Using ultrasound as an accurate method of determining bone age: A safe method specially in young athletes

Mehdi Karami[1] Reza Khaleghnejad Tabari[2]* Fatemeh Karami[1]

[1]Department of Diagnostic Radiology, Isfahan university of Medical science, Isfahan, Iran

[2]Pediatric Surgery Research Center, Research Institute for Children Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran

*Address for Corresponder: Dr. Reza Khaleghnejad Tabari, Pediatric Surgery Research Center, Research Institute for Children Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran (email: Khaleghnejadr@gmail. com)

How to cite this article:

Karami M, Khaleghnejad Tabari R, Karami F. Using ultrasound as an accurate method of determining bone age: A safe method specially in young athletes. Iranian Journal of Pediatric Surgery 2017; 3(2): 69-77.

DOI: htt://dx.doi.org/10.22037/irjps.v3i2.19087

Abstract

Introduction: Bone age determination is used in situations such a migration and sports. Radiography, MRI and ultrasound are different methods of determining bone age. This study was designed to evaluate the effectiveness of ultrasound in determining bone age in 14 -18 year olds.

Materials and Methods: One hundred male and 100 female students between 14 and 18 years of age were evaluated. The thickness of the epiphysis of the left distal radius in the ventral, dorsal and lateral views, were measured.

Results: In the females most of the growth plates were closed and the rest were inconclusive therefore ultrasound cannot be used in females in this age group. In the males, a minimum thickness of 0.7mm in dorsal and 0.8mm in ventral view in 14 and 15 year olds can be used to differentiate them from the 16 and 17 year olds. A maximum thickness of 1.6mm in dorsal and 1.1mm in ventral view can be used to differentiate 16 and 17 year olds from 14 and 15 year olds. Finally a maximum thickness of 0.8mm in the dorsal view can be used to differentiate 17 year olds from 16 year olds and younger.

Conclusion: Bone age determination via sonographic evaluation of the distal radius is an easy, fast and radiation free method that if confirmed by future studies can be used to differentiate 15 and younger from 16 and older boys. Ultrasound cannot be used to differentiate 14 to 18 year old girls.

Keywords

- Bone age
- Skeletal age
- Ultrasound
- Sonography
- Distal radius
- Growth plate

received: 8 August 2017

accepted: 30 September 2017

ISSN 2423-5067

Introduction

Bone age is important for diagnosis and management of endocrine disorders and evaluating patient's response to treatment. [1] Other uses of bone age are in legal procedures for determining reliability and the individual's age in cases of asylum seekers.

Since deceitful chronological age reporting is considered a major problem in youth sport, increasing trends towards scientific means of determining the accurate age in underage sport events are shaping; [2]such as bone age determination which is used to prevent participants from cheating. [3,4]

The dilemma of determination of precise age in athletes participating in youth sport competitions has been undertaken by the International Olympic Committee and a review was published. [5] It mainly pinpointed the personal differences in maturation among different athletes during the puberty and adolescent period and showed that age determination methods have considerable limitations. [6]

There are several methods of determining bone age by today's technology. Radiography, magnetic resonance imaging and ultrasonography have all been used, with different sensitivity and specificities.

Greulich and Pyle method (G&P) is by far the most commonly used method in clinical practice. This method is used by 76% of pediatricians.[7] In this method an x-ray of the patients left wrist is taken and matched with the representative radiographs of the same sex and age. [8] Another method that uses wrist x-rays is the Tanner and Whitehouse method (TW2). This method uses twenty regions of interest. Each region is scored and together a maturity score is given that estimates the skeletal age.[1] TW2 is more flexible and accurate than G&P but more difficult and time consuming. [9] The difference of these methods and the individual's chronological age is minor but not significant. [1-13]The down side is the ionizing radiation.

Magnetic resonance imaging is another method used for bone age determination. In this method the extent of fusion of the distal radius is scored separately into six classes and individuals are categorized accordingly. [10, 12] Drawbacks of MRI are cost and unavailability.

In recent years with advent of new and more sensitive ultrasound devices, sonography has been used to determine patients bone age. Sunlight bone age system estimates skeletal bone age using the velocity of sound waves which pass through the distal radial and ulnar epiphysis. This method requires a specific device and the results in some studies showed not so high a correlation with the x-ray based methods. [13, 14, 15]

Another use of ultrasound was to measure the width of growth plate of different bones. The hip, iliac bone and radius have been used with promising results. Cost -effectiveness and worldwide availability of ultrasound and the lack of ionizing radiation, makes it an appealing option to replace the radiation based methods. Of course ultrasound also has limitations. Preliminary results have shown different positive and negative predictive values. [16, 17, 18]

In our study, we decided to further evaluate the effectiveness of ultrasound based methods in a larger and more diverse socioeconomic group of

older children, where the accuracy of this method seems to be least.

Materials and Methods

Two hundred children between the ages of 14 and 18 from 4 different high schools in Isfahan where selected (100 boy and 100 girls). To minimize the effect of different socioeconomic and ethnic groups on the result, the high schools were chosen from different neighborhoods.

Also to eliminate potential underlying endocrine diseases which might affect growth such as disorders of the pituitary, thyroid and adrenal glands that affect height, weight and pubertal development, the individuals selected were between 25 and 75% of normal body weight and height for their age group. Two radiology residents performed the exams by measuring the width of growth plate in distal radius without knowing the child's chronological age. The epiphyseal plate of the distal radius of the left hand was measured in the ventral, dorsal and lateral aspect in the thickest view. Patients with a history of fracture in the distal left radius were eliminated. The study was performed using a high frequency linear probe.

Results

In this study 100 male students and 99 female students were evaluated. The mean age of male students was 14.9 (SD=1.0) and the female students was 15.5 (SD=1.2). **Table 1** shows the frequency of closure of the epiphyseal plate according to sex and age and **Table 2** shows the mean thickness of the epiphyseal plates in different views according to sex.

Table 1- Frequency of closure of the epiphyseal plate according to sex and age

		Male (100 cases)		Female (99 cases)	
		n	%	n	%
Dorsal	y/o 14	0	0.0	5	20.0
	15y/o	1	2.9	7	28.0
	16y/o	1	9.1	15	62.5
	y/o 17	4	36.4	23	92.0
	Total	6	6.0	50	50.5
Lateral	y/o 14	0	0.0	5	20.0
	15y/o	1	2.9	7	28.0
	16y/o	1	9.1	16	66.7
	y/o 17	3	27.3	25	100.0
	Total	5	5.0	53	53.5
Ventral	y/o 14	0	0.0	5	20.0
	15y/o	1	2.9	7	28.0
	16y/o	1	9.1	15	62.5
	y/o 17	5	45.5	25	100.0
	Total	7	7.0	52	52.5

Table 2- Mean thickness of the epiphyseal plates in different views according to sex

	Male		Female	
	Mean	SD	Mean	SD
Dorsal	13.1	6.0	3.6	4.1
Lateral	13.7	6.5	3.5	4.2
Ventral	13.1	6.4	3.4	4.0

Considering the age of the female participants and closure of the epiphyseal plate in more than 50% of the girls and the broad distribution of the remaining female participants (**Table 1**), further statistical analysis was not possible and therefore determining the age of 14 to 18 year old girls using the growth plate of distal radius utilizing our data is not possible.

In male students, we achieved the following results:

1. The maximum and minimum thickness of the growth plate of distal radius measured by sonography in 14 and 15 years old males are the same and therefore cannot be used as a cut off to differentiate 14 from 15 year olds.
2. The minimum thickness of the growth plate in the lower age groups that is 14 and 15 year olds in the dorsal view is 0.7mm and in the ventral view is 0.8mm, in other words it can be said that if the thickness of the growth plate in a male teenage is less than these value, he is 16 years or older.
3. The maximum thickness for differentiating the higher age group of 16 or 17 year olds in the dorsal view is 1.6mm and in the ventral view is 1.1mm, that is if the growth plate in a teenage boy is more than the mentioned values, he is 15 years or younger.
4. The maximum thickness of the growth plate for 17 year olds in the dorsal view is 0.8mm, which means that if the growth plate thickness in a teenage boy is more than 0.8mm, he is 16 years or younger.

In this regard, 27 male students had borderline results, thus determining their age group was not possible. Indices of diagnostic accuracy of sonography in determining bone age in high and low male age groups after eliminating the indeterminate individuals is shown in **Table 3**.

Table 3- Diagnostic accuracy of sonography in determining bone age in high and low* male age groups (n=73) **

Index	%	95% confidence interval
Sensitivity	98.3	99.9-90.8
Specificity	100	78.2 – 100
Accuracy	98.6	92.6 – 99.9
PPV (Positive Predictive Value)	100	93.7 – 100
NPV (Negative Predictive Value)	93.8	69.8 – 99.8

*14 and 15 year olds are low age group and 16 and 17 year olds are high age group
** 27 male students had indeterminate results and were eliminated

Discussion

Radiologic determination of bone age is used in various medical and legal applications and is also used for determining the accurate age of young athletes aged 15 to 16 years; participating in international football matches [19, 20] and cricket [21] competitions. MRI of distal epiphysial fusion of radius has also been used for this purpose. [22, 23]

Although sufficient enough for medical purposes, in legal issues and sports, the low accuracy of the classic methods of using radiography for bone age determination (G&P and TW2) are not acceptable. This is beside the obvious fact that ionizing radiation itself, is harmful and is not justified for screening purposes. According to recent studies even low doses of Ionizing radiation can actually increase the risk of cancer especially in children which is more the reason to be avoided in youth sport. [24, 25] Therefore we decided to investigate the use of an alternative method for determining bone age.

Lack of ionizing radiation in sonography in respect to radiography creates an opportunity for a more thorough evaluation although operator dependency is a downside, on the other hand the radiographic method of Greulich and Pyle is fast which limits the exposure of the wrist to radiation, and is easy to utilize.

Up to now studies evaluating bone age determination by ultrasound have been limited. In this regard sonography of the iliac crest and comparing it with radiography in patients with scoliosis [16] and an ultrasound version of G&P atlas [15] have been studied. Also measuring the thickness of the cartilaginous portion of the head of femur with US to determine the bone age has been proposed by Castriota and De Micheli. [18] It has been shown that there is a reverse correlation between the cartilage thickness and the patient's actual age. Although researchers have succeeded in establishing an acceptable statistical relation between the patient's age and the cartilage thickness of the anterior femoral head, using correlation coefficient for clinical measurements can be misleading and comparison of difference in measurements is more accurate. [26] Their next study [27] showed that the method of using the anterior femoral head cartilage in fact had a low accuracy and therefore could not be proposed for clinical use. It is important to mention that they used patients with various skeletal abnormalities that had been referred as a study group and normal individuals were not included, an important factor that may have had a major impact on the results.

Using the Sunlight Bone age device is another method of determining bone maturity via ultrasound that utilizes the velocity of ultrasound wave passing skeletal tissue. Transmission velocity of ultrasound in cartilage tissue is 1700m/s, which almost doubles in bony tissue. [13] With gradual increase in the volume and density of the growth plate, the transmission velocity of the waveform through the tissue increases. Although the preliminary study by Mentzel et al [13] was promising, Khan and colleagues [28] showed that using this method cannot be a reliable alternative to the present radiographic techniques, even without considering the high price of the device.

Continuing the efforts to eliminate radiography as a method that utilizes ionizing radiation, MRI has been suggested for age determination in recent years. In their studies, Dvorak et al [18, 26] showed that by imaging the wrist of young individuals, their age can be estimated accurately. In their first study

[18], Dvorak and his colleagues imaged the physical plate of the distal radial bone of the left hand in the coronal plane with MRI and graded the degree of its fusion from I to VI. Grade I being a completely unfused growth plate and grade VI being a completely fused plate. The studied population was 14 to 19 year old football players from 4 different countries who were not participating in any tournament. The result was then compared to their official documents. The result showed that as the grading of fusion increased so did the mean age of the young football players and there was a high correlation between age and grade of fusion ($p< 0.001$).[18] In their second study, they evaluated professional soccer players participating in U17 international tournaments. They found that the number of football players with the two highest degree of fusion (grade V and VI) was considerably more than age related normal non athlete population.[26] In the first competition, 15 to 27% of all under 17 year old participants were completely fused. After announcing to the teams that MRI evaluation would be performed, the frequency of grade V and VI in younger players decreased. In this study, despite what was expected, there was no significant correlation between the grade of fusion in the athletes and their age ($p=0.13$). [26] The authors could not clearly explain the reason for these results, sighting that cheating may be a factor. Although not proven 100% accurate, at present FIFA has chosen MRI instead of x-ray as the routine method for bone age determination in international competitions.

Other studies were performed on the ossification of the clavicle. [29,30] Hillewig et al used a 1.5T MRI with a 4 min protocol in 11 to 30 year old healthy individuals, and by creating high resolution images were able to determine the bone age more easily and with higher frequency than conventional radiography.

As a result of these studies, the preliminary success of MRI and the inadequate results of ultrasound based methods; it appeared that the direction of further research for a radiation free method of determining bone age would be mostly based on MRI.

Despite this fact, taking into consideration the high cost and low accessibility of MRI and the new state of the art ultrasound units, with higher spatial resolution than MRI, sonography still remains a tempting, at least primary choice. Also comparing the current methods in use (MRI of growth plate of distal radius with sonography) might be an interesting future study in this subject.

To our understanding, our present study is the first to evaluate the accuracy of sonography in bone age determination using the cartilage thickness of distal radius in male and female individuals. In accordance to previously mentioned studies, our results also show that sonography, except in certain age groups; cannot be an appropriate method of determining bone age in adolescents especially in girls. Because the growth plates close in a younger age, measuring the cartilage thickness of distal radius in 14 to 17 year old girls is not useful in bone age determination in this age group, other than the obvious fact that an open growth plate indicates that the individual is under 18 years of age. Of course ultrasound could still be used to determine age in younger females.

Still, using a certain set of criteria (a minimum of 0.7 mm in the dorsal and 0.8mm in the ventral view and a maximum of 1.6mm in dorsal and 1.1mm

in ventral view) we were able to distinguish with high accuracy 15 year old and younger from 16 year old and older boys. For those individuals that filled both the maximum and minimum criteria, the sensitivity was 98.3% and the specificity was 100%. Using these criteria, sonography can be used as a diagnostic tool eliminating the need for any further study. Of course for achieving criteria with such high accuracy, 27% of the boys in these age groups had to be reported as indeterminate. These 27% were those that with one criterion would be considered less than 15 years and with the other over 16 years. In this group, ultrasound could only be used as a screening tool and alternative methods such as MRI is required for definitive results. Regarding this matter sonographic evaluation of the bone age can be used in two concepts, diagnostic and screening. In the matter of measurements with definite results such as differentiating 15 from 16 year old boys, ultrasound can be used as a diagnostic method, whereas in those age groups where an indeterminate or non diagnostic result has been accomplished via sonographic screening, the individual can be referred for an MRI study, giving that MRI would be accepted as a definite diagnostic method by the ordering body.

In interpreting the results of our research, it should be pointed out that unlike previously mentioned studies, our participants were all healthy individuals not patients who required evaluation due to growth abnormalities. These include a heterogeneous spectrum of disease that result in various forms of abnormal epiphyseal closure, thus interfering in sonographic measurement. This difference in patient selection can be the cause of their failure and our success.

The same as any other clinical use of ultrasound, measurement of the cartilage thickness of distal radius is also operator dependent. Although in our study, we did not evaluate the intra and inter observer variations, but the study by Castriota et al [31] in measuring the thickness of the femoral head cartilage showed that in this regard sonography has enough precision for clinical practice. Despite this fact it is our understanding that this issue must be addressed in future studies.

Also in our study we intentionally used a portable device to demonstrate the overall efficiency of it, so that it could be utilized in almost every scenario, mostly athletic competitions in underdeveloped countries. Obviously using a nonportable high definition ultrasound device would result in more accurate criteria.

Conclusion

Bone age determination via sonographic evaluation of the distal radius is an easy, fast and radiation free method that if confirmed by future studies can be used to differentiate 15 and younger from 16 and older boys. Ultrasound cannot be used to differentiate 14 to 18 year old girls.

Acknowledgments

Acknowledgments: We would like to thank Dr Nasibeh Khaleghnejad Tabari for her valuable Knowledge in English Litrature and Dr Ali AliAsgari for his precious input regarding statistical accuracy of our study.

Competing Interests

There were none.

Funding

The deputy for research of Isfahan University of Medical Sciences

References

1. Zhang A, Gertych A, Liu BJ: Automatic bone age assessment for young children from newborn to 7-year-old using carpal bones. Computerized Medical Imaging and Graphics 2007;31(4):299-310.
2. Malina RM: Skeletal age and age verification in youth sport. Sports Medicine 2011;41(11):925-47.
3. Mokone T: Poverty no excuse for cheating. News24.com, accessed: July the 27th 2004.
4. Kwenaite T: Little cheats: who to blame. The Star 1998;26.
5. Engebretsen L, Steffen K, Bahr R, et al: The International Olympic Committee Consensus Statement on age determination in high-level young athletes. British journal of sports medicine 2010;44(7):476-84.
6. Malina R M, Pen˜a Reyes M E, Figureueiredo A J, et al: Skeletal Age in Youth Soccer Players: Implication for Age Verification. Clin J Sport Med 2010;20:469–474.
7. Giordano D, Spampinato C, Scarciofalo G, et al: An automatic system for skeletal bone age measurement by robust processing of carpal and epiphysial/metaphysial bones. IEEE Transactions on Instrumentation and Measurement 2010; 59(10):2539-53.
8. Greulich WW, Pyle SI: Radiographic atlas of skeletal development of the hand and wrist. The American Journal of the Medical Sciences 1959;238(3):393.
9. Dvorak J, George J, Junge A, et al: Application of MRI of the wrist for age determination in international U-17 soccer competitions. Br J Sports Med 2007;41:497–500.
10. Johnston FE: The use of the Greulich–Pyle method in a longitudinal growth study. Am J Phys Anthropol 1971;35:353–357.
11. Dvorak J, George J, Junge A, et al: Age determination by magnetic resonance imaging of the wrist in adolescent male football players. Br J Sports Med 2007;41:45–52.
12. King DG, Steventon DM, O'Sullivan MP, et al: Reproducibility of bone ages when performed by radiology registrars: an audit of Tanner and Whitehouse II versus Greulich and Pyle methods. Br J Radiol 1994;67:848–851.
13. Mentzel HJ, Vilser C, Eulenstein M, et al: Assessment of skeletal age at the wrist in children with a new ultrasound device. Pediatric radiology 2005;35(4):429-33.
14. Shimura N, Satomi K, Osamu A, et al: Assessment of measurement of children's bone age ultrasonically with sunlight Bonage. Clin Pediatr Endocrinol 2005; 14:17-20.
15. Bilgili Y, Hizel S, Altan Kara S, et al: Accuracy of Skeletal Age Assessment in Children From Birth to 6 Years of Age With the Ultrasonographic Version of the Greulich-Pyle Atlas. J Ultrasound Med 2003;22:683-690.
16. Wagner UA, Diedrich V, Schmitt O: Determination of skeletal maturity by ultrasound: a

preliminary report. Skeletal Radiol 1995; 24:417–420.

17. Nessi R, Garattini G, Zaffaroni R, et al: Ultrasonography assessment of ossification foci of the wrist and pubertal growth spurt [in Italian]. Radiol Med (Torino) 1997; 94:43-46.

18. Castriota-Scanderbeg A, De Micheli V: Ultrasound of femoral head cartilage: a new method of assessing bone age. Skeletal Radiol 1995;24(3):197-200.

19. CNN Sports Illustrated. ‘‘Cheating does not pay’’: Asia bans teams, players for over-age infractions. 2001. http://sportsillustrated.cnn.com/ soccer/news/2001/05/10/Asia. Accessed June 14, 2001.

20. Tritrakarn A, Tansuphasiri V: Roentgenographic assessment of skeletal ages of Asian junior youth football players. J Med Assoc Thai 1991;74: 459–464.

21. Asian Cricket Council. U-15 ACC elite age-verification results issued. 2007. http://www.asiancricket.org/h_1207_u15eageverification. cfm. Accessed January 15, 2008.

22. Dvorak J, George J, Junge A, et al: Application of MRI of the wrist for age determination in international U-17 soccer competitions. Br J Sports Med 2007;41:497–500.

23. Fe´de´ration Internationale de Football Association. FIFA to introduce MRI screening at Nigeria 2009 to combat the fielding of over-age players. 2009. http://www.fifa.com/u17worldcup/news/newsid=1096817.html. Accessed September 22, 2009.

24. Orchard JJ, Orchard JW, Grenfell T, et al: Ionising radiation: three game-changing studies for imaging in sports medicine. Br J Sports Med 2014;48 (8).

25. Forster BB: The game has changed…but it still needs to be played: the role of imaging tests using ionising radiation in the practice of sports medicine. Br J Sports Med 2014;48(8).

26. Bland JM, Altman DG: Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1(8476):307-10.

27. Castriota-Scanderbeg A, Sacco MC, Emberti-Gialloreti L, et al: Skeletal age assessment in children and young adults: comparison between a newly developed sonographic method and conventional methods. Skeletal Radiol 1998;27(5):271-7.

28. Khan KM, Miller BS, Hoggard E, et al: Application of ultrasound for bone age estimation in clinical practice. J Pediatr 2009;154(2):243-7.

29. Schmidt S, Mühler M, Schmeling A, et al: Magnetic resonance imaging of the clavicular ossification. Int J Legal Med 2007;121(4):321-4.

30. Hillewig E, De Tobel J, Cuche O, et al: Magnetic resonance imaging of the medial extremity of the clavicle in forensic bone age determination: a new four-minute approach. Eur Radiol 2011;21(4):757-67.

31. Castriota-Scanderbeg A, De Micheli V, Scarale MG, et al: Precision of sonographic measurement of articular cartilage: inter- and intraobserver analysis. Skeletal Radiol 1996;25(6):545-9