Original Article

Correlation of spheno-occipital synchondrosis fusion stages with a hand-wrist skeletal maturity index: *A cone beam computed tomography study*

Anwar Alhazmi[a]; Mohammed Aldossary[b]; J. Martin Palomo[c]; Mark Hans[c]; Bruce Latimer[c]; Scott Simpson[d]

ABSTRACT

Objectives: To examine the correlation between spheno-occipital synchondrosis fusion stages and the hand-wrist skeletal maturity index.

Materials and Methods: Digital records of 164 individuals (77 males, 87 females) aged 10 to 18 years old were examined. Three-dimensional CBCT scans and hand-wrist two-dimensional radiographs were scored for the spheno-occipital synchondrosis fusion stages and hand-wrist skeletal maturity index, respectively. Statistical analyses were performed for associations using R software with a significance threshold of $P < .01$.

Results: A significant positive relationship was demonstrated between spheno-occipital synchondrosis fusion stages and hand-wrist skeletal maturity in both sexes. The Kendall's rank correlation τ between hand-wrist skeletal maturity index and spheno-occipital synchondrosis fusion percentage were high and positive in males and females ($r = .74$ and $r = .71$, respectively).

Conclusions: The significant, positive relationship between the hand-wrist skeletal maturity index and spheno-occipital synchondrosis fusion stages support the idea of using spheno-occipital synchondrosis fusion as a biological indicator for craniofacial and mandibular growth spurt prediction. (*Angle Orthod.* 2021;91:538–543.)

KEY WORDS: Cone-beam computed tomography; Dental development; Orthodontic; Skeletal age measurement; Skeletal maturation index; Spheno-occipital synchondrosis

INTRODUCTION

Evaluation of a patient's growth is an essential part of dentistry. Assessment of a patient's maturational status and developmental stage, whether the pubertal growth spurt of that patient has been reached or not, can have an influence on diagnosis, treatment objectives, treatment planning, prognosis, and outcome of the treatment.[1]

In orthodontics and dentofacial orthopedics, the timing of treatment commencement may be as important as the selection of the specific treatment method and modality.[2,3] Treatment planning and retention decisions are influenced by the growth rate and the amount of remaining growth, necessitating a need to assess levels of skeletal maturity accurately. By starting treatment at the individual patient's optimal maturational stage, practitioners can get the most favorable response with the least potential morbidity.[4] The value of optimal timing for orthodontic treatment is linked to the identification of periods of accelerated growth that can contribute to the correction of malocclusion in an individual patient.[5] It is recommended to wait for growth completion before conducting surgical or implant prosthesis treatment.[6,7]

[a] Assistant Professor, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, Ohio, USA. Assistant Professor, Department of Preventive Dental Science, Division of Orthodontics, College of Dentistry, Jazan University, Jazan, Saudi Arabia.

[b] Specialist, General Directorate of Dentistry, Ministry of Health, Riyadh, Saudi Arabia.

[c] Professor, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, Ohio, USA.

[d] Professor, Department of Anatomy, School of Medicine, Case Western Reserve University, Cleveland, Ohio, USA.

Corresponding author: Anwar Alhazmi, Assistant Professor, Department of Preventive Dental Science, Division of Orthodontics, College of Dentistry, Jazan University, Jazan, Saudi Arabia (e-mail: anwar.alhazmi@gmail.com)

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Variations in the growth and development in children of same age have led to the use of physiological age instead of chronological age for growth evaluation purposes. Physiologic age is the registry of the rate of progress toward maturity that can be estimated by somatic, skeletal, sexual, and dental development.[8]

Skeletal maturity or bone age assessment is a common method for biological age assessment. For more than a half century, the hand-wrist, cervical vertebrae, and dental development have been used as biological indicators. However, each method has some limitations such as extra radiation or reliability issues.[9,10] The hand-wrist radiograph is commonly used for skeletal maturity assessment because it includes many ossification centers in small areas.[4] Skeletal maturation assessed on hand-wrist radiographs is considered a reliable indicator of skeletal maturity and has been found to be closely related to the facial growth spurt.[3] There was a significant relationship between hand-wrist skeletal maturation stages and changes in stature height and facial growth during the pubertal growth period.[5,11,12] Its main drawback is that an additional X-ray is required.

There is still a need for a reliable skeletal maturity biological indicator that shows efficacy in detecting mandibular growth without the need for an additional X-ray and with minimum interexaminer and intraexaminer error.[13,14]

In the past decade, three-dimensional (3D) imaging or cone beam computed tomography (CBCT) has become widely used in dental imaging and orthodontics for more comprehensive diagnosis, treatment planning and assessment of treatment outcomes.[15,16] The CBCT images provide clinicians with more accurate anatomic details and facilitate visualization of small osseous and hard tissue structures such as the spheno-occipital synchondrosis (SOS) that are not easy to see on conventional two-dimensional (2D) radiographs.[17]

The SOS is a cartilaginous growth center between the occipital and sphenoid bones. It is composed of hyaline cartilage, which is abundant during growth of the cranial base and then ossifies during skeletal maturation.[18] Orthodontics and craniofacial growth studies show that the SOS plays a vital role in cranial base growth and flexion, which contribute to defining the final shape of the cranial base and its relationship to the upper and lower jaws.[19,20]

The SOS has a prominent role in ontogeny of the human skull during adolescence. According to Scheuer and Black,[21] the fusion process of the SOS is believed to be related to skeletal maturation events associated with adolescence such as growth spurts and hormonal fluctuations. However, no study has examined and clarified the relationship between SOS fusion time and maturational events. This relationship, if it exists, could allow using SOS fusion stages as an indicator for facial growth and skeletal maturity status.

Therefore, this project examined SOS fusion stages and correlated them with skeletal maturity in a modern American population. A previously published study aimed to examine the relationship between SOS fusion and puberty onset and investigated the timing and the rate of SOS closure in both sexes.[22] Sexual dimorphism in SOS fusion was found with a mean age of SOS fusion starting at 12.95 $\pm$1.38 years and 11.67 $\pm$ 0.93 years in males and females, respectively. There was also a significant association between menarche in females and SOS fusion.[22] These findings were consistent with the suggestion from Scheuer and Black regarding the relationship between SOS fusion and maturational events.[21]

The current study continued investigations based on the results of the published previous study.[22] The aim of this study was to examine the correlation between SOS fusion and hand-wrist skeletal maturity in males and females.

MATERIALS AND METHODS

Sample Composition and Data Acquisition

Records of 164 individuals (77 males and 87 females) with a mean age of 13.24 $\pm$ 1.76 years (range, 10–18 years) were examined. Cross-sectional data from individuals who had standard orthodontic treatment and had both a 3D CBCT scan and 2D hand-wrist radiograph before they started their orthodontic treatment were used. The study sample was selected from the digital patient database of the Department of Orthodontics, Case Western Reserve University (CWRU), School of Dental Medicine, Cleveland, Ohio. Preexisting records between 2009 and 2016 that included CBCT scans, hand-wrist radiographs, and medical charts of a sample of patients were used. Each individual had one 3D CBCT scan and one hand-wrist 2D radiograph; both were taken within a 1-month period. The CWRU Institutional Review Board approved the study protocol used in this retrospective study (IRB-2016-1422). Each patient had a signed consent form allowing the use of orthodontic records.

Imaging, SOS, and Hand-Wrist Skeletal Maturity Indicator Scoring

Patient scanning was conducted using a CBCT machine (CB MercuRay, Hitachi Medical Systems America Co., Twinsburg, Ohio) with the patient sitting upright in a natural head position while looking at a remote point at eye level. After rendering 3D images with the Dolphin program (Dolphin Imaging, Chats-

Figure 1. Mid-sagittal CBCT evaluation of spheno-occipital synchondrosis with the head in the default orientation.

worth, Calif), a 3D virtual model was created for each individual and used to establish head orientation and standardize the center of the 3D coordinate system. The 3D model orientation and SOS scoring was done following the methods described in a previous study.[22] Visualization of the synchondrosis ossification was done in the mid-sagittal view while setting the head in default orientation (Figure 1). However, in this study, a three-stage scoring system for SOS fusion was used: open SOS stage (SOS completely unfused), fusing SOS stage (fusing more than 1% and less than 100%), and fused SOS stage (SOS completely fused) (Figure 2).

The definitions of the staging system used for scoring SOS fusion degree were the following: (1) unfused/open fusing stage, completely open with no evidence of fusion between the basilar portion of the occipital and the sphenoid bones and no bone present in the gap; (2) fusing/closing stage, synchondrosis beginning to ossify (proceeding endo- to ecto-cranially), and the gap was narrowing and becoming filled with bone; and (3) fused/closed stage, complete fusion between the occipital and sphenoid bones. Data were then compared with results from the three growth stages that were used in the hand-wrist growth analysis.

Skeletal maturity assessment was done using the hand-wrist radiograph. A hand-wrist radiograph of the right hand with palm facing toward the cassette and fingers slightly open was performed. The settings (kVp $= 60$, mA $= 8$, time $= 0.2$ seconds) were defined, and the Sirona XG machine was used (Sirona Dental Systems, Bensheim, Germany).

To evaluate the maturational stages of the hand-wrist, the Skeletal Maturity Indicators (SMI) of Fishman was used.[23] Each patient was evaluated and ranked according to the SMI. This system used four stages of bone maturation found at six anatomical sites located on the thumb, third finger, fifth finger, and radius. The sequence of the four ossification stages progressed through epiphyseal widening on selected phalanges,

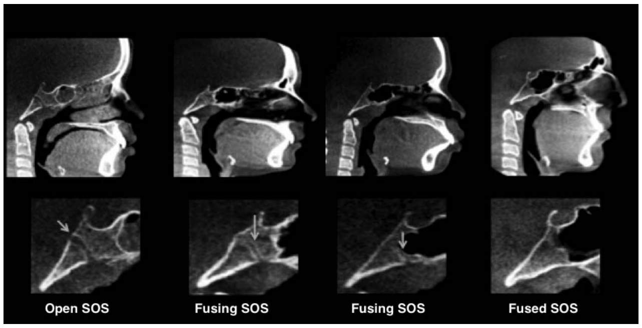

Figure 2. The SOS stages: the open SOS stage shows 100% opening, and fusing SOS stages show about 30% and 70% fusion that starts on the superior border and moves in the same direction to finally reach a completely fused SOS.

the ossification of the adductor sesamoid of the thumb, the capping of selected epiphyses over their diaphysis, and the fusion of selected epiphyses and diaphyses. The subjects were divided according to their bone maturation level into three groups; group I (accelerating phase or Fishman SMI stages 1–3), group II (peak of growth velocity phase or Fishman SMI stages 4–7), and group III (decelerating phase or Fishman SMI stages 8–11).

One investigator (A.A.) completed the evaluation of the hand-wrist SMI and scoring of SOS for the sample (164 CBCTs and 164 hand-wrist radiographs). Randomly selected records of 30 patients were reevaluated after 3 weeks to test the reproducibility of the assessments.

Statistical Analyses

The relationship between hand-wrist skeletal maturation stages and the SOS fusion stages was evaluated. Nonparametric data were evaluated using contingency tables. Statistical analyses were performed using R software (R Foundation for Statistical Computing, Vienna, Austria). Descriptive analysis (mean and standard deviation [SD]), chi-square, Fisher exact test, and Kendall's rank correlation τ were performed. Intraobserver agreement was assessed using κ statistics. A P value of $< .01$ was considered as statistically significant.

RESULTS

The records of 164 individuals (77 males, 87 females) with an age range between 10 and 18 years were examined. The mean age of the males and females were 13.42 years (SD = 1.6 years) and 13.11 years (SD = 1.40 years), respectively. Based on the repeat assessment of three modalities for 30 individuals, the κ measures of agreement were .901 and .890 ($P < .001$) for SOS and hand-wrist scoring, respectively. The strength of agreement between repeated observations was thus rated as "almost perfect."[24]

SOS Fusion and Hand-Wrist SMI Relationship

The distribution and association between SOS and hand-wrist skeletal maturity stages for both sexes are shown in Table 1. The Kendall's rank correlation τ between hand-wrist SMI and SOS fusion percentage were high and positive in males and females ($r = .74$ and $r = .71$, respectively), indicating that subjects advanced for SMI were also advanced for SOS stage and vice versa (Figure 3).

A significant association between the SOS stages and SMI stages (Fisher exact test, $P < .01$) was shown (Table 1). In males, the open SOS stage showed the highest distribution (87%) at growth acceleration SMI stages (SMI stages 1–3), the fusing SOS stage showed the highest distribution (88%) at growth peak SMI stages (SMI stages 4–7), and the fused SOS stage showed the highest distribution (85%) at growth deceleration SMI stages (SMI stages 8–11).

In females, the distribution of the open SOS stage was (75%) at growth acceleration SMI stages, which was less than in the male group. However, the fusing SOS stage showed the highest distribution (94%) in growth peak SMI stages, which was greater than in the male group. Fused SOS stage showed 85% distribution at growth deceleration SMI stages, which was equal to the value in males. This showed that there was similarity of trajectory in the growth of the hand and wrist and the SOS. Chronological ages for study subjects grouped by hand-wrist SMI and SOS fusion status are presented in Tables 2 and 3, respectively.

DISCUSSION

Determination of facial growth spurt onset, duration, rate, and end has always been an area of extensive research because of its significant impact on clinical decisions such as timing of orthodontic treatment, timing of implant placement in dentistry, and timing of surgery in orthognathic surgery. The objective of this study was to examine the relationship between SOS fusion and hand-wrist skeletal maturity.

The Relationship Between SOS Fusion and Hand-Wrist Skeletal Maturity

Using SOS fusion for skeletal maturity evaluation can eliminate the need for extra hand-wrist radiation and also be helpful for patient's growth assessment. Knowing the patient's maturational status, whether the pubertal growth spurt of that patient has been reached, can have an influence on diagnosis, treatment objec-

Table 1. Contingency Table Showing Distribution and Association Between SOS and Hand-Wrist Skeletal Maturity Stages in Both Sexes

Sex	Hand-Wrist Stage	Open SOS n (%)	Fusing SOS n (%)	Fused SOS n (%)	Total
Male	Acceleration (1, 2, 3)	20 (87)	3 (13)	0	23
	Peak (4, 5, 6, 7)	4 (12)	28 (88)	0	32
	Deceleration (8, 9, 10, 11)	0	7 (15)	15 (85)	22
	Total	24	38	15	77
		Chi-square = 87.85, $P < .01$, Kendall's rank correlation $\tau = 0.74$			
Female	Acceleration (1, 2, 3)	3 (75)	1 (25)	0	4
	Peak (4, 5, 6, 7)	1 (3)	27 (94)	1 (3)	29
	Deceleration (8, 9, 10, 11)	0	8 (15)	46 (85)	54
	Total	4	36	47	87
		Chi-square = 99.50, $P < .01$, Kendall's rank correlation $\tau = 0.71$			

tives, treatment planning, prognosis, and outcome of treatment in orthodontics and in dentistry.[1,3,6,25]

In this study, the SOS fusion assessment was based on Franklin and Flavel.[26] However, SOS stages 1 and 2 were considered as one stage and was called the fusing SOS stage. Merging SOS stages 1 and 2 into one fusion SOS stage was done to facilitate comparison with the skeletal maturity assessment that was developed by Fishman.[23] The results demonstrated a significant positive relationship between hand-wrist skeletal maturity indexes and stage of spheno-occipital fusion for both sexes (male: Kendall's τ, .742, significance = $P < .001$; female: Kendall's $\tau = .713$, significance = $P < .001$).

There was a significant association between the SOS stages and SMI stages (Fisher's exact test $P < .01$). The open SOS stage showed the highest distribution at growth acceleration SMI stages with 87% and 75% for males and females, respectively. The fusing SOS stage showed the highest distribution at growth peak SMI stages with 88% and 94% for males and females, respectively. Fused SOS stage showed the highest distribution at growth deceleration SMI stages with 85% for both males and females (Table 1).

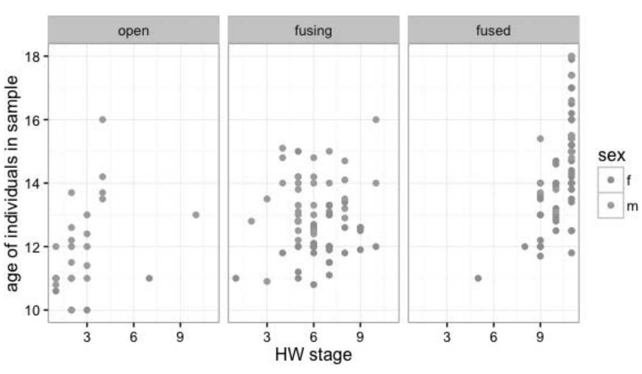

Figure 3. The Kendall's rank correlation tau (τ) between hand-wrist SMI (11 stages) and SOS fusion groups (3 stages) and its relationship with age in both sexes.

As Scheuer and Black suggested,[21] fusion time of SOS was related to maturational events. The results showed a similar trend in maturation age for SMI groups and SOS fusion stages in which female subjects almost always matured earlier than male subjects. Based on the sample, the mean age of the SOS opening group was 12.12 years and 10.40 years in males and females, respectively. The fusing group mean age was 13.47 years and 12.13 years in males and females, respectively. The mean age of the fused group was 15.38 years and 14.06 years in males and females, respectively. These ages were comparable to hand-wrist SMI stages, which showed the mean age in the accelerating growth group as 11.77 years and 10.40 years in males and females, respectively; the mean age in the peak growth group was 13.55 years and 12.01 years in males and females, respectively; and the mean age of the deceleration growth group was 14.96 years and 13.88 years in males and females, respectively (Tables 2 and 3). As the mean age for each SOS stage and SMI group indicated, female subjects matured earlier than male subjects by an average of 1.1 to 1.7 years. This finding was in agreement with other growth and maturation studies.[5,23,27] Future work should be done to determine the value of using SOS fusion as a biological indicator. The progressive nature of SOS fusion, which has a clear starting point at the endocranial and definitive end point at the ectocranial, gives it added value over other indicators and makes it easier to see how much fusion is left if fusion has already started.

Table 2. Chronological Ages for Study Subjects Grouped by Hand-Wrist Skeletal Maturity Indicators

Hand-Wrist SMI	Sex	Number of Subjects	Chronological Age, Mean ± SD
Acceleration	Male	23	11.77 ± 0.99
(1, 2, 3)	Female	4	10.40 ± 0.49
Peak (4, 5, 6, 7)	Male	32	13.55 ± 0.97
	Female	29	12.01 ± 0.85
Deceleration	Male	22	14.96 ± 1.50
(8, 9, 10, 11)	Female	56	13.88 ± 1.59

Table 3. Chronological Ages for Study Subjects Grouped by SOS Fusion Status

SOS Status	Sex	Number of Subjects	Chronological Age, Mean ± SD
Opening SOS	Male	24	12.12 ± 1.38
	Female	4	10.40 ± 0.49
Fusing SOS	Male	38	13.47 ± 1.02
	Female	36	12.13 ± 0.79
Fused SOS	Male	15	15.38 ± 1.52
	Female	47	14.06 ± 1.63

CONCLUSIONS

- A significant positive relationship between hand-wrist skeletal maturity index and SOS fusion stages in both sexes was demonstrated. Taken together, these findings support using SOS fusion as a biological indicator for detecting the craniofacial and mandibular growth spurt.
- The potential value of SOS as a biological indicator over the hand-wrist method is that an additional radiograph is not needed.

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