Original Article

Relationship between Cervical Vertebral Maturation and Spheno-occipital Synchondrosis Closure

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ABSTRACT

Introduction: Increased growth in three-dimensional imaging has created the opportunity for alternative measures of growth assessment. The aim of this study was to evaluate the relationship between the cervical vertebrae maturation (CVM) method and closure of the spheno-occipital synchondrosis (SOS) in children and young adults using cone-beam computed tomography (CBCT). **Methods:** Two hundred and seventy-five extended field CBCT scans of patients aged 6–30 years were analyzed. The cervical vertebrae maturity was assessed using the CVM method. The closure of the SOS was evaluated using a five-stage scoring system. Correlation and agreement between CVM and fusion of the SOS were analyzed for statistical significance. **Results:** A strong significant correlation (r_s= 0.908; 95% confidence interval: 0.885, 0.927) was found between cervical vertebrae maturational status and the closure of the SOS. Based on the variables assessed, an ordinal regression model was constructed to predict cervical stage, to which age, gender, and SOS closure were statistically significant. **Conclusion:** This pilot investigation demonstrated that the maturation stage of the SOS, as determined using CBCT, is a potential indicator for skeletal maturity assessment.

Key words: Cervical Vertebrae, Cone-beam computed tomography, Growth and development, Orthodontics, Spheno-occipital Synchondrosis

INTRODUCTION

The identification of the optimal timing for orthodontics and dentofacial orthopedics has been a continuing investigation. The current understanding suggests that such timing is linked closely with a patient's growth status. There is a general agreement that the most effective response to functional orthopedic intervention occurs during the pubertal growth spurt.[1-4] In fact, it has been proposed that rather than the type of appliance, it is the timing of treatment that would bring about the greatest increase in the quantity of mandibular growth.[5] In addition, the identification of the decreased growth period and skeletal changes is important for the timing of orthognathic surgical intervention. As such, a reliable indicator to detect peak growth velocity becomes a crucial assessment tool in orthodontic treatment planning.

A variety of biological indicators has been employed to assess general body growth. These indicators include body height, chronological age, dental development, maturation of the hand and wrist, secondary sexual characteristics, and cervical vertebral maturation (CVM).[6-14] With the advent of three-dimensional imaging technology, clinicians are now provided with more details and landmarks previously inaccessible with two-dimensional imaging modalities. One such structure able to be visualized with three-dimensional imaging such as cone-beam computed tomography (CBCT) is the spheno-occipital synchondrosis (SOS), an essential cartilaginous junction between the occipital and sphenoid bones of the cranium.

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This anatomical structure is of particular interest, as it plays a prominent role in the development of the craniofacial complex. The flexion and elongation at this junction result in changes in the cranial base angle, which ultimately influences the location of the maxilla and mandible.[15] In addition to growth, due to the noted displacement and changes in the SOS during rapid maxillary expansion, there has been an interest in the assessment of the junction as a marker for the non-surgical expansion intervention.[16] From a growth measure point of view, there has been evidence to propose that the fusion of the SOS is linked to the pubertal growth changes and skeletal maturity.[17,18]

Considering the various clinical applications, it is possible that the assessment of the SOS may provide clinicians with more insight and information in making clinical decisions involving growth, maxillary expansion, and identification of craniofacial developmental anomalies.

In this study, the aim was to assess the relationship between the CVM stage and SOS closure in children and young adults using CBCT. This will serve as a pilot investigation into the assessment of SOS closure as a potential indicator of growth maturation.

MATERIALS AND METHODS

The appropriate size for this cross-sectional study was determined using a power analysis calculation. Using an alpha of 0.05, a power of 0.95, and a correlation of 0.3, the minimum sample size was estimated to be 56. At the time of collection, a total of 500 consecutive deidentified CBCT datasets were acquired from the University of Queensland Radiology Clinic and a private radiology practice. Ethical approval was obtained from the University of Queensland (Project Number 1702). All of the CBCT scans had been previously acquired as a part of orthodontic diagnosis and management requirements. DICOM data of each scan were exported and manipulated with Anatomage In Vivo 5 (Anatomage, San Jose, CA, USA).

Dataset that was chosen to be analyzed was of scans with an extended field of view. The age range of the study group was 6–30 years. The field of view must extend from the base of skull to the lower border of C4. Participants were excluded if any of the following were noted: Distortion of the dataset due to patient movement; developmental anomalies affecting the craniofacial structures or vertebrae; and previous history of craniofacial surgery.

Out of the 500 datasets, 275 CBCT scans fulfilled the inclusion criteria. The majority of the rejections were due to the body of C4 not being included in the scan.

Qualitative assessment of the CVM stages was based on the six-stage system described by Bacetti *et al.*,[5] whereas the assessment of the SOS closure was conducted using the five-stage scoring system developed by Bassed *et al.*[19]

Statistical Analysis

The data were analyzed using statistical software (SPSS version 21.0 for Windows, Chicago, Il, USA). With regard to the levels of significance, $P < 0.05$ was considered to be statistically significant. Furthermore, the relationship between CVM stage and SOS fusion was analyzed with Spearman's correlation coefficient (r_s).

In this investigation, the complete dataset was analyzed by a single scorer (S.F). To ascertain a satisfactory reliability, 25 randomly selected datasets were assessed by another experienced expert (P.M.). A further reassessment was conducted after 2 weeks to ensure a repeatable measurement. The evaluation of the intra- and inter-rated agreements was conducted using Cohen's Kappa coefficient.

RESULTS

The intrarater agreement at the 2 time points was 0.88 (95% confidence interval [CI]: 0.86, 0.90) for the assessment of the cervical vertebrae staging and 0.93 (95% CI: 0.92, 0.95) for the SOS closure. Thus, the strength of intrarater agreement was excellent. The assessment of the inter-rater agreement was accomplished using the same 25 datasets. The weighted Kappa coefficient agreement was 0.82 for the vertebrae assessment and 0.85 for the SOS closure. In all cases, the difference in the assessment for either CVM or SOS staging was no more than 1 stage.

The demographic distribution by gender of the sample is shown in Figure 1. Most participants were within the age group of 10–15 years, with more females (166; 60%) than males (109; 40%).

The distribution of the maturational stages of the synchondrosis by cervical vertebrae is shown in Table 1. The pattern indicates the positive relationship between CVM stages and the closure of the SOS. In addition, the correlation coefficient between the cervical vertebral stage and spheno-occipital closure was found to

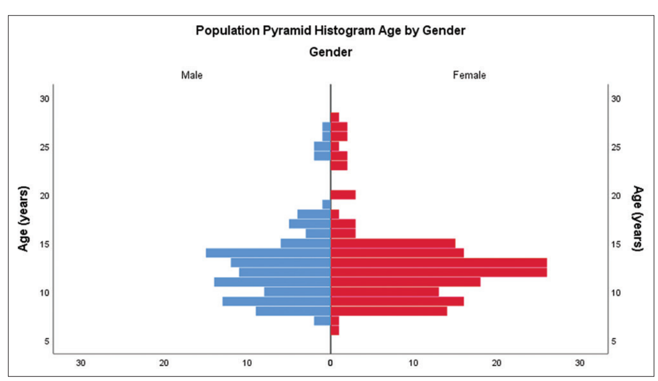

Figure 1: Demographic characteristics of the sample

be $r_s = 0.908$ (95% CI: 0.885, 0.927). Alternatively, the correlation between SOS stage and age was $r_s = 0.857$ (95% CI: 0.822, 0.885).

The percentage breakdown of SOS stage by pre- or post-peak growth peak, as based on CS maturation, is shown in Table 2.

The result of ordinal regression is shown in Table 3. The findings indicate that an increase in SO stage was associated with an increase in CS stage, although, the rate of increase was not linear. Moreover, significant association among the variables age, sex, and SOS closure stages was noted. The model shows that all variables were independently associated with CVM stages.

DISCUSSION

Treatment timing is an essential consideration in orthodontic management, in particular when dentofacial orthopedics is planned. It has been suggested that the use of a functional appliance during the peak growth period would produce more favorable skeletal change.[1-4,20] At present, several methods have been adopted. However, there is currently no single optimum method in the determination of the accelerated period of peak growth, and thus clinicians often use a combination of the currently available methods.

The CVM method has been studied extensively in recent times and has been suggested as an acceptable way of assessing skeletal growth in orthodontic patients.[21] Due to the subjective nature of the CVM method, many studies examining the inter-rater reliability have shown concerns over its consistency in identifying the separate distinct stages. However, from a clinical perspective, such concern proved to be minimal, as it is the identification of the pre- and post-peak growth that is essential. For the purposes of distinguishing pre- and post-mandibular growth peak, Ballrick *et al*. have recommended using the CVM stage as a 2-phase measure (pre- and post-peak growth), rather than differentiating it into five or six detailed stages.[22] The result of their study showed the CVM method to be not only a valid tool, but one that is reliable and clinically useful.

Much of the literature on the analysis of SOS closure has largely relied on macroscopic, histologic, and CT investigations. Unfortunately, with regard to the various methodologies employed by the researchers, the findings have resulted in a spread of age ranges due to the varying sensitivity at detecting the "closure" of the synchondrosis. It has recently been proposed that the skeletal maturity of an individual can be estimated by assessing the closure of the SOS.[23] This cartilaginous union in the posterior cranial fossa continues to grow throughout childhood and increases the length of the cranial base. With the continual development of the cranial base until adolescence, the closure of the SOS has been related to the onset of puberty in teenagers. Overcoming the limitation of conventional radiographs with restricted view of the synchondrosis closure, Bassed *et al*. were able to successfully analyze the fusion of the structure using CBCT.[19] In their study, they evaluated the closure of the SOS by modifying the classification system suggested by Powell and Brodie.[24] They concluded that the ossification of the SOS is correlated with chronological age.

The present study assessed the relationship of the CVM maturational stage and the closure of the SOS in a sample of 275 CBCT scans. The result showed a statistically significant strong positive association ($r_s = .908$), which is similar to that of a recent study done by Fernández-Pérez *et al*.[23] Moreover, it was found that age also showed a strong positive association with SOS closure ($r_s = .857$), establishing that the ossification is likely related to skeletal maturity.

The findings of this study set forth a promising possibility of assessment of skeletal maturity using CBCT to evaluate

Table 1: Distribution of synchondrosis stage by vertebrae stage

	Vertebrae stage						
Synchondrosis stage	1	2	3	4	5	6	Total
1	52	39	8	0	0	0	99
2	5	13	36	5	0	0	59
3	0	1	6	15	1	0	23
4	0	0	3	22	20	1	46
5	0	0	0	3	15	30	48
Total	57	53	53	45	36	31	275

Table 2: Characteristic variables and the percentage of participants at pre- or post-growth based on CS stage

Characteristics	CS stage	
	Pre-growth *o* (%)	Post-growth *o* (%)
Gender		
Female	84 (50.6)	82 (49.4)
Male	79 (72.5)	30 (27.5)
Synchondrosis stage		
1	99 (100)	0 (0)
2	54 (91.5)	5 (8.5)
3	7 (30.4)	16 (69.6)
4	3 (6.5)	43 (93.5)
5	0 (0)	48 (100)

Pre-growth ≤ 3 on CS stage; Post-growth ≥ 4 on CS stage

Table 3: Results of the ordinal logistic regression model with the cervical vertebral maturation as the outcome variable and age, sex, and SOS closure as predictors

CS stage	Odds ratio	95% confidence interval		*Q*-value
		Lower bound	Upper bound	
Age (years)	1.84	1.53	2.20	< 0.001
Gender				
Male	0.29	0.16	0.51	< 0.001
SO stage				
1 (reference)				
2	6.7	2.8	15.7	< 0.001
3	88.2	21.6	360.0	< 0.001
4	495.8	98.3	2499.7	< 0.001
5	5803.5	825.8	40784.0	< 0.001

the SOS stages. Interestingly, on reaching SOS Stage 3, the fusion of the superior half of the synchondrosis, there is a high likelihood that the patient has passed their peak growth (69.6%). Beyond this, in SOS Stages 4 and 5, this percentage of patients that have passed the peak velocity increases to 93.5% and 100%, respectively.

From a clinical perspective, while a routine CBCT scan is not recommended for every patient undergoing orthodontic management, should CBCT dataset be available that includes the SOS, the assessment of the SOS staging may assist in determining the growth status of the patient. Moreover, with the continued development and improvement of three-dimensional imaging, perhaps, it is just a matter of time before CBCT will supersede conventional radiographs in providing a more accurate and precise view of the anatomical structures with lower radiation doses. Considering this, further diagnostic tools will undoubtedly be developed to capture additional information useful for planning orthodontic management and intervention, such as for functional appliances or maxillary expanders.

This study has demonstrated the promising potential of SOS closure assessment to determine growth status. However, there are limitations to this study that needs to be considered. The assessment of the CVM staging was conducted by two operators who underwent a calibration process and followed the guidelines as suggested by Bacetti *et al*.[5] in their six-stage assessment of the cervical vertebrae. Many studies have shown that the agreement among a small number of raters proved to be excellent.[21,25,26] However, when more than 3 operators were introduced, the reliability reduces.[27] To overcome such issue, as suggested by Ballrick *et al.*, the use of the CVM assessment was based on two-phase measure, pre- and post-growth peak.[22] Nonetheless, our assessment with either the six-stage or 2-phase assessment of the cervical vertebrae showed a strong and significant relationship between the CVM stage and SOS closure.

Another limitation of this investigation, although a commonly encountered problem, is the absence of uniformity regarding the demographic distribution in the data. All of the datasets were anonymized before the collection of the data, and thus, the only accessible linked information available was the gender and age. Consequently, we are unable to sort the sample into their cultural or ethnic backgrounds. Conversely, our dataset provides a snapshot of the Australian population that may undergo orthodontic treatment.

Based on the literature surrounding SOS closure assessment, there is currently no singular diagnostic assessment standard. This is due to the SOS being difficult to assess using plain film. Conventionally, the assessment has been based on anthropological/forensic evaluation involving macroscopic and/or histological studies. It is only in recent time that three-dimensional modalities have been utilized to assess the structure. As such, this is a relatively recent method that has yet to be comprehensively investigated.

CONCLUSION

The results from this pilot investigation indicate that the stage of SOS closure and the CVM stage is highly correlated using CBCT dataset. With further research, it should be possible to develop a system for using the SOS, as demonstrated using CBCT, to assess growth maturation.

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