Ossification pursue of the lower ends of radius and ulna and age determination in a sample of Egyptian population between 12 and 19 years

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SUMMARY

The epiphyseal plates of cartilage of ulna and radius is responsible for bone elongation, the fusion of their distal ends and bodies is used for age estimation. Variation exists due to many factors including ethnicity; accordingly, it is important to create a national profile for age determination using an affordable easy method. The aim of the work was to follow up the ossification of the lower end of the radius and the ulna in the Egyptian population between 12-19 years using X-ray, validating the use of Greulich and Pyle atlas. 197 subjects (103 males and 94 females) aged between 12-19 years were included. Skeletal age was determined using a plain X-ray on the lower end of the radius and the ulna comparing it to Greulich and Pyle's atlas, and also to chronological age.

In males, the mean of chronological age, skeletal age, and the difference between them were 15.35, 15.53 and +0.18 years respectively. In females, the ages were 14.77, 14.92 and +0.15. There was high correlation in all age groups. Examination of the lower end of the radius and the ulna is a suitable method for age detection in Egyptians between the ages of 12-19 years old.

Key words: Egyptian – Greulich and Pyle – Ossification – Radius and ulna – Skeletal age

INTRODUCTION

Like most of the upper limb bones, both the ulna and the radius develop from an intrauterine cartilaginous model, which is the precursor of the future bone. The cartilage is formed of chondrocytes and a collagen-rich matrix, and is surrounded by the perichondrium, formed of connective tissue (Hunziker et al., 2014). The innermost layer of the perichondrium differentiates into osteoblasts, which secrete bone matrix forming a perichondral bony collar around the cartilage model. At the same time, ossification starts within the body of the cartilage model by a primary ossifica-

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tion center leading to its transformation into bone (Hellings et al., 2016).

The primary ossification centers of both radius and ulna appear in the eighth week of fetal life. Unlike the proximal end of the ulna, which develops from two secondary centers of ossification, and the occasional radial tuberosity ossification center, the distal ends of both bones develop from a single secondary ossification center for each of them. Ossification begins in the distal end of the radius by the end of the first year of life. As regards that of the ulna, it appears as late as the fifth and sixth years in females and males respectively (Standring, 2020).

An epiphyseal plate of cartilage persists between the ossified body and ends. This cartilage is responsible for the longitudinal growth of the bone by chondrocyte proliferation and matrix secretion (Dupuis et al., 2019). The cartilage is gradually transformed into bone, thins with age, and is finally completely replaced by bone tissue (Blumer, 2021). The compromisation between cellular hypertrophy, removal of excess of unwanted tissues by apoptosis and autophagy regulate this process (Shapiro et al., 2005).

Broadly speaking, the fusion between the distal ends of both bones and their shafts begins in females at the age of thirteen or fourteen years, and in males at the age of fifteen or sixteen years (Hassan et al., 2016; Ottow et al., 2022). The distal ends of both bones completely fuse with their shafts at the age of the seventeenth year in females and the eighteenth to the nineteenth year in males. (Standring, 2020).

As expected, ethnic variation appears in the process of ossification. For example, using a five ossification-stage classification, Al-Khater et al. (2020) noticed an earlier appearance of ossification of the distal end of the ulna in females in the third year of life. Baumann et al. (2009) concluded that a complete union of the lower end and the shaft with a visible epiphyseal scar in the radius or the ulna in the males and the indiscernible scar in the female radius points to a fourteen-year-old subject or older, while the disappearance of the scar in the male radius proves that he reached the age of eighteen years.

Age estimation has always been a matter of interest in both medical and criminal cases. In pediatric practice, age estimation is important for the assessment of normal growth and the detection of any abnormalities (Gilsanz and Ratib, 2005). On the other hand, in different countries, abandoned individuals of unknown age, illegal age falsification at marriage, crimes and even sports competitions are not uncommon practices. Accordingly, there is an increasing demand for a reliable –yet affordable– method of age determination.

In 1959, Greulich and Pyle developed their famous Radiographic atlas of skeletal development of the hand and wrist. Despite the long duration, and because of its simplicity and rapid application, the atlas has been found to be more suitable for practice in comparison to other methods (Horter et al., 2012), the most used SA reference worldwide (Gilsanz and Ratib, 2005) and even figured as the ideal bone age detection method (Daneff et al., 2015).

Many trials have been made to assess the reliability of different methods of ossification detection and age determination using wrist scans. MRI (Tomei et al., 2014; Schmidt et al., 2014; Serin et al., 2016; Laor et al., 2016), CT scan (Ekizoglu et al., 2016) and Ultrasonography (Schmidt et al., 2013; Daneff et al., 2015; Hajalioghli et al., 2015) have been all examined. However, the relatively high cost of these methods has eliminated their use in developing countries.

Bone ossification, and accordingly SA estimation, may be affected by many genetic as well as environmental factors: race (Zhang et al., 2009), ethnics (Patil et al., 2012; Zabet et al., 2015), socioeconomic status (Schmeling et al., 2006), hormone levels (Kwon et al., 2017; Zhao et al., 2020) and nutritional habits (Nicholas et al., 2019) are all known to be important factors for variability in ossification and age estimation results. That is why it is important to provide a profile of a correlation between chronological age (CA) and skeletal age (SA) based on known individual ages.

The aim of the present work is to follow up the ossification of the lower ends of the radius and the ulna in the Egyptian population between 12-19 years using plain X-ray as an available, affordable, and easy method, exploring the coincidence between CA and SA, and to detect the correspondence of GP atlas in ossification and age determination in Egyptian population.

MATERIALS AND METHODS

197 healthy subjects (103 males and 94 females) aged between 12-19 years were included in the present study. Approval of this study was obtained from Institutional Ethics Committee. The subjects were outpatient individuals checking themselves after simple injuries. All the cases of fractures were excluded. A careful history was taken to exclude individuals with chronic diseases or developmental disorders. Their exact CA was obtained by identity proof, as well as written consent from the parents. The age range of the subjects (12-19) was detected to follow the process of ossification of the lower ends of the radius and the ulna from the beginning until its complete fusion (Serin et al., 2016); it also coincided with the maximum ages used in GP atlas (19 years in males and 18 years in females). The subjects were divided according to their age into 7 groups in males and 6 in females, each consisting of a chronological year (12-12.99, 13-13.99, etc.) (Table 1).

As earlier reports insured the absence of significant difference in bone maturation of both wrists (Hackman and Black, 2012), and to harmonize with most of the previous studies, an anteroposterior plain X-ray was done on the left forearm and hand. The left side is often frequently used due to the larger number of right-handed persons, making it more vulnerable to injury. The X-ray were obtained in October 6 University hospital – Giza – Egypt.

The fusion of the epiphysis of the lower ends of the ulna and the radius was inspected. SA was concluded using GP atlas, which consists of a series of standard plates to compare the examined radiograph with the most similar item in the atlas. This was considered the SA of the radiograph. In some cases, the examined X-ray inset between two plates specified the age of the radiograph, which was considered a fairly practice (Greulich and Pyle, 1959).

The same investigator examined all the X-ray films twice two weeks apart. Corresponding results were directly included in the research. Those who did not match (11 cases) were re-examined after two weeks, and they matched one of the previous results. Each time, the CA of the subject and the previous results were hidden. This protocol was previously used by Safer et al. (2015).

The SA was then compared to the CA of the subject, and the results were analyzed using Statistical Package for the Social Science computer software (SPSS, version 20.0, SPSS Inc., Chicago, IL, USA).

RESULTS

This study was conducted on 197 subjects (103 males & 94 females) ranging between 12 and 19 years old. The results were arranged according to the CA groups and compared with the estimated SA according to GP atlas (Figs. 1-2). The differences between both values were calculated, where the positive values indicate that the mean of the SA exceeds the CA, while negative values indicate delayed SA compared to CA.

Table 1. Showing the age intervals groups, and the number of subjects of each interval.

Males		Females	
Age	**No**	**Age**	**No**
12 – 12.99	18	12 - 12.99	18
13 – 13.99	14	13 - 13.99	20
14 – 14.99	10	14 - 14.99	14
15 – 15.99	21	15 -15.99	13
16 – 16.99	14	16 - 16.99	16
17 – 17.99	11	17 - 17.99	13
18 -18.99	15		
Total	**103**	**Total**	**94**

The mean of the CA in males was 15.35 (12.08-18.87) years, whereas the mean of the SA was 15.53 (11-19), with a mean difference between them + 0.18. There was a low heterogeneity with no statistically significant differences in all age groups (P <0.05). The mean difference between the CA and SA ranged between -0.07 years (between 13-13.99 years old) to +0.38 years (between 17-17.99 years old) (Table 2 and Fig. 3).

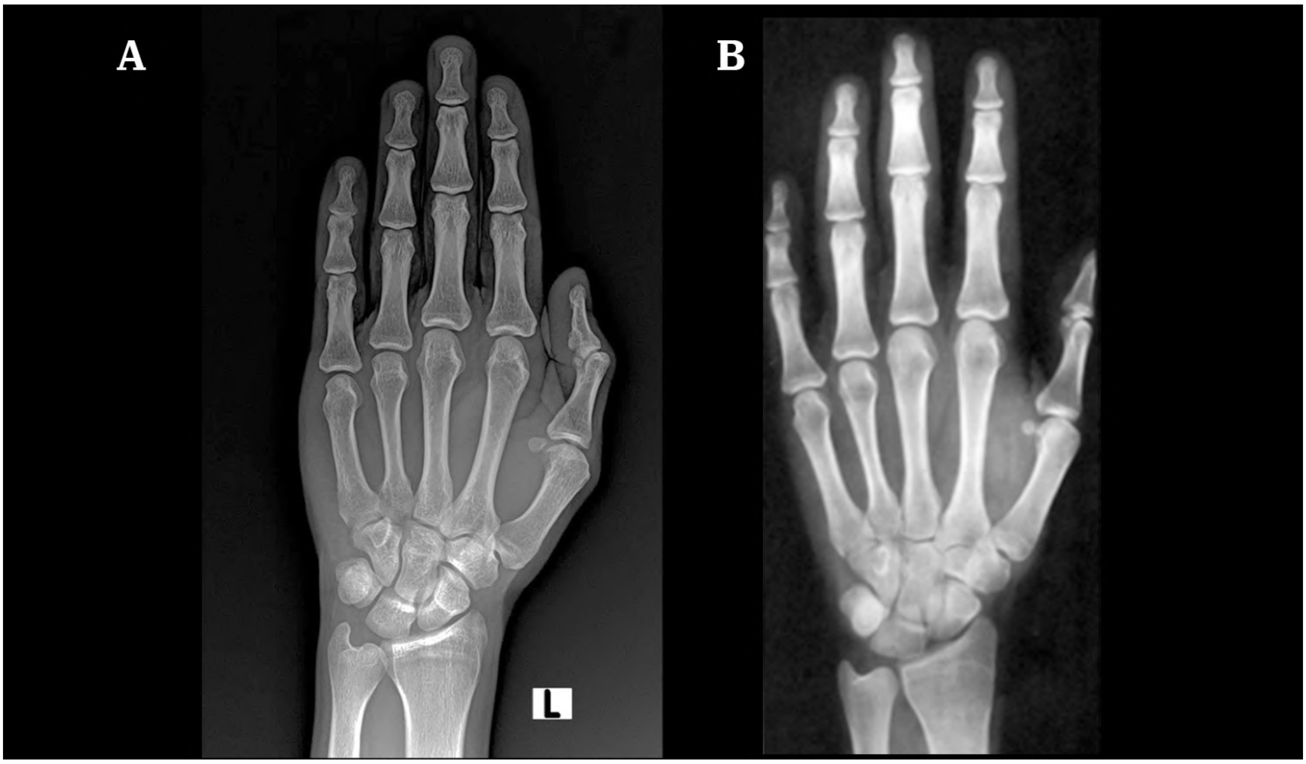

Fig. 1.- A) Hand radiograph of a male subject (CA= 12.13 years) matched with **B)** male standard 22 image in GP atlas (SA= 12.5 years).

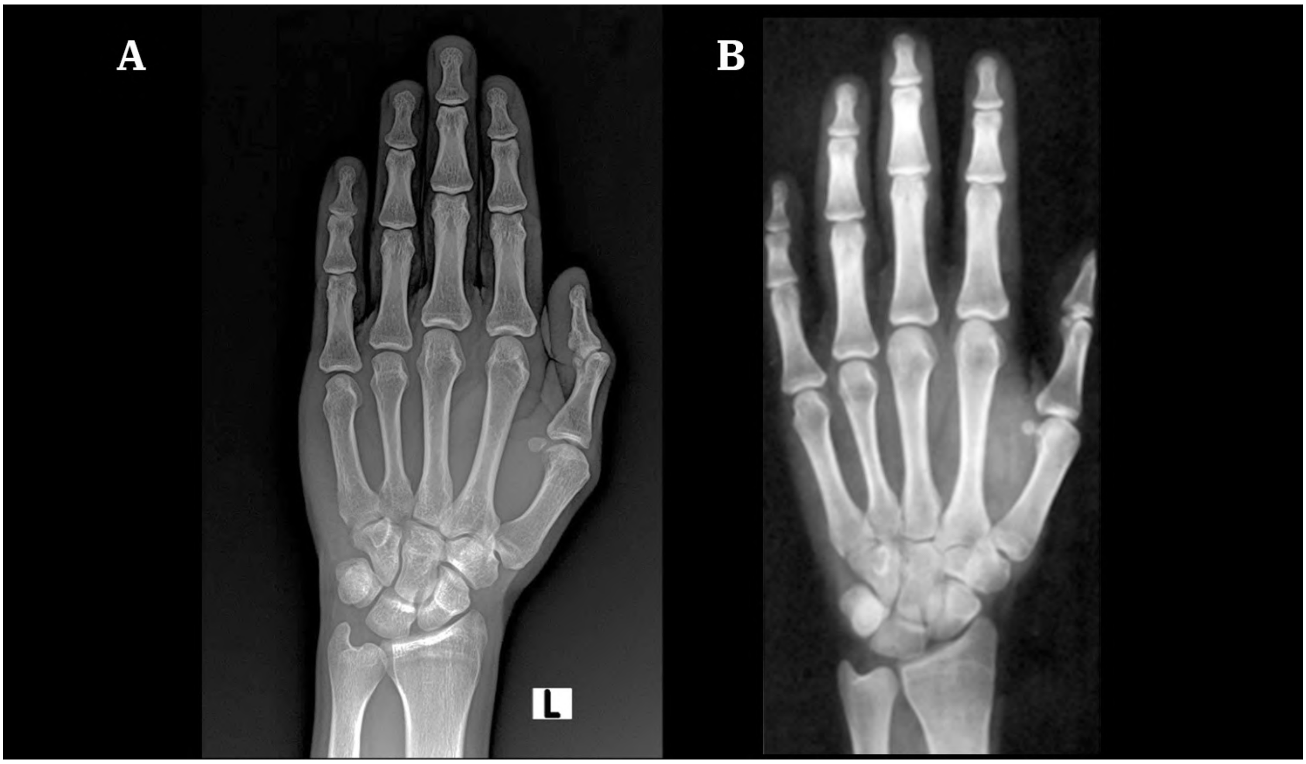

Fig. 2.- A) Hand radiograph of a female subject (CA= 16.23 years) matched with **B)** female standard 26 image in GP atlas (SA= 17 years).

The mean of CA in females was 14.77 (12.13-17.82) years and the mean of their SA was 14.92 (11-18) years, with a mean difference between them + 0.15. Again, no statistically significant differences were found in any age group (P <0.05). The mean difference between the CA and SA ranged between -0.08 years (at 13-13.99 years old) to +0.28 years (at 16-16.99 years old) (Table 3 and Fig. 4).

Table 2. Mean, standard deviation, minimal and maximal CA and SA and difference between them in different age groups in males.

Age	No	CA				SA				SA-CA	
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
12 – 12.99	18	12.44	0.38	12.08	12.83	12.58	0.84	11.00	14.00	+ 0.14	0.24
13 – 13.99	14	13.50	0.68	13.15	13.88	13.43	0.76	12.00	15.00	- 0.07	0.40
14 – 14.99	10	14.50	0.72	14.24	14.90	14.60	0.84	13.00	16.00	+ 0.1	0.56
15 – 15.99	21	15.46	0.46	15.03	15.91	15.60	0.86	14.00	17.00	+ 0.14	0.74
16 – 16.99	14	16.47	0.52	16.12	16.94	16.71	0.91	15.00	18.00	+ 0.24	0.62
17 – 17.99	11	17.48	0.56	17..16	17.82	17.86	0.95	16.00	19.00	+ 0.38	0.58
18 -18.99	15	18.40	0.64	18.09	18.87	18.77	0.42	18.00	19.00	+ 0.37	0.47
Total	**103**	**15.35**	**2.03**	**12.08**	**18.87**	**15.53**	**2.27**	**11**	**19**	**+ 0.18**	**0.65**

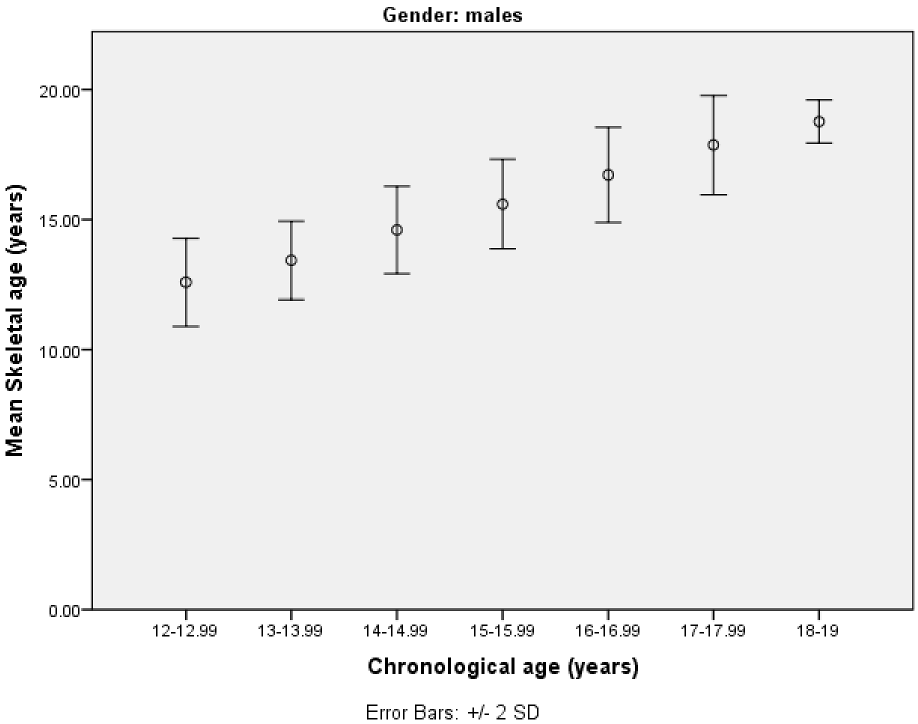

Fig. 3.- Error bar showing the mean and standard deviation of CA and SA in different age groups in males.

Pearson Correlation between CA and SA showed a highly significant positive correlation in both males and females (r = 0.96 in males and 0.95 in females, P <0.001 in both groups). The linear regression model of variables showed that SA significantly affect occurrence of CA by O.R. 0.96 in males and 0.96 in females (Figs. 5-6). The accuracy of the GP atlas in age determination was assured by the 95% confidence interval between the CA and SA in both groups (0.810-0.907 in males and 0.810-0.907 in females), both results were highly significant (P<0.001) (Figs. 7-8). Average measures of interclass correlation coefficient (ICC) indicated a high agreement between the CA and SA. Average measures ICC is calculated the same way Cronbach's alpha and is almost equal to it. It is, however, reliable to use a single measure instead of both as seen by single measures values.

DISCUSSION

In the present study, there was a high degree of agreement between the CA and SA detected based on the GP atlas, in Egyptian males between 12-19 years, and females between 12-18 years old. The SA is highly comparable to the CA in earlier ages, with more variance in later ages. All age groups

Table 3. Mean, standard deviation, minimal and maximal CA and SA and difference between them in different age groups in females.

Age	No	CA				SA				SA-CA	
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
12 - 12.99	18	12.45	0.12	12.13	12.86	12.58	0.73	11.00	14.00	+ 0.13	0.35
13 - 13.99	20	13.46	0.56	13.08	13.84	13.4	0.94	12.00	15.00	- 0.08	0.43
14 - 14.99	14	14.46	0.69	14.02	14.93	14.71	0.83	13.00	16.00	+ 0.25	0.52
15 -15.99	13	15.55	0.52	15.18	15.89	15.69	0.85	14.00	17.00	+ 0.14	0.65
16 - 16.99	16	16.50	0.51	16.06	16.91	16.78	0.80	15.50	18.00	+ 0.28	0.56
17 - 17.99	13	17.41	0.43	17.12	17.82	17.65	0.47	17.00	18.00	+ 0.24	0.42
Total	**94**	**14.77**	**1.75**	**12.13**	**17.82**	**14.92**	**1.97**	**11.00**	**18.00**	**+ 0.15**	**0.64**

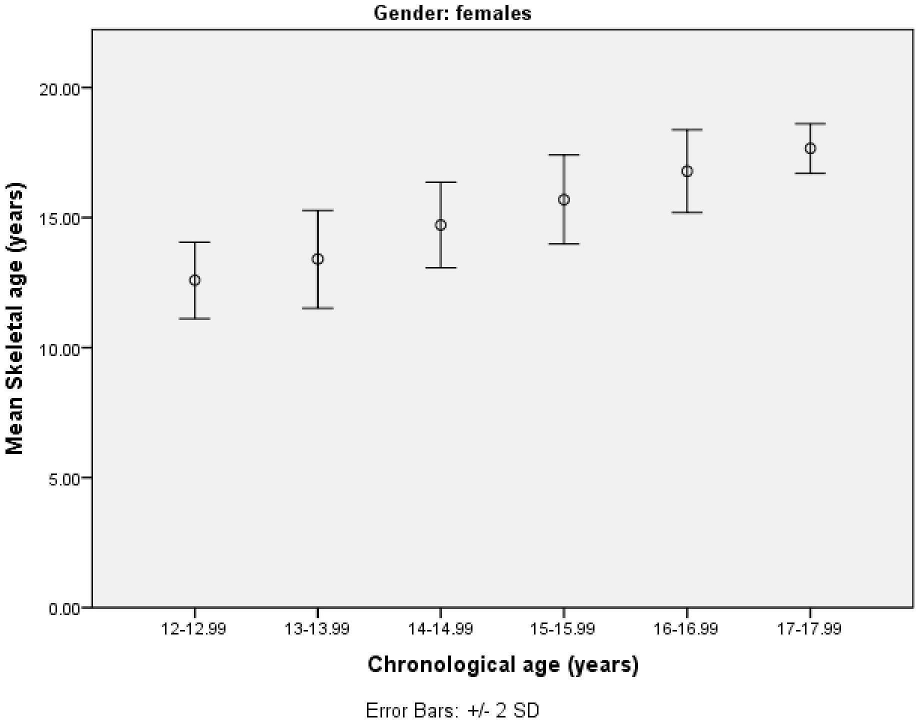

Fig. 4.- Error bar showing the mean and standard deviation of CA and SA in different age groups in females.

showed a preceding SA in comparison to the CA, except for the age 13-13.99 years in both males and females. Although the difference was slight and statistically non-significant, it points to a pattern in the Egyptian population.

To reach a convenient method for age estimation, many researchers have examined the lower ends of the radius and the ulna, which is easy to evaluate even by a non-radiological physician (Kaplowitz et al., 2011). Kaplan (1990) has proved the exceptional advantage of the examination of distal ends of the radius and the ulna over that of the hand bones. Serin et al. (2016) deduce that examination of the distal end of the radius only evenness the examination of the distal epiphyses of the radius, ulna, and the base of the first metacarpal.

Significant variation was ascertained in the evaluation of the applicability of GP atlas as an age determination method. In relation to CA, Koc et al. (2001) have reported a delayed SA in Turkish boys between 7-13 years old and an advanced relation between 14-17 years. However, the unisex appraisal and the less specific evaluation using a pubic hair correlation have been criticized. Supportively, Buken et al. (2007) found a more than

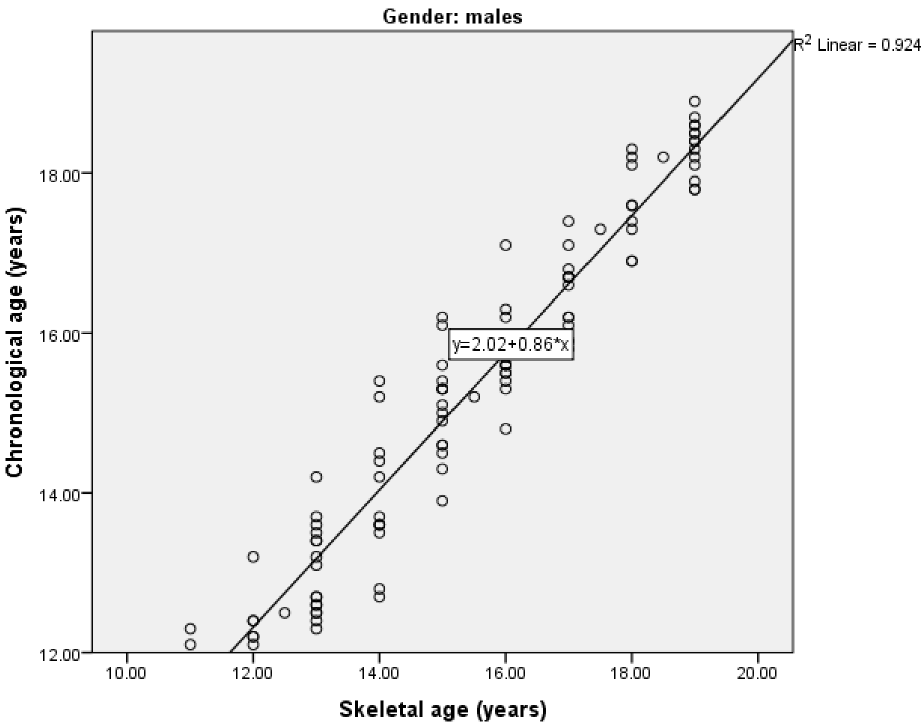

Fig. 5.- Scatter plots representing correlation line between CA and SA in males.

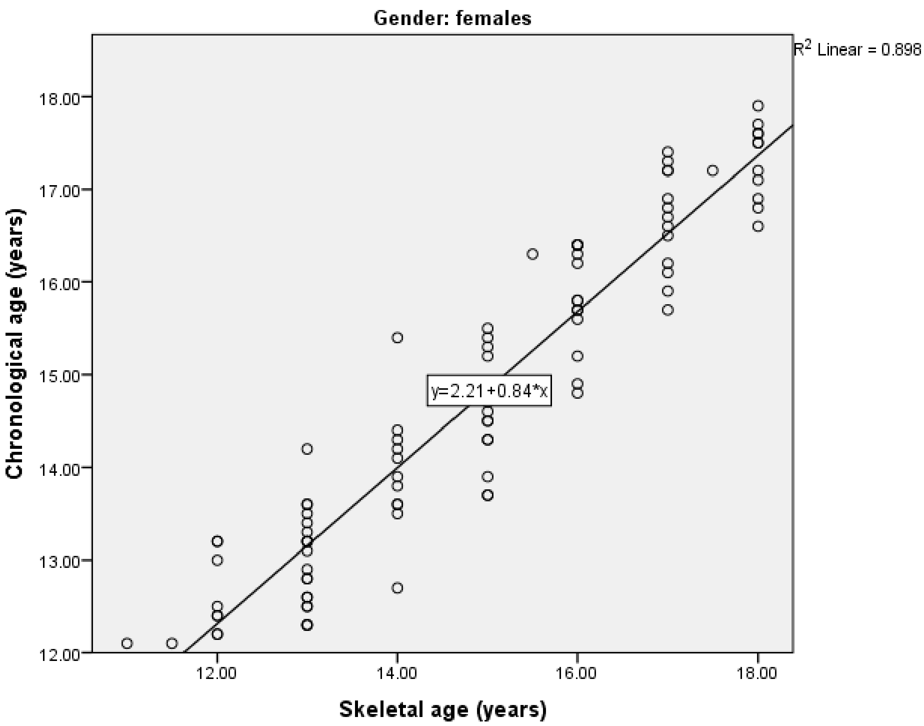

Fig. 6.- Scatter plots representing correlation line between CA and SA in females.

one-year standard deviation at 12 and 15 years of age for girls, and 12, 15 and 18 years of age for boys in the Turkish population, eliminating the criticism directed to the former study. On the other hand, Patil et al. (2012) denied the applicability of GP atlas in Indian children, and found a retarded SA of 0.7 and 0.33 years in males and females respectively.

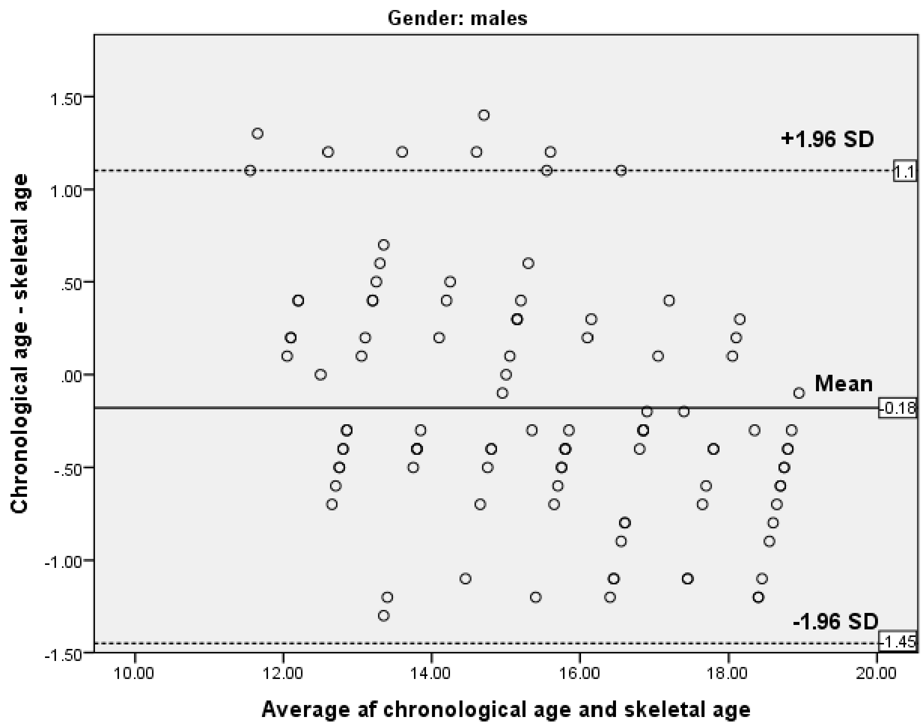

Fig. 7.- Bland Altman Plot showing variability in measurement between CA and SA among males. The line at the middle represents the mean difference and the upper and lower lines represent the upper and lower limits of 95% Confidence interval (CI).

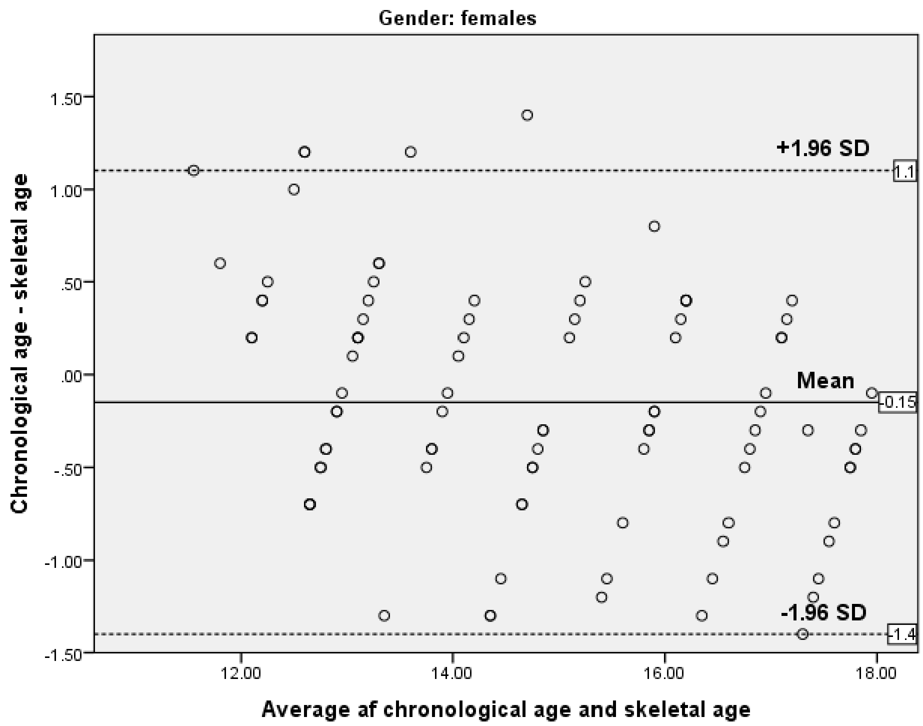

Fig. 8.- Bland Altman Plot showing variability in measurement of CA and SA among females. The line at the middle represents the mean difference and the upper and lower lines represent the upper and lower limits of 95% CI.

In a study concerning the Iranian population, the SA of males was 4.5 months less than CA, and it was 0.5 month more than it was in females. Considering the few months' difference, the authors considered the GP atlas as an applicable method with an acceptable accuracy (Moradi et al., 2012). On the other hand, Zhang et al. (2009) found a significantly overestimated bone age in both male and female Asian and Hispanic subjects. They appeared to mature sooner than their African-American and white study-fellows. In contrast, Mansourvar et al. (2014) found a strong correlation between Caucasians and Hispanic and a non-applicability in African-American and Asian groups.

Hackman and Black (2013) and Zabet et al. (2015) found that the GP atlas can be applied to a modern Scottish and French population respectively. However, the later pointed to a tendency for this method to overestimate age. On the other hand, Nang et al. (2023) found that GP atlas underestimates age in east Malaysia.

This variation was not surprising. The fashioning of the GP atlas has no doubt included a larger number of radiographs, with the selection of the most centralized ones. With the known ethnic variation, it will be much easier to evaluate the age of different ethnicities. The reliability of GP atlas in the determination of age in Caucasians has been proven (Moradi et al., 2012; Hackman and Black, 2013; Mansourvar et al., 2014; Zabet et al., 2015), as well as in the present study. That is why, in our consideration, the Egyptian dominant Caucasian ethnicity and other variants and mixed ethnicities (African, Middle Eastern, Mediterranean, Arabic) showed less variation and more reliability with the GP atlas than other countries.

The dose range of a wrist radiograph is 0.003-0.005 mSv. This dose poses minimal risk and is considered negligible (Safer et al., 2015). The risk for a fatal cancer development caused by this dose is 1 in 5,460,000 (Cross et al., 2003). However, to overcome the ethical dilemma of the cumulative radiological hazards (Eikvil et al., 2012; Daneff et al., 2015), it is better to allocate the conventional X-ray in age determination for single uses in forensic and medico-legal cases. Other methods with less hazardous radiological effects seem to be more convenient in repetitive and follow up cases.

Considering the propitious results obtained from the present study, it can be assumed that the GP atlas is a reliable way for age determination in the Egyptian population at the examined ages. GP atlas, although old, has been regarded as the golden standard for bone-age estimation (Daneff et al., 2015), it is even applied as a reliable reference to other methods of age estimation (Lee et al., 2021). Despite that, the use of SA estimation to assume the CA in legal cases as an age of consent and criminal responsibility must take in consideration the variability and lack of complete accuracy, and must add other methods of assessment (Serinelli et al., 2015). The subjective evaluation as well as personal, ethnic, racial, and even socioeconomic variations limit the complete reliance on this method alone. This limitation is not confined to the present work, but rather to all radiological methods. Adding a physical, dental, and psychological examination may aid to the accuracy of age detection (Willems 2001; Mesotten et al., 2002; Benson and Williams, 2008; Kumari et al., 2022) and fulfill the guidelines for the estimation of the biological age of living individuals (Schmeling et al., 2008).

The present work is, to our knowledge, the first study concerning the comparison between the CA and SA using the GP atlas in the Egyptian population. In such a case, further studies with a larger number of individuals with different socioeconomic status and different methods of scanning are required to extract an affirmed profile.

CONCLUSION

Examination of the lower end of the ulna and the radius is a suitable method for age detection of Egyptian males between the ages of 12-19 years old and females between 12-18 years old. Using a plain X-ray of the left wrist region for that purpose appears as an easy and affordable method. The reliance on GP atlas as a cushy, trustworthy -although old- way should not be discouraged. However, the repeated examination should be performed using other methods with less hazardous radiological effects. Due to the presence of personal variations, such an examination should be used in forensic, medico-legal, and criminal cases with extensive prudence.

DECLARATIONS

Authors contribution

Conceptualization, Ahmed F. AlDomairy and Radwa M. Elsabban; Methodology, Ahmed F. Al-

Domairy, Tamer T. Farag, Manar A. Eldesouky and Radwa M. Elsabban; Validation, Mohamed A. Yehia; Formal Analysis, Yasmine H. Eisa; Investigation, Mahmoud M. Assem; Data Curation, Ashraf Kotb; Writing – Original Draft Preparation, Ahmed F. AlDomairy; Writing – Review & Editing, Ashraf Kotb, Radwa M. Elsabban; Supervision and Project Administration, Ahmed F. AlDomairy. All authors shared the literature search, revised and commented on previous versions of the manuscript and approved the final manuscript. They all agree to be personally accountable for their own contribution and for the accuracy and integrity of all parts of the work.

Institutional Review Board Statement and Compliance with Ethical Standards

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of October 6 University (protocol code PRC-Me-2105013 4- 5-2021).

Consents and privacy rights

A written informed consent was obtained from the parents of the subjects included in this study. The privacy rights of the subjects were preserved.

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