Opinion regarding the use of skeletal age determination technique to estimate chronological age.

For the Commonwealth Director of Public Prosecutions,
May 2011

My name is Dr Vincent Hock Seng Low. I am 53 years of age. From 17 January 2011 I have been employed as a Consultant Radiologist at the InSight Clinical Imaging Group, WA. Prior to this I was employed as the Head of the Radiology Department and then as a Consultant Radiologist at the Sir Charles Gairdner Hospital.

My medical qualifications and experience are:
1982 Bachelor of Medicine, Bachelor of Surgery (MBBS) University of Western Australia
1983 – 1985 Post Graduate Medical Experience
1986 – 1990 Specialized Radiology Qualification, including several months rotation at Princess Margaret Hospital WA looking at all aspects of paediatric radiology
1991 Completed radiological qualifications and admitted as full 'Fellow member' of the Royal Australasian College of Radiologists (FRACR). Clinical Fellowship in Diagnostic Radiology (Fluoroscopy, Ultrasound, CT, Interventional Radiology) with Professor Giles Stevenson at the McMaster University medical Centre, Hamilton, Ontario, Canada.
1991 – 1992 Clinical fellowship in gastrointestinal radiology (fluoroscopy) with Professor Igor Laufer at the Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania USA.
1992 – 1994 Consultant Radiologist, Department of Radiology, Sir Charles Gairdner Hospital, Nedlands WA
1994 – 2001 Assistant Professor of Radiology, Abdominal Imaging Section, Department of Radiology Duke University Medical Centre Durham, North Carolina, USA
2001 - 2009 Head of Radiology Department, Sir Charles Gairdner Hospital
2009 – 2011 Consultant Radiologist, Department of Radiology, Sir Charles Gairdner Hospital, Nedlands WA

I am a member of the following organisations:
1986 ÷ Member of Royal Australasian College of Radiologists
1991 ÷ Fellow of Royal Australasian College of Radiologist
1996 ÷ Member of Society of Gastrointestinal Radiologists
2001 ÷ Examiner, Medical School, University of Western Australia
2004 ÷ Member of European Society of GI & Abdominal Radiology
2005 ÷ Member of American Roentgen Ray Society

I have given evidence in the following court proceedings:

The determination of skeletal age is made by looking at the changes in the growth areas of the bones of the hand and wrist on x-ray. As background information, the bones of the human skeletal develop by a process of fusion of a number of smaller components known as growth centres. Where they fuse as the bones mature are known as growth plates. Changes are most pronounced across the years of puberty. As the subject matures, the various growth centres fuse at their growth plates in quite well defined timelines. This has been well studied and documented into reference books.

The reference book "Radiographic Atlas of Skeletal Development of the Hand and Wrist" by W.W. Greulich and S. I. Pyle ("the Atlas") is the standard guide by which such a determination is made. I refer to this reference book in order to determine the age of a subject. Age is determined by comparing the x-ray of the individual with the comprehensive studies in this text that have resulted in statistical standards of skeletal development. These standards are currently used worldwide, although they were developed from studies carried out in the United States and United Kingdom in the late 1950s. It was and remains to today the most exhaustive study of its kind with 6,879 radiographs and at least 100 cases of each age.

In males, skeletal maturity at the hand is reached at approximately 19 years of age. This means that at this point in time, all the growth plates have fused. Therefore the limit of determination by this technique is to say that the person is 19 years or older.

The two studies referred to in the Atlas done by the Brush Foundation and by Dr Harold Stuart of the Harvard School in Boston determined standard deviations in development of 13.05 months and 15.4 months respectively. Taking the larger standard deviation, this provides the following table of probabilities that a person showing skeletal maturity is the corresponding age or less:

Years of Age	% Probability ≤ this age
14	0
14.5	0.02
15	0.09
15.5	0.32
16	0.97
16.5	2.57
17	5.96
17.5	12.12
18	21.79
18.5	34.84
19	50

It needs to be recognized that there is no definitive test available that provides an absolutely accurate chronological age assessment. The best that can be done is to provide an estimated mean together with providing an indication of the possible age spread.

Are these standards determined over 50 years ago still relevant today?

- Greulich & Pyle is used today by radiologists in practice and research worldwide. I have personally communicated with colleagues throughout Australia and New Zealand, Canada, USA, United Kingdom and Sweden. In the East, colleagues in Lebanon, Saudi Arabia, India, Sri Lanka, Malaysia, Singapore and Japan use this standard.

- There has not been any professional recognition of a need to reassess the standards through fresh studies, because radiologists worldwide have not perceived any significant clinical changes in the rate of skeletal development.

- Anthropologically, 50 years is not enough time to see a change in skeletal development.

- Gilsanz & Ratib in their work and publication of 2005 studied 522 Californian Caucasian children and found no significant difference with the findings of Greulich and Pyle. They also found a standard deviation of 15.4 months at the age of maturity, identical with the Boston study of Greulich & Pyle. Therefore the findings of Greulich and Pyle from over 50 years ago remains relevant today.
(Gilsanz V, Ratib O. Hand Bone Age: A digital atlas of skeletal maturity. Springer-Verlag 2005)

What pathological factors are known to affect skeletal maturation?

- An *advanced* bone age (the bones look old for age, the subject is really younger than the radiograph suggests) occurs with pathological situations such as prolonged elevation of sex steroid levels, as in precocious puberty or congenital adrenal hyperplasia. The bone age is marginally advanced with premature adrenarche, when a child is overweight from a young age or when a child has lipodystrophy. Bone age may be significantly advanced in genetic overgrowth syndromes, such as Sotos syndrome, Beckwith-Wiedemann syndrome and Marshall-Smith syndrome.

- Bone maturation is *delayed* (the bones look young for age, the subject is really older than the radiograph suggests) with constitutional growth delay, growth hormone deficiency and hypothyroidism. The Atlas studies are based upon well-nourished subjects, whereas if the person were not well-nourished they may take longer to reach skeletal maturity than is predicted by the Atlas technique. This is the scenario which is an arguable possibility in the situation of Indonesian subjects from an unprivileged background. This would result in the radiographic technique underestimating the subject's age, he would actually be older than the age estimate suggests by the atlas method.

Are there significant racial differences in skeletal development?

Although there may be racial differences in skeletal size, the consensus amongst radiologists and clinicians in practice is that there is no known substantial change across races in skeletal development.

In the 1950's, Ohwada and Sutow studied healthy Japanese children in the Hiroshima area, finding significant skeletal retardation compared with the Greulich and Pyle standards. Studying Japanese children born and living in California, skeletal development was similar to the Caucasian reference. The implication is that environmental factors have a far greater effect upon skeletal development and maturation compared with genetic (ethnic) factors which may not have any measurable effect at all.
(Sutow WW. Skeletal maturation in healthy Japanese children, 6 to 19 years of age – comparison with skeletal maturation in American children. *Hiroshima Journal of Medical Sciences* 1953; 2: 181-191.)
(Sutow WW, Ohwada K. Skeletal standards of healthy Japanese children from age 6 to 19 years. *Clinical Pediatrics (Japanese)* 1953; 6: 738-746.)
(Greulich WW. A comparison of the physical growth an development of American-born and Native Japanese children. *American Journal of Physical Anthropology* 1957; 15: 489-491.)

In 1991, Tritrakarn and Tansuphasiri found the Greulich and Pyle standard to be a reliable and dependable guide for Thai youths.
(Tritrakarn A, Tansuphasiri V. Roentgenographic assessment of skeletal ages of Asian junior youth football players. *J Med Assoc Thai* 1991; 74: 459-464.)

In 1990, Chen et al found that the Greulich and Pyle standard could be used with confidence for the Malaysian population.
(Chen ST, Jee FC and Mohamed TB. Bone age of Malaysian children aged 12 to 28 months, *Journal of the Singapore Pediatric Society*, 1990; 32(3-4): 97-101.)

In 2000, Schmeling et al undertook a meta-analysis of the available research into this matter. The abstract of that paper serves as a pertinent summary to the question of ethnicity on bone age measurements:

"An x-ray of the hand is an important method in forensic science for estimotion of the age of juvenile suspects with uncertain dates of birth. Relevant x-ray standards for evaluation of skeletal maturity are available for white US Americans as well as for North and Central Europeans. The applicability of these standards to members of ethnic groups different from the reference population has been the subject of controversial discussion. More than 80 publications were analyzed with a view of finding out whether skeletal maturation is affected by ethnic identity. It was concluded that skeletal maturation takes place in phases which are identically defined for all ethnic groups. Time related differences in passing those stages of skeletal maturation within the relevant age group appear to be unaffected by ethnic identity. It is the socio-economic status of the given population which is of decisive importance to the rate of ossification. The application of x-ray standards to individuals of a socio-economic status lower than that of the reference population usually

leads to underestimation of the person's age. In terms of criminal responsibility, this is of no adverse effect on the person concerned."
(Schmeling A, Reisinger W, Loreck D, Vendura, Markus W and Geserick G. Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. *Int J Legal Med* 2000; 113(5): 253-258.
- cited in para.37 Federal magistrates Court of Australia, *Applicant Vfay v Minister for Immigration [2003] FMCA 289.)*

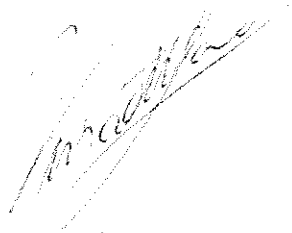
What is the impact of nutrition on skeletal development?

Dr Kevin Osborn (Secretary, ACT Branch, Royal Australian and New Zealand College of Radiologists) testified to the Australian Senate Legal and Constitutional Legislation Committee on 23 March 2001 and when asked by Senator Cooney 'Is diet a factor [with assessing bone age] responded:

"Very much so – nutrition is quite a big factor. Provided nutrition is adequate the standards are good. Where nutrition is significantly reduced, without doubt there will be delay in maturation. For any given chronological age the skeletal age will be younger than you expect. Nutrition will not cause increased maturation or early maturation. It will only make you tend to underestimate the chronological age rather than overestimate it."
(Dr Kevin Osborn (Secretary, ACT Branch, Royal Australian and New Zealand College of Radiologists) testimony to the Australian Senate Legal and Constitutional Legislation Committee on 23 March 2001, Reference Crimes Amendment (Age Determination) Bill 2001.)

CONCLUSION

The bone age test (Greulich and Pyle) is a valid tool for the limited evaluation of a subject's age as relates to the age of legal responsibility (18 years). The relevance of ethnicity on bone age testing can be discounted. Issues of socio-economic background and nutrition are factors that can influence the chronological age estimations. In the situation of subjects from less favourable backgrounds and poorer nutrition, the test would tend to be favourable to the subject (underestimate the subject's age).



Assoc. Prof. Dr Vincent Low, MBBS, FRANZCR
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