Methods Used in Computer-Assisted Bone Age Assessment of Children

Sema Aydoğdu and Fatih Başçiftçi

Abstract—For many years, various studies have been conducted to determine methods to identify the age of living persons. Nowadays, the method most commonly used for the identification of age is bone age assessment. Bone age assessment is a method that is very frequently used in forensic cases and by child development specialists. However, the decision process in these assessments depends on the observations of a specialist; hence, the assessment results may vary from one specialist to another. The purpose of automatic assessment with computers is to render the decision process more objective, and to consequently allow more consistent results to be obtained. Studies in this area have drawn considerable attention to automatic assessment methods, especially following the developments in the area of image processing. In the current study, the Greulich-Pyle (GP) and the Tanner-Whitehouse (TW) methods used in computer-assisted bone age assessment were presented, and information was also provided regarding the automation of these methods.

Index Terms—Bone age assessment, Greulich-Pyle method, Tanner-Whitehouse method, TW3.

I. INTRODUCTION

In medicine, the identification of bone age is used for the diagnosis, follow-up and treatment of diseases and endocrine disorders. It is also important in judiciary cases for establishing whether individuals are adults and have legal capacity. For example, Turkish laws and regulations divide individuals into different age groups from both a legal and penal perspective. Depending of the nature of the crime, a sentence or penalty may vary according the age group of the perpetrator. It is especially important to determine whether the individual in question is at least 7, 12, 15, or 18 years of age [1], [2].

In growing individuals, the bone age is the most commonly used criterion of biological growth and age. Bone age assessments are based on studying the stages of growth associated with skeletal development through the evaluation of hand and wrist radiographies. The level of skeletal maturity can, essentially, be determined based on two characteristics: The level of growth in areas undergoing ossification, and the level of calcium accumulation in those areas. From infancy to adulthood, these two characteristics follow a certain and specific pattern and timeline [3].

Studies performed from the beginning of the 20th century to the present have made use of left hand and wrist radiographies

for assessment purposes. There are certain advantages associated with using only the left hand instead of both hands. In particular, using one hand reduces both the cost of procedures and the person's exposure to radiation by half. The fact that the left hand has lower chances of experiencing accidents and injury due to the higher prevalence of right-handedness in most societies, and the fact that researchers performing the initial studies on bone age assessment preferred using the left hand are the leading reasons why the left hand is employed in bone age assessments. In the International Agreement for the Unification of Anthropometric Measurements to be made on Living Subjects, prepared during the Physical Anthropologists Congresses held in Monaco in 1906 and in Geneva in 1912, the decision was made that assessments on living persons should be performed on the left side of the body. In previously conducted studies, it was determined that differences between the two sides of the body were sufficiently minor, such that they would not lead to errors in the assessment of skeletal development [4].

II. METHODS USED FOR BONE AGE ASSESSMENT

A. Greulich-Pyle Method

There is currently no standard clinical method for the identification of bone age. The two methods most commonly used today are GP and TW methods.

The method developed by Greulich and Pyle is based on matching hand and wrist radiographies with the most similar and compatible sample on the GP atlas, and accepting the bone age of the selected sample as the actual bone age of the examined case [5]. The standards determined by Greulich and Pyle consist of two standard templates, developed between 1931 and 1942 from the hand and wrist radiographies of white, upper-middle class male and female children included in the Brush Foundation Growth Study. The standard templates developed for male children consist of 31 radiography images covering the growth stages between 0 and 19 years of age, while the standard templates for female children consists of 27 radiography images covering the growth stages between 0 and 18 years of age.

The reason the template series were developed separately for female and male children is related to the fact that bone growth and development displays gender-related differences. When performing assessments according to the GP atlas, the first step involves the selection of the applicable template series based on gender. The radiography samples in this template series are then compared with the radiographies of the evaluated case. The atlas also describes the characteristics

Manuscript received June 15, 2013; revised October 16, 2013.

S. Aydoğdu is with the Fatih Technical High School, Konya, 42003 Turkey (e-mail: sema_ayd@hotmail.com).

F. Başçiftçi is with the Faculty of Technology, Selcuk University, Konya 42003 Turkey (e-mail: basciftci@selcuk.edu.tr).

to be examined during the comparisons between the radiographies. These comparisons are performed until the radiography that corresponds to the most to the studied case's radiography is found. Finding a 100% match is generally difficult. In such cases, the closest matching template radiography is selected.

B. Tanner-Whitehouse Method

The Tanner – Whitehouse (TW) method is based on obtaining a score for the relevant bones through a detailed structural analysis, and the sum of points assigned to the bones based on this analysis [6]. Bone analysis and scoring process are used to assign the examined bones to a previously determined growth stage.

As shown in the relevant figure (see Fig. 1), the bones that are subject to ossification analysis are the radius, the ulna, the short bones, and the carpal bones. For each stage of every bone, separate scores are used for female and male children. This assessment can be performed in two different ways: one approach is the use of the RUS score, which involves an assessment of the ulna and short bones; while the other approach is the use of the Carpal score, which involves and assessment of the carpal bones.

Fig. 1. Hand and wrist bones. Carpal bones: 1-Trapezium, 2-Trapezoid, 3-Capitate, 4-Hamate, 5-Triquetrum, 6-Lunate, 7-Scaphoid

Each stage that the epiphysis undergoes from birth until the completion of ossification is coded with a letter, which begins at A and continues until H or I. “A” describes the stage and period in which ossification has not yet begun in any of the epiphyses. H or I, on the other hand, describe full bone maturation.

During the evaluation of cases, the stages of all the relevant bones and the corresponding scores are determined with the aid of sample images and descriptions from the atlas. A total of 13 different RUS scores are determined by the sum of the scores assigned to the radius, ulna, and short bones; while 7 different carpal scores are determined by summing the scores assigned to the carpal bones. Each one of these scores are scaled between 0 (not visible) and 1000 (full maturation). The obtained RUS or carpal scores are then used to identify the examined case's bone age on RUS Bone Age or Carpal Bone Age tables, which are available in two separate versions for

female and male children [1].

The TW method was updated over the years to provide the TW2 and TW3 methods. The TW method's modular structure renders it suitable for automation; however, its complexity has caused it to become the least preferred method in manual assessments. The assessment process can take several minutes for an experienced radiologist, while a new and inexperienced radiologist may require much more time to complete the assessment. On the other hand, the GP method is far easier to implement due to its approach based mainly on comparisons of general appearance, which the human visual system is capable of performing quite rapidly. However, it is possible to state that the accuracy rate of this method rests more on the experience of the radiologist.

In a study conducted by King *et al.*, 50 bone age assessments were performed by 3 evaluators using both the GP and TW2 techniques [7]. In the study, the error margin was determined as 0.74 years for TW2, and as 0.96 years for GP. The average time spent on the assessments was 7.9 minutes for the TW2 method, and 1.4 minutes for the GP method.

The radiography samples in the GP atlas were developed based on the radiographies of American children; for this reason, the GP method is commonly used the United States of America. The TW method, on the other hand, was developed in the United Kingdom, and its use is preferred in Europe.

III. COMPUTER-ASSISTED BONE AGE ASSESSMENT SYSTEMS

Due to its modular structure, the TW method is more suitable and preferable for automation. For this reason, computer-assisted bone age assessment systems are generally based on imaging techniques that evaluate the extent of ossification in the carpal bones and the development of epiphyses on the phalanges.

Fig. 2. General procedure for computer-assisted bone age assessment system.

The different stages of computer-assisted assessments involve obtaining hand and wrist radiographies, the removal of any background and undesirable signals from the images, the separation and selection of the relevant area within the image, the identification of the relevant area's characteristics, and the use of comparisons for age identification. Fig. 2

demonstrates the general procedure for computer-assisted bone age assessment system.

Medical studies have indicated that due to the maturation of the carpal bones, it is not possible to clearly and conclusively identify the carpal bones in children older than 7-12 years of age [8]. The underlying reason for this is the overlapping of carpal bones that begin at the age of 7 years in male children, and at the age of 5 years in female children. After the age of 7 years, using the phalanges to analyze the development stage will yield more reliable results [9].

Fig. 3 demonstrates the growth pattern of carpal bones of Asian males from newborn to 7 year old. Carpal bones ossified in chronological order, Capitate, Hamate, Triquetral, Lunate, followed usually by Scaphoid, then either the Trapezium or the Trapezoid [9].

Fig. 3. Growth pattern of carpal bones of male children. The number represents the corresponding age group for each image.

Fig. 4. Metaphysis, Epiphysis and Diaphysis in a Phlange

In phalangeal analysis, development of epiphysis and metaphysis is monitored (see Fig. 4). Epiphyses usually ossify after birth. At the early stage of skeletal development the epiphyses are separated from the metaphyses. With increasing age, the bony penetration advances from the initial focus in all directions (see Fig. 5). In the later stage the gap between epiphysis and metaphysis starts disappearing and fusion begins. It continues until fusion is completed and one adult bone is found [10].

Fig. 5. Growth pattern of phalanges of male children. The number represents the corresponding age group for each image.

In the studies that have been conducted to date, the identification of the necessary characteristics (such as the boundaries of the bones) prior to bone age assessments was performed through the use of various methods. Pietka et al. in [11], proposed a method which used mathematical morphology for extracting objects from the thresholded image. A computer-aided system to estimate bone age based on Fourier analysis was assessed by reference to the original radiographs used to produce the Tanner-Whitehouse 2 (TW2) standards for the radius, ulna and short finger bones [12]. In Reference [10], an approach based on wavelet processing for extracting carpal bones that are fused is proposed. De Luis Garcia *et al.* proposed an algorithm for automatically detecting bone contours from hand radiographs using active contours [13]. Niemeijer *et al.* proposed a method that landmarks are detected using an Active Shape Model [14].

After the necessary characteristics were identified, Fuzzy Logic, the Artificial Neural Network, and Support Vector Regression methods were commonly used for assessing bone age and classification [15]–[17].

IV. CONCLUSION

Aside from hand and wrist radiographies, the identification of bone age can also be performed through the evaluation of teeth, elbow, shoulder, and pelvis radiographies, and the assessment of the numerous ossification centers in these areas [18], [19]. However, the use of hand and wrist radiographies has many advantages in comparison to the other areas, such as lower exposure to radiation, the use of a simple radiographic position, and the use of specific number of bones.

As bone development depends on many genetic and environmental factors, it is necessary to constantly update the data and related information on this subject, and to adapt these data and information according to present-day conditions and societies [1].

It may not be possible to determine bone age exactly to a specific day; however, an assessment that is close to the actual age, with only a difference of few months, can be achieved. We may encounter situations in which even a difference of 1 year in age is very important, especially in legal cases. For this reason, these studies are of greater importance for ensuring that the assessment procedures are performed more objectively and reliably; for ensuring that the assessments can be performed by an assisting program in case an expert is not available; and for ensuring that the assessment results can be obtained within a shorter frame of time.

ACKNOWLEDGMENT

This work is supported by Selçuk University Scientific Research Projects Coordinatorship, Konya, Turkey.

REFERENCES

- [1] M. Uzel, "Kemik yaşı belirlenmesi, sosyoekonomik faktörler ve beslenme ilişkilerinin incelenmesi," Ph.D. dissertation, Cerrahpasa Medical Faculty, Istanbul University, Istanbul, Turkey, 2002.
- [2] I. Sarıkardaşoğlu, *Adli Tıpta Ana Konular ve Örneklerle Rapor Yazma Tekniği*, Eskişehir: Anadolu Üniversitesi Yayınları, 1990, pp 141.
- [3] V. Gilsanz and O. Ratib, *Hand Bone Age*, Berlin, Heidelberg: Springer-Verlag, 2005.

- [4] S. Dreizen, R. M. Snodgrasse, H. Webb-Peploe, G. S. Parker, and T. D. Spies, "Bilateral Symmetry of Skeletal Maturation in The Human Hand And Wrist," *American Journal of Diseases of Children*, vol. 93, pp. 122-127, 1957.
- [5] W. W. Greulich and S. I. Pyle, *Radiographic Atlas of Skeletal Development of Hand Wrist*, Stanford, CA: Stanford University Press, 1959.
- [6] J. M. Tanner, R. H. Whitehouse, and W. A. Marshall, *Assessment of Skeletal Maturity And Prediction of Adult Height*, London-New York-San Fransico: Academic Pres, 1975.
- [7] D. G. King, D. M. Steventon, M. P. O'Sullivan, A. M. Cook, V. P. Hornsby, I. G. Jefferson, and P. R. King, "Reproducibility of bone ages when performed by radiology registrars: an audit of tanner and whitehouse II versus greulich and pyle methods," *Br. J. Radiol.*, vol. 67, no. 801, pp. 848-851, 1994.
- [8] F. E. Johnston and S. B. Jahina, "The contribution of the carpal bones to the assessment of skeletal age," *Am. J. Phys. Anthropol.*, vol. 23, pp. 349-354, 1965.
- [9] A. Zhang, A. Gertych, and B. J. Liu, "Automatic bone age assessment for young children from newborn to 7-year-old using carpal bones," *Comput. Med. Imaging Grap.*, vol. 31, pp. 299-310, 2007.
- [10] E. Pietka, S. Kurkowska, G. Arkadiusz, and F. Cao, "Integration of Computer Assisted Bone Age Assessment With Clinical PACS," *Comput. Med. Imaging Graph.*, vol. 27, pp. 217-228, 2003.
- [11] E. Pietka, L. Kaabi, M. L. Kuo, and H. K. Huang, "Feature Extraction in Carpal-Bone Analysis," *IEEE Trans. Med. Imag.*, vol. 12, pp. 44-49, 1993.
- [12] N. M. Drayer and L. A. Cox, "Assessment of bone ages by the tanner-whitehouse method using a computer-aided system," *Acta Paediatric Suppl.*, pp. 77-80, 1994.
- [13] R. de Luis-Garcia, M. Martin-Fernandez, J. Arribas, and C. Alberola-Lopez, "A fully automatic algorithm for contour detection of bones in hand radiographs using active contours," in *Proc. Int. Conf. Image Process.*, vol. 3, pp. III-421-III-424, 2003.
- [14] M. Niemeijer, B. van Ginneken, C. A. Maas, F. J. Beek, and M. A. Viergever, "Assessing the skeletal age from a hand radiograph: automating the Tanner-Whitehouse method," in *Proc SPIE (Medical Imaging 2002, Image Processing)*, pp. 1197-1205, 2002.
- [15] S.A. Fernandez, R. Garcia, M. A. M. Fernandez, and C. A. Lopez, "A computational TW3 classifier for skeletal maturity assessment. A computing with words approach," *Journal of Biomedical Informatics*, vol. 37, pp. 99-107, 2004.
- [16] J. Liu, J. Qi, Z. Liu, Q. Ning, and X. Luo, "Automatic bone age assessment based on intelligent algorithms and comparison with TW3 method," *Comput. Med. Imaging Graph.*, vol. 32, pp. 678-684, 2008.
- [17] K. Somkantha, N. Theera-Umpon, and S. Auephanwiriyakul, "Bone age assessment in young children using automatic carpal bone feature extraction and support vector regression," *J. Digit Imaging*, vol. 24, pp. 1044-1058, 2011.
- [18] S. Gök, N. Erdoğan, and C. Özen, *Adli Tıpta Yaş Tayini*, İstanbul: Adli tıp kurumu yayınları 2. Baskı, 1985.
- [19] R. Cameriere, L. Ferrante, D. Mirtella, and M. Cingolani, "Carpals and Epiphyses of Radius and Ulna as Age Indicators," *Int. J. Legal Med.* vol. 120, pp. 143-146, 2006.

Sema Aydoğdu received the B.Sc. degree in electronic and computer education from Selcuk University, Turkey, in 2007.

Since 2008, she has been an information technology teacher at Fatih Technical High School, Konya, Turkey and she is currently a M.Sc. student in department of electronic and computer education, Selcuk University. Her research interest includes

pattern recognition, image processing and fuzzy sets.

Fatih Başçiftçi received the M.Sc. degree in electronic and computer education and Ph.D. degree in electrical – electronics engineering from Selcuk University, Turkey, in 2000 and 2006, respectively.

He is currently an associate professor with the Faculty of Technology, Selcuk University, Turkey. He has coauthored more than 40 studies on national and international journals. His research interest includes programming languages, logic circuits, logic functions simplification methods, control circuits and distance education.