal status is therefore difficult to determine, hence, some authors considered that no epiphysis is formed at the acromial end (Black and Scheuer 1996). The earliest report on medial clavicular epiphyseal fusion was by Stevenson in 1924 (Schmitt *et al.,* 2002)) who documented epiphyseal union in arms, legs and girdles using the Hamann-Todd's collection of clavicles in the United States. Stevenson noted the commencement of the union was as early as age 22 years and was completed in all cases by 28 years: however, the effect of sex or geographical differences on the stages of the epiphyseal union was not mentioned. Todd and D'Errico1928 (1928)) published a more extensive study on the medial clavicle using a four-phase scoring system: (1) no union (2) beginning of union, (3) recent union with scar, and (4) complete union. Their result indicated that union began at 18 years and was completed at 29 years of age.

Advantages of using the clavicle for age estimation

The clavicle has unique features, and as noted earlier, it is the first and the last bone to ossify (Humphrey 1998). It is the only long bone that lies horizontally and has been reported to lack a marrow cavity (Kellinghaus *et al.,*, 2010) : apart from this, it is also the only bone of the upper limb articulating with the axial skeleton. The bone develops through intramembranous and endochondral ossification at its medial and lateral ends, respectively (Scheuer and Black 2000), which is not common in long bones. Therefore, the clavicle has the longest period of growth related activity and thus, retaining its predictive value as a useful and reliable indicator of age from the adolescent period to the third decade of life. The hand and wrist bones are useful for age determination up to 18 years of age, because their development ends by this age, while mineralization of the roots of the wisdom teeth ends by 21 years of age (Kellinghaus *et al.,*2010). The proximal and distal epiphyses of long bones with the exception of the clavicle fuse before the third decade of life (Table 1). The medial clavicular epiphysis is important for age determination during forensic examination, because epiphyseal fusion begins at the onset of puberty and is completed approximately 10 years after its initial appearance (Schmeling *et al.,* 2000). In establishing whether an individual has attained the criminal liability threshold of 21 years, the ossification of the sternal clavicular cartilage is of particular interest because it is not fully matured by this time (Schmeling *et al.,* 2000). Developmentally, growth of the clavicle slows after birth until puberty while maintaining its adult shape (Black and Scheuer1996), therefore, its use in age estimation in children is difficult.

Methods of staging (scoring) ossification process of the clavicle for age estimation

Age estimation from clavicular ossification based on the pattern and degree of epiphyseal union has been studied by many researchers using dry bone specimens and radiographic images such as X-rays, CT and MRI. Todd and D'Errico (1928) in a study of the medial and lateral clavicular epiphyses scored the medial epiphysis of clavicles according to a four phase system: (1) no union, (2) beginning union, (3) recent union with a scar, and (4) complete union (with loss of all trace of the site of union). They reported that union occurred between 18 and 29 years and that the ossifying epiphyses typically begin to unite around age 21, and union is practically complete by age 25, however, the significant sex or race on the ossification process was not reported.

Several years later, Szilvassy (1977) presented a three phase scoring system of clavicular ossification to avoid overlapping: the first phase was defined between 18 to 20 years, the second phase with active fusion was defined between 21 to 25 years, and the third phase completed between 26 to 30 years. Later, Scheuer and Black (2000) also classified the period of maturation of the clavicle into three levels: The first level appeared between ages of 16 and 21 years with a well-defined medial clavicular ossification; the second level was between ages of 24 and 29 years with most of the medial clavicular end filled by flakes, whilst the last period appeared between 22 and 30 years with a complete fusion. Black (2000) further improved the scoring method and divided the phases into four stages with the ossification centre not ossified; ossification centre ossified, epiphysealplate not ossified; epiphysealplate fully ossified for stages one, two, three and four, respectively.

Schmeling *et al.* (2004) divided the last stage into two further stages; stages four and five with the epiphyseal plate fully ossified, epiphyseal scar visible and the epiphyseal plate fully ossified, epiphyseal scarno longer visible for these stages, respectively (Figure 1).

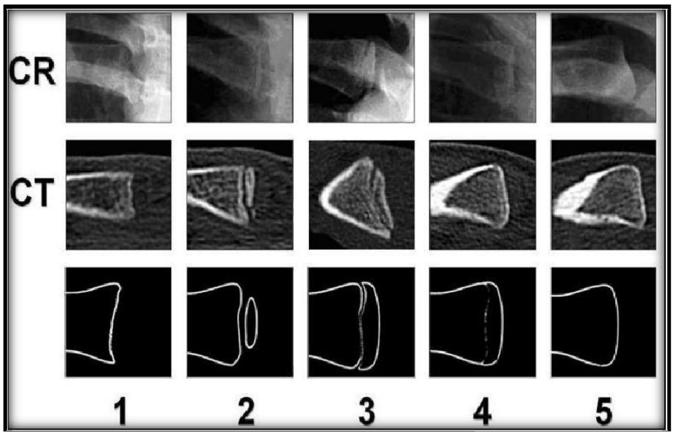

Figure 1. Schematic drawings and images of the stages 1-5 of clavicular ossification as revealed by means of anteroposterior X-ray(Adapted with permission from Schmeling et al., 2011)

Schmeling *et al.,* (2004) and his team also concluded that the earliest age at which stage 3 (partial fusion) was detected in both sexes was 16 years. The stage 4 (total fusion) was first observed in females at 20 years and in males at 21 years. The stage 5 (disappearance of scar) appeared earliest at the age of 26 years in both the sexes. Their report is the only study that has met the requirements of a reference study as stated by the Forensic Age Diagnostic Study Group and is currently considered as the standardized method of defining the ossification status of medial clavicular epiphyses (Schmeling *et al.,* 2004).

For further sub-classification of Schmeling's scoring system, Kellinghaus *et al.,* (2010) amplified stage 2 and 3 in order to narrow the interval of estimated age thus increasing its accuracy as follows:

- Stage 2a: The lengthwise epiphyseal measurement is one third or less compared to the widthwise measurement of the metaphyseal ending.
- Stage 2b: the lengthwise epiphyseal measurement is over one third to two thirds compared to the widthwise measurement of the metaphyseal ending.
- Stage 2c: the lengthwise epiphyseal measurement is over two thirds compared to the widthwise measurement of the metaphyseal ending.
- Stage 3a: the epiphyseal-metaphyseal fusion completes one third or less of the former gap between epiphysis and metaphysis.
- Stage 3b: the epiphyseal-metaphyseal fusion completes over one third to two thirds of the former gap between epiphysis and metaphysis.
- Stage 3c: The epiphyseal-metaphyseal fusion completes over two thirds of the former gap between epiphysis and metaphysic (Figure 2).

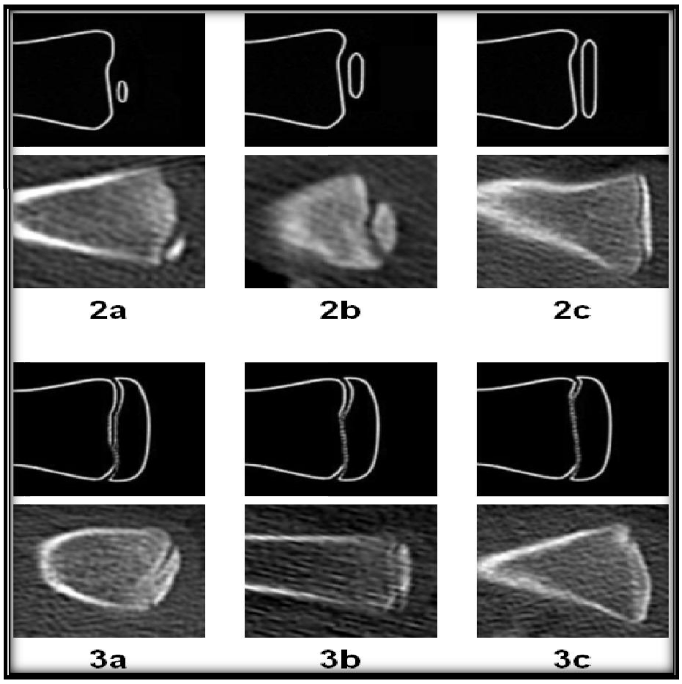

Figure 2. Schematic drawings and pictures of the stages 2a-3c of clavicular ossification as revealed by means of anteroposterior X-ray (Adapted with permission from Springer)

Variations in the time frame of ossification of the medial clavicle

Several studies have examined the time frame for ossification of the medial epiphyseal cartilage. Some of these studies adopted an anatomical approach by evaluating the ossification status through postmortem examinations or the direct inspection of the human skeleton (McKern and Stewart 1957), while others used the radiological approach (conventional X-ray or CT) (Kreitner *et al.,*, 1998; Schmeling *et al.,*, 2004). However, the time frame of ossification of the medial epiphyses reported in these studies varies. These variations have made bone age estimation a controversial subject in the field of forensic medicine, hence, the need for population specific standards to address such issues. It has also been debated whether the age intervals for the various stages of ossification identified using anatomical studies can also be applied to X-ray images (Kreitner *et al.,*, 1998 Schmeling *et al.,*, 2004). Therefore, harmonized radiological reference studies are needed to aid forensic age estimation in living individuals which can be confidently applied during legal proceedings.

Several authors have conducted dry bone (osteological) studies of the clavicle for age estimation (Table 1), while few in India and Germany used CT and conventional X-rays. Most of the studies that have evaluated age estimation using clavicular ossification were carried out in the Northern Hemisphere (Ogata and Uhthoff 1990). Variations in the age difference and the minimum age of fusion of the medial clavicular end have been reported by various researches in different population groups (Table1). From the literature reviewed, there is paucity of information on the radiological assessment of the development of the medial clavicular end in Africa.

Table 1. Estimated time of fusion of long bones

Bone	Estimated age of complete fusion (Years)	
	Proximal/ medial end of fusion	Distal/lateral end of fusion
Fibular	19-19	15-18
Radius	14-19	16-22
Humerus	10-15	9-15
Femur	15.5-19.5	14.5-22
Clavicle	19-30	19-20
Ulnar	20-21	16-18
Tibia	15.5-22	14.5-19.5

Table 2. The variations in the time of fusion of the medial epiphyses of the clavicle from the literature

Authors	Country of study	Complete fusion	Scoring method	Minimum Age(Years)
Osteological series				
Stevenson(1924)	USA	Stage 4	Stevenson	24-28
McKern and Stewart (1957)	USA	Stage 4	McKern-Stewart	23
Webb and Suchey(1985)	USA	Stage 4	McKern–Stewart	20
Mac Laughlin (1992)	Portugal	Stage 5	Mac Laughlin	27
Ji(1994)	Japan	Stage 4	McKern–Stewart	20
Black and Scheuer (1996)	Europe	Stage 5	Mac Laughlin	20
Veschiet al.(2002)	Italy	Stage 5	-	19
Schaeffer and Black(2005)	Bosnia	Stage 4	McKern–Stewart	21
Radiological series				
Galstaun(1937)	India	Stage 5	Galstaun	19
Jit and Kulkarni (1976)	India	Stage 3	Jit–Kulkarni	22
Scheming et al. (2004)	Germany	Stage 4	Schmeling	20
CT series				
Kreitner et al. (1997	Germany	Stage 4	McKern–Stewart	22
Richel(2005)	Germany	Stage 4	Schmeling	19.14

Hence, the need to develop reference values that are specific for this particular geographical area, so that forensic age estimation will more accurate.

Factors affecting clavicular development

There are potential factors that may affect the age of onset and complete fusion of the clavicle in the different geographical regions, and their simultaneous effect in bone growth may make osteologicage estimation a difficult exercise (Jit and Kulkarni 1976). These factors may include: the use of a small sample size, the exclusive consideration of non-relevant age groups, and lack of information on health, ethnic identity, socio-economic status, and ethnicity.

Several authors have also pointed out that data from dry bone specimens are not directly comparable with data from radiological studies. Krogmanand Isçan (Krogman and Iscan 1986) and Kreitner *et al.* (1998) argued that the commencement of fusion can be detected in radiographs before the union of epiphysis and metaphysis can be visible on dry bones. Therefore, reference values from dry bone studies should not be applied to assessments based on radiographs. Currently, there is no specific gold standard for age estimation using the clavicle. Some researchers have attributed variation in skeletal maturation specifically to ethnic differences (Schaefer and Black 2005). Population- specific skeletal growth velocities were cited as the primary reason that Japanese adolescents differ from English adolescents in terms of skeletal maturation (Murata *et al.,* 2013). Murata (2013) and his team concluded that this genetic difference in the skeletal maturation process during puberty may explain the difference in adult stature be tween these population groups.

Such important findings can play an important role in developing standards for estimating an individual's age. Frutos (2002) noted the commencement of medial clavicular union as early as 22 years of age and a completed union in all cases by 28 years of age; however, the influence of sex and geographical location on epiphyseal union was not stated. His report differed from the findings of Black and Scheuer (1996) who documented that the ossifying epiphysis typically begins to unite around 21 years of age and the unionis practically complete by 25 years of age. From the above studies, it can be deduced that studies from different populations may give different values due to geographical and socio-economic status. The estimation of age in Africa has only been restricted to a general morphometric and anatomical study of the clavicle, whilst little has been done using more accurate radiological approach.

Conclusion

The assessment of medial clavicular epiphyseal growth has been established as a reliable method of age estimation in the period when all other epiphyseal age indicators are no longer active. This makes it a very important bone for age assessment in determining whether an individual has reached the age of criminal or civil responsibility. In addition, its position in the human body makes it accessible for examination in living individuals as well as in cadaveric material. Several factors which include geographical location do affect the rate of maturity of an individual, therefore, there is the need for a standard scoring system in the African setting as this has been hitherto unavailable.

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