Original Article

Correlation between Chronological Age, Cervical Vertebral Maturation and Fishman's Skeletal Maturity Indicators in Southern Chinese

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ABSTRACT

Objective: To investigate the correlation between chronological age, cervical vertebral maturation (CVM), and Fishman's hand-wrist skeletal maturity indicators in southern Chinese.

Materials and Methods: Four hundred contemporary hand-wrist and lateral cephalometric radiographs of southern Chinese subjects were randomly selected and analyzed. The female subjects were between 10 and 15 years of age, and the male subjects were between 12 and 17 years of age; all subjects were within the circumpubertal period. The CVM was assessed using the method developed by Baccetti and coworkers, but the hand-wrist maturation was assessed using the method developed by Fishman. These two methods and the chronological age were correlated using the Spearman rank correlation analysis.

Results: The CVM was significantly correlated with the hand-wrist skeletal age (Spearman *r* male = 0.9206, female = 0.9363). All patients in the cervical maturation stage (CS3) of CVM were discovered to be in the skeletal maturational indicator (SMI2 or SMI3) stages of hand-wrist maturation (HWM), which was around the peak of the growth spurt. Low correlations were found between the CVM and chronological age (male $r = 0.7577$; female $r = 0.7877$) and between the HWM and chronological age (male $r = 0.7492$; female $r = 0.7758$).

Conclusions: CVM is a valid indicator of skeletal growth during the circumpubertal and has a high correlation with the HWM for the southern Chinese population. However, the low correlations found between the chronological age and both CVM and HWM showed that the chronological age was not suitable to measure skeletal maturity.

KEY WORDS: Cervical vertebral maturation; Hand-wrist maturation; Skeletal maturity; Chronological age

INTRODUCTION

The utilization of a functional appliance in the orthodontic field is the main treatment modality in the correction of mandibular hypoplasia.[1–3] The treatment depends on the modification of growth of the mandible and the maxilla.

In assessing the skeletal responses, both animal studies[4] and clinical studies[5] have found that dentofacial orthopedic appliance therapy could stimulate growth of the mandibular condyle,[6] and remodeling of the glenoid fossa.[4] The efficiency of these growth modifications depends on skeletal maturity.

Ruf and Pancherz[6] reported that the appropriate timing for growth modification was around the peak of the pubertal growth spurt, which corresponds to hand-wrist maturity stages, skeletal maturation indicator (SMI2 or SMI3) determined by Fishman.[7] The skeletal responses were less in subjects both before and after the maximal pubertal growth.[8,9] Therefore, a series of biologic indicators was used to assess growth spurts in order to determine the optimal timing for growth modification treatment. These methods included sexual maturation characteristics,[9–11] facial growth and peak height velocities, chronological age,[11] dental development,[12] body height[13,14] body weight,[14] and hand-wrist maturity.[7,8,15,16]

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Accepted: September 2007. Submitted: May 2007.

The hand-wrist radiographs have been used routinely in orthodontic clinics to assess the peak of the growth spurt.[16–18] However, there have been concerns about the additional radiation exposure of the hand-wrist radiographs. In addition, the British Orthodontic Society guideline[19] has stated that the use of hand-wrist radiographs to predict the onset of the pubertal growth spurt is not indicated.

Because of this radiation, the cervical vertebral maturation (CVM) in the lateral cephalometric radiographs was evaluated for its correlation to the skeletal maturity as an alternative to the hand-wrist radiograph.[20–24] One obvious advantage of using the CVM method is that the lateral cephalometric radiograph is routinely required for orthodontic diagnosis and treatment planning and, therefore, no extra radiograph is required.

However, this method is not sensitive in detecting the growth maturity in periods away from the growth spurt. Previous studies correlating the CVM method with skeletal maturity often included subjects with a wide age range, such as between 5 and 18 years.[22] This might affect the correlation coefficient obtained due to inclusion of subjects with skeletal maturity before or after the pubertal growth spurt.

Therefore, in this study we investigated the correlation between the CVM and hand-wrist maturity by only including subjects near or within the pubertal growth spurt, using the southern Chinese as a study population.

MATERIALS AND METHODS

Four hundred contemporary hand-wrist and lateral cephalometric radiographs of southern Chinese subjects (200 male, 200 female) were randomly selected from the record files at Prince Philip Dental Hospital, University of Hong Kong and analyzed.

The selection criteria of the radiographs were as follows:

- The radiographs were taken within the circumpubertal period; the female age range was 10 to 15 years, and male age range was 12 to 17 years;
- The bones should appear clearly and should have been unaffected by systemic disease;
- The interval between the hand-wrist and the lateral cephalometric radiograph should not exceed 1 month;
- The inferior border of the first four vertebrae was obvious;
- The hand-wrist radiograph was of the right hand.

The CVM was evaluated using the method developed by Baccetti and coworkers. This method depended on the anatomical changes of the three cervical vertebrae (C2, C3, and C4), which were evaluated visually concerning two sets of variables[24]: (1) the presence or absence of a concavity at the inferior border of the C2 (odontoid process), C3, and C4; and (2) the differences in the shape of the body of cervical vertebrae with the progressive ages, where four shapes were considered, namely trapezoid, rectangular horizontal, square, and rectangular vertical. These two variables were subdivided into six consecutive stages in cervical maturation (CS1 to CS6).

The hand-wrist maturation (HWM) of the same patient was evaluated using the Fishman method.[7] This method used four stages of bone ossification found at six anatomical sites located on the thumb, third finger, fifth finger, and radius. Eleven distinct adolescent skeletal maturational indicators (SMIs) are found on these six sites where the radius represented three growth events: the onset (ONSET), peak (PHV), and end (END) of the pubertal growth spurt. For every subject, the skeletal maturity (CS) obtained with CVM in the lateral cephalometric radiograph was correlated with the hand-wrist skeletal maturity obtained with Fishman SMI in the hand-wrist radiograph. In addition, these skeletal maturity indicators were also correlated with that patient's chronological age.

Statistical Analysis

The data of CVM and HWM were analyzed using statistics software (InStat version 3.00, GraphPad, San Diego, Calif). Spearman rank correlation coefficient (no assumption of normality of the samples) was used to determine the correlation between skeletal maturation stages obtained by the CVM method and skeletal maturational indicators obtained by the HWM.

Method Errors

The intraexaminer error was calculated for 25 patients (following protocol from a previous study).[8] Randomly selected lateral cephalometric and hand-wrist radiographs for both methods were evaluated by the investigator and then reevaluated by the same investigator after 3 weeks. Twenty-four of 25 interpretations were the same at the second examination. The interexaminer error was calculated using the same radiographs of the same 25 patients and reevaluated by another orthodontist. Agreement of the skeletal maturity indicator assessment occurred in 23 of 25 cases. The method error was insignificant. The Kappa statistic for concordance was 0.846 ($P < .001$). Cohen's kappa measures the agreement between the evaluations of two investigators when both are rating the same object. A value of 1 indicates perfect agreement. A value of 0 indicates that agreement is no better than chance. Kappa is available only for tables in which

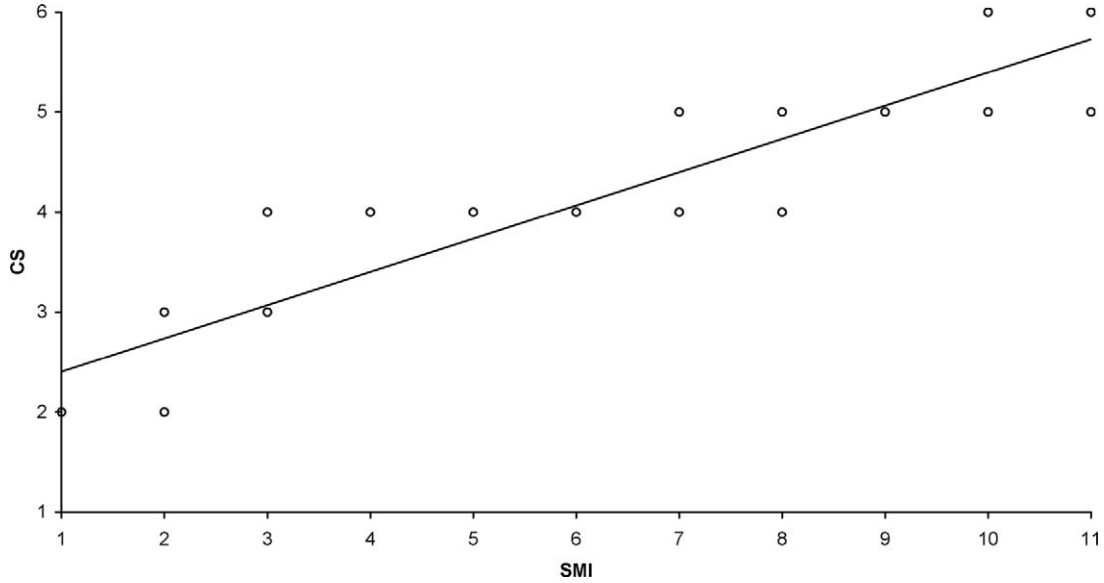

Figure 1. Correlation between CVM (CS) and HWM (SMI) in male subjects.

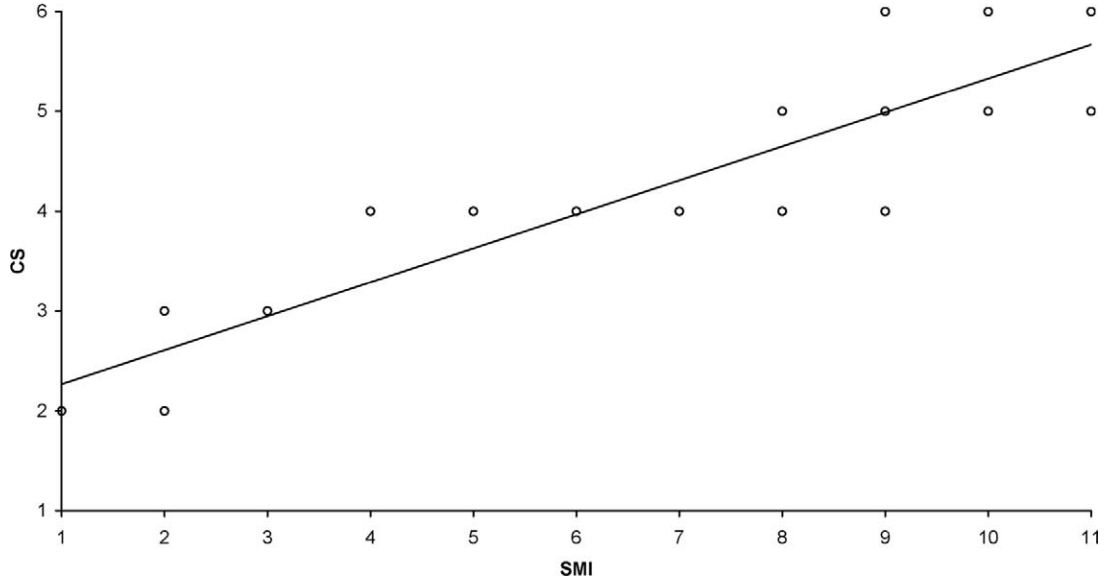

Figure 2. Correlation between CVM (CS) and HWM (SMI) in female subjects.

both variables use the same category values and both variables have the same number of categories.

RESULTS

Correlation between CVM (CS) and HWM (SMI), the CVM (CS) was significantly correlated with HWM (SMI) (Spearman r male = 0.9206, female = 0.9363). The correlation plot appeared linear. In all subjects investigated, the CVM stage CS3 corresponded to the HWM stages SMI2 (14 male, 6 female) and SMI3 (19 male, 23 female), which were around the peak of the growth spurt.

There was a linear relationship between the CVM (CS) and the HWM (SMI) in both male (Figure 1) and female subjects (Figure 2):

- For male subjects, $r = 0.9206$ and $r^2 = 0.8475$
- For female subjects, $r = 0.9363$ and $r^2 = 0.8767$

The number of subjects in each plot of the correlation is shown in Table 1.

Correlation Between CVM (CS) and Chronological Age

There was low correlation between the CVM (CS) and chronological age (Figures 3 and 4). The correlation plots appeared scattered widely.

Table 1. The Correlation Between Cervical Vertebral Maturation (CS) and Hand-Wrist Maturation (SMI) in Male and Female Subjects[a]

SMI	2	3	4	5	6	7	8	9	10	11
CS6								(2)	16 (15)	42 (36)
CS5						2	12 (3)	11 (23)	28 (37)	4 (5)
CS4		1	8 (7)	3 (1)	3 (3)	19 (19)	15 (15)	(1)		
CS3	14 (6)	19 (23)								
CS2	3 (4)									

[a] Cells contain the number of male subjects in a particular CVM stage and the HWM stage. The numbers in parentheses denote the number of female subjects. SMI indicates skeletal maturational indicator; CS, cervical maturation stage.

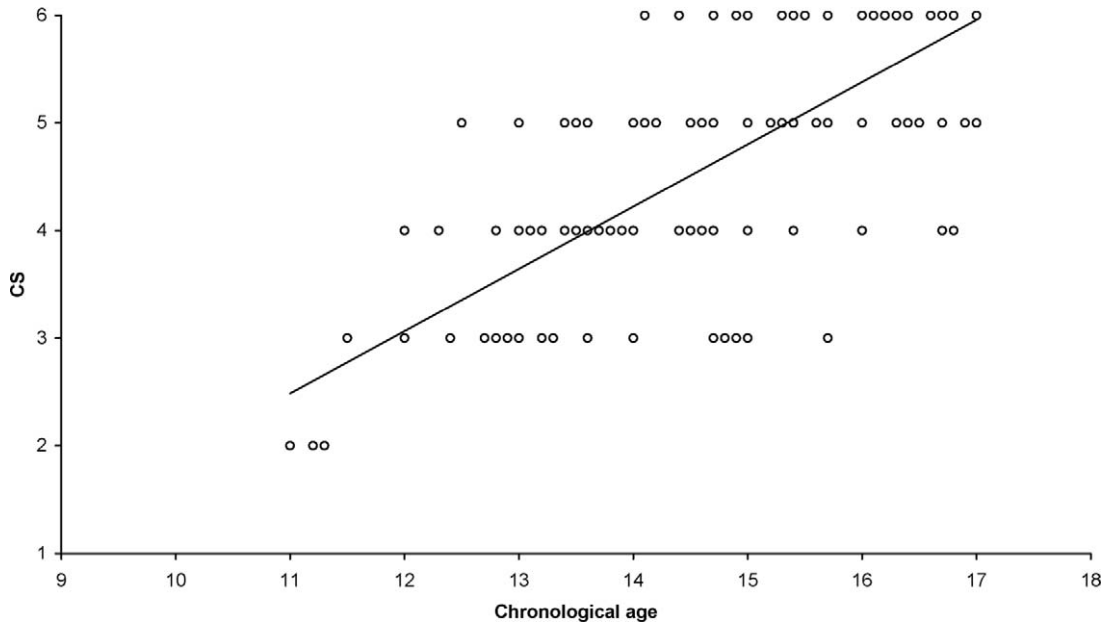

Figure 3. Correlation between CVM (CS) and chronological age in male subjects.

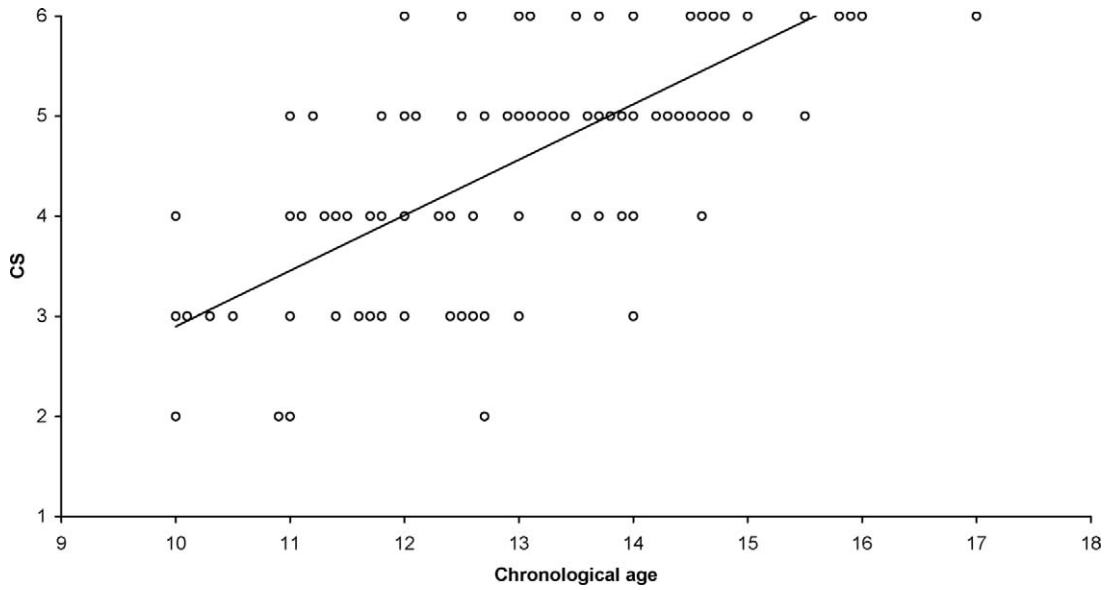

Figure 4. Correlation between CVM (CS) and chronological age in female subjects.

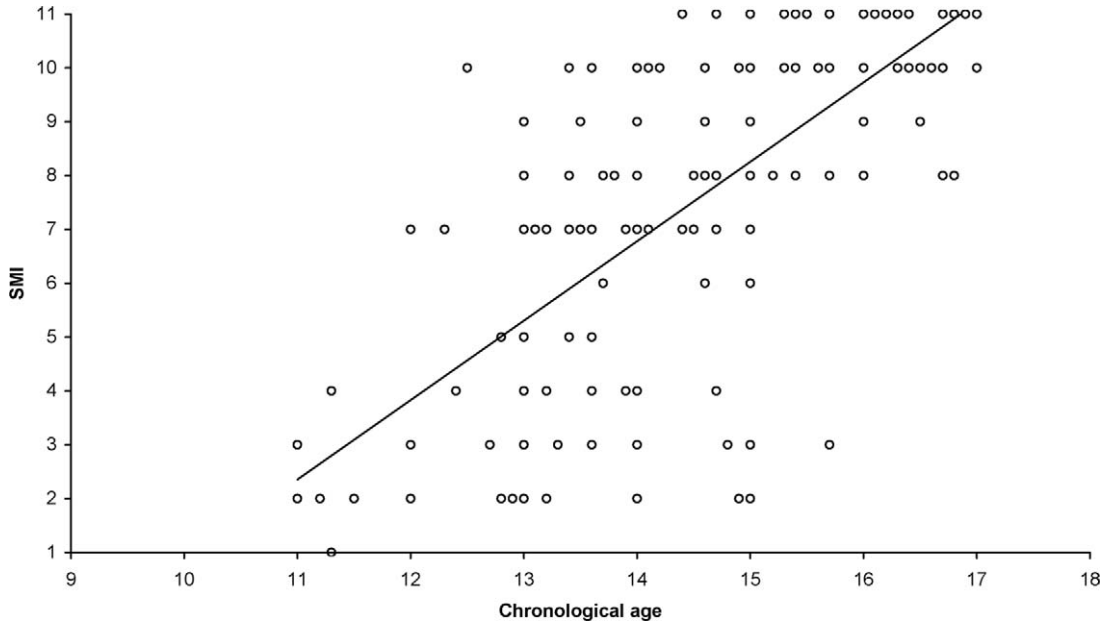

Figure 5. Correlation between HWM (SMI) and chronological age in male subjects.

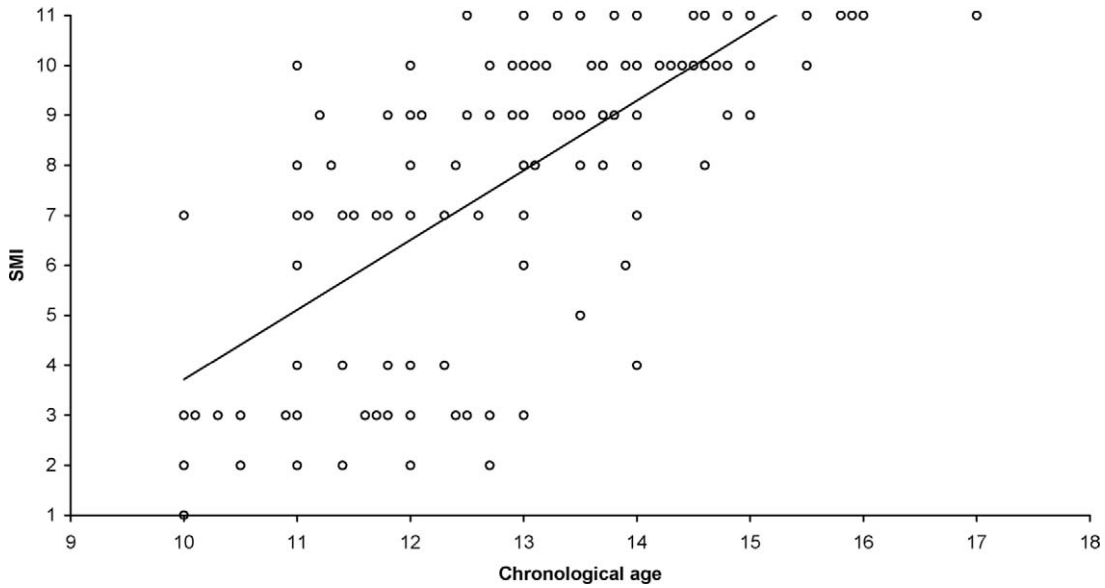

Figure 6. Correlation between HWM (SMI) and chronological age in female subjects.

- For male subjects, $r = 0.7577$ and $r^2 = 0.5741$
- For female subjects, $r = 0.7877$ and $r^2 = 0.6205$

Correlation Between HWM (SMI) and Chronological Age

There was little correlation between the HWM (SMI) and chronological age (Figures 5 and 6). The correlation plots appeared scattered widely.

- For male subjects, $r = 0.7492$ and $r^2 = 0.5613$
- For female subjects, $r = 0.7758$ and $r^2 = 0.6019$

DISCUSSION

In this study, both methods of skeletal maturity measurements were sensitive and precise in evaluating the maturity changes within this period. A wide age range of the population may affect the correlation result because of inability of skeletal maturity methods to detect changes in skeletal maturity precisely when the subjects are either too young or too old, ie, too far ahead of or too far past the pubertal growth spurt.

To ensure the subjects were within or close to the

circumpubertal period, different age ranges for different sexes were selected as subjects for this study. This is because of the difference in the onset of the circumpubertal periods between boys and girls.

The high correlation obtained between the CVM method and the HWM method in this applies to the southern Chinese population. This study was the first study of the CVM and the HMW methods performed in this population. The high correlation obtained may be due to the above-mentioned reason of confining the correlation within the circumpubertal period. It may also be due to the ethnic characteristics of the southern Chinese population. Further studies are needed to evaluate the correlation between these indicators in other ethnic groups within circumpubertal period.

The CVM method can be applied to determine the optimal treatment time in orthodontics to eliminate exposing an extra hand-wrist radiograph. In those patients, the CVM method has an advantage for the assessment of the peak of mandibular growth. The CVM can be determined on the lateral cephalometric radiograph, which is a radiograph regularly being used in orthodontics for other treatment planning purposes. Sziska and Pancherz[25] attempted to ascertain if analysis of C3 cervical vertebrae development is reliable and valid in the assessment of skeletal and somatic maturity. They found that the reliability and validity of the C3 analyzing method was acceptably high and could replace the hand radiograph approach in the assessment of skeletal and somatic maturity. However, the low correlations found between the chronological age and CVM and the chronological age and HWM showed that chronological age was not suitable to measure skeletal maturity.

CONCLUSIONS

- The CVM method shows high correlation with the HWM method in the southern Chinese population.
- Low correlations were found between chronological age and HWM, and between chronological age and CVM in the southern Chinese population.

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