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RESEARCH ARTICLE

EVOLUTION OF EVALUATION": SKELETAL AGE ASSESSMENT USING CERVICAL VERTEBRAL MATURATION: A LITERATURE REVIEW

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ABSTRACT

The ideal time to start an orthodontic treatment is a controversial topic.Different authors have reported different methods in an attempt to determine the best indicator of maturity, which include body height, body weight; sexual maturation; frontal sinus, chronological age, biological age or physiological age; hand-wrist maturity cervical vertebrae; dental eruption; dental calcification stages and biomarkers. Although the carpal radiograph is proven to be efficient and safe, presently, new proposals to evaluate the bony age have appeared with the intention to reduce the number of radiographic exposures to the patients. The purpose of this article is to review one such method, which is Cervical vertebral maturation analysis and its various application in dentistry.

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INTRODUCTION

In both, paediatric dentistry and orthodontics & dentofacial orthopaedics, it is evident that the timing of treatment onset is as critical as the selection of a specific treatment plan. Especially when treating the cases where growth modification is required. By starting the treatment at the patient's optimal maturational stage, the best results with least chance of treatment failure can be predicted.[1] Orthodontic intervention does not cause growth but only deals with growth modification, hence the best time of treatment depends on the most rapid growth period that can specifically help to modify the skeletal defects.[2] Another important application of accuracy of growth prediction other than paediatrics and orthodontics is in Forensic medicine, not only in the identification of dead bodies but also to identify individuals who provide inaccurate details of age in cases of illegal immigrants.[3]Earlier, the accurate age was a vital indicator in determining the nutritional status in public health programs.[4] Age of a child can be assessed with the help of various parameters such as Chronological age, Peak growth velocity of heights, Weight, Secondary sexual characteristics & Skeletal age or Dental age. 'Peak growth velocity' in standing height is the valid representation of skeletal growth but it has limited predictive value in term of future growth remaining.[5] Chronological age that we usually call as 'age' is determined by simple flow of time, so it has limitation in accurate evaluation of one's physiological function, health or aging status. Also, it is not possible to accurately forecast, from chronological age, that when the growth spurt will take place because the standard deviation of its timing is nearly 1 year. According to Houston et al, 30% of children start their growth spurt more than 1 year before or after the average age for their sex. This has lead to the concept of 'Biological age or Physiological age'.[6] The biological age is determined by the degree of maturation of different tissue systems. Physiological age can be estimated by maturational status of Somatic, Sexual, Skeletal and Dental system. 'Somatic maturity' is the annual growth in height or weight [7]; 'Sexual maturity' is estimated using secondary sexual characters,Tanner had given five separate sexual maturity stages from preadolescent to adult.[8] 'Skeletal maturation' is determination of certain bone in body demonstrate an organized event of ossification. Thus bones of hand, foot, knee, elbow, shoulder, hip & cervical vertebra can be used to assess skeletal maturity. Dental age estimation includes the estimation of tooth development, calcification, or age changes in adults.[9] The ideal age estimation technique aims to arrive at an age as close to chronological age as possible. Some investigators have reported that chronological age can be regarded as a reliable predictor of the adolescent growth spurt. The circumpubertal growth spurt, however is influenced not only by patient age but also by sex, genetics, ethnicity, nutrition and socio-economic status.[10-12]The adequacy of Somatic and Sexual maturity indicator is of limited value for the immediate clinical judgement of a patient because these indicators can be applied only after the serial recording of

height or the inception of puberty. Dental age estimation might be considered more reliable than other methods of age estimation and at the same time it is easy for pedodontics to predict the developmental score whereas; the Skeletal maturity method is considered the most reliable method to assess the development status. Earlier, hand and wrist bone maturity estimation was considered a more accurate method but there are few limitations as the ossification sequence and timing of skeletal maturity show polymorphism and sexual dimorphism, and patient is exposed extra radiation resulting from the use of this method, and lastly hand and wrist maturity index indicates only the peak and the end of the pubertal growth spurt, but it does not signal the onset of the pubertal growth spurt. Thus, its use must be questioned if similar methods of assessment are available.[8] Nowadays, the cervical maturity index has gained increasing interest as a biological indicator because the analysis of cervical maturity index is performed on the lateral cephalogram, a type of radiograph routinely available for orthodontic diagnosis. Whereas; a combination of some techniques should be considered to get an accurate result. This article aims to review the method of estimation of cervical maturity index and also its application in dentistry.

MATERIAL AND METHODS

A search of PubMed MEDLINE was undertaken with the search expression "skeletal maturation, Cervical Vertebrae Maturity Index, Methods of Cervical Vertebrae Maturity evaluation". The search includes the article from 1950 to 2019, as most of the commonly used methods deals with age assessment were published in the early years, and were modified subsequently to some extend, with addition of recent advances and easy method of assessment. Out of 118 articles62were relevant to the present work and were selected for the review. For all the included studies, the information relating to the medico legal importance of age estimation requirements for skeletal age estimation significance and criteria for radiological age determination, phases of age estimation, various bone development surveys or methods used, rationale and advantages of radiological method was extracted.

DISCUSSION

Growth, defined as an increase in cellular size and number, can be linked with development i.e., increase in specialization or function. It is an important factor in orthodontics as it can directly or indirectly influence treatment[13]. The obvious direct effect is potential growth modification in various cases including class 2 [14-16] and class 3 skeletal cases etc.[17,18] At the same time, growth may sometimes have an adverse effect on the occlusion and may result in delay of treatment e.g. a class III skeletal pattern or an anterior open bite may become more severe due to continuous growth during the treatment being provided. Therefore, as a part of development assessment, it is essential to consider the likely direction, magnitude and most importantly the timing of growth in our patients. Several clinical studies have shown that the greatest response to functional jaw orthopaedics tends to occur during the circumpubertal growth period.[19-25] It has also been reported that the rate of active tooth movement is likely to be greater at times of rapid growth particularly around the time of the pubertal growth spurt.[26] According to Houston, if full advantage is to be taken of this period of rapid growth, orthodontic treatment should be started nearly 1 year earlier to the onset of the pubertal growth spurt . However, for each individual, the time of onset, duration, velocity and amount of growth over the period varies.[27-29] But on an average the pubertal and the adolescent growth spurt occur nearly 2 year earlier in girls than in boys. The reason of occurrence is not known, but the timing of puberty is a highly heritable trait. Thus, it has an important impact on the timing of orthodontic treatment, which must be done earlier in girls than in boys to take advantage of the adolescent growth spurt. It must be remembered that chronological age is only a crude indicator of where an individual's variation stands developmentally. Thus, the knowledge of physiological age is vital, in which skeletal age indicators such as cervical vertebra maturity index and hand and wrist analysis are considered more reliable. The term skeletal maturation means the stage when the highest degree of ossification and functional improvement have been achieved. There are two periods of high growth; the first stage is the first 2 years of life and the other period of rapid growth corresponds to pubertal stage.[30]

Though hand and wrist skeletal age assessment method has been the gold standard, because it causes extra radiation exposure and it also needs of critical analysis of differential rate of maturation of different bones, cervical vertebrae bone maturation index is becoming more popular these days. One of the reasons of Cervical vertebrae bone maturation index's growing popularity is that it can be evaluated using lateral cephalogram, which is the most common radiographic diagnosing element done before any growth modification procedure or providing the orthodontic treatment.[31,32] The basis of cervical vertebra maturity index is to detect the changes in size and shape of vertebra which keep on changing as the age advances. The ossification events in the cervical vertebrae begin during foetal life and continue until adulthood. Dating back to the first decade of twentieth century, Todd and Pyle, Lanier and Taylor measured the dimensional growth modifications of cervical vertebrae on lateral radiographs. Based on the findings of earlier investigations in 1972, Lamparski created separate standard of cervical vertebral maturation for female and male subjects similar to hand and wrist radiographic assessment. This method analysed the changes in five cervicalvertebrae (C2 to C6).[33] Later Hassel and Farmer reviewed lateral cephalograms to develop an index based on the observed changes of second, third and fourth cervical vertebrae. They stated that these vertebrae were selected because these could be visualized even when thyroid protective collar was worn during the radiation exposure, making the method less complex.[34] These methods are based on qualitative analysis of vertebrae shape and size.[35]

The method given by hassel and Farmer (CVMI) was later modified by Bacceti et al in 2002, [36]which was named Cevical Vertebral Maturation Stage (CVMS) and consisted of 5 stages. Bacceti et al later updated CVMS to newer version called Cervical Vertebral Maturation (CVM), consisting of 6 stages.[37] Which is based on quantitative analysis of vertebrae (limited to height and width distance and ratios, depth of the inferior concavities of vetebrae).[35] While analysing the Cervical vertebral maturity, we look for two main changes; Namely,

- Inferior border of the three vertebrae i.e. C2,C3,C4 which during the young age is flat and develops concavity as the age advances(vertebral growth take place by cartilaginous tissue on superior and inferior surface) Figure:1

- Shape of the three vertebrae. i.e. trapezoid (the superior border is tapered from posterior to anterior); rectangular horizontal (the heights of the posterior and anterior border are equal, the superior and inferior borders are longer than the anterior and posterior borders); Squared (the posterior, superior, anterior and inferior border are equal); rectangular vertical (the posterior and anterior borders are longer than the superior and inferior borders).[37]Figure:2

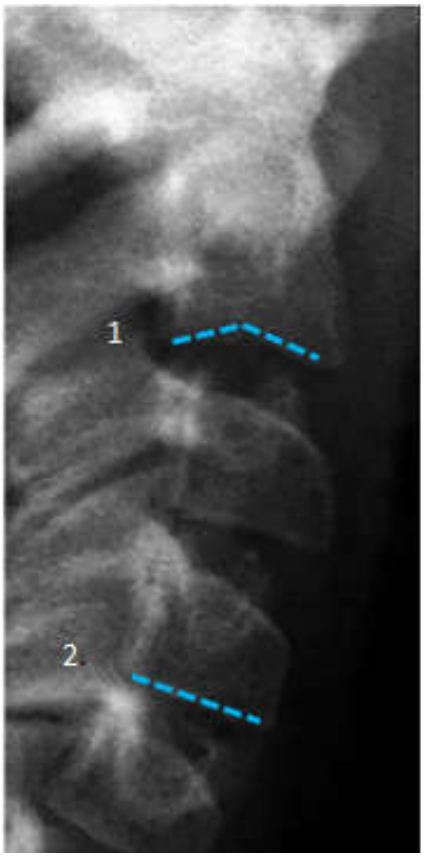

Figure 1. Marking showing the inferior border of vertebra (1.) Concavity related to C2 (2.) flat border related to C4

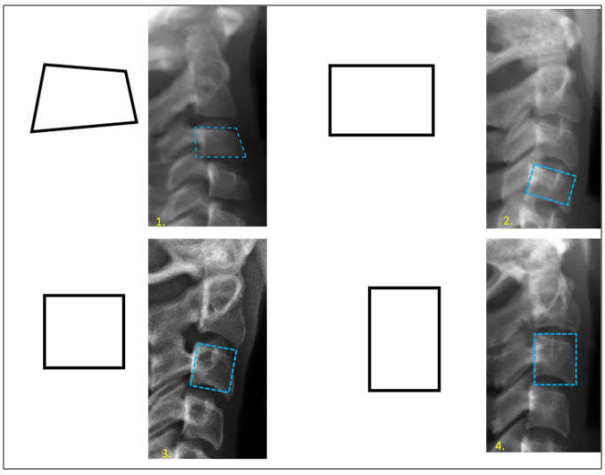

Figure 2. Shape of body of vertebrae- 1. Trapezoid 2. Rectangular horizontal 3. Square 4. Rectangular vertical

Table 1 presenting the various stages of cervical vertebra maturation and the significance of each stages[37]. The procedure to follow while evaluating the changes observed in the radiograph is explained in Figure:3

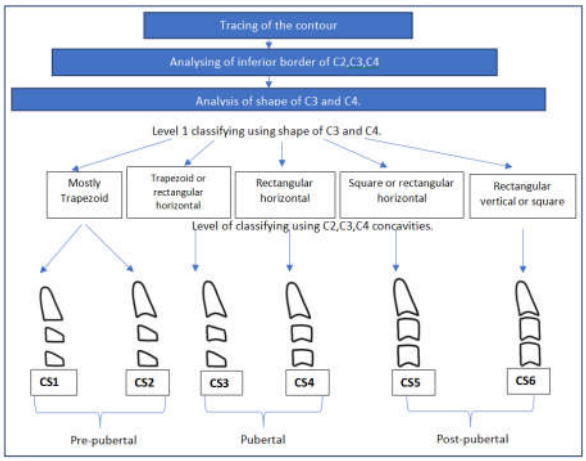

Figure 3. The procedure to follow while evaluating the changes observed in the radiograph

Other methods for more specific measurement of cervical vertebral bone age are geometric morphological analysis [38] (using tools of geometric morphometric on first 4 vertebrae) and linear regression formula[39,40]e.g.Caldas et al[40] in 2007 had given different formulae for the depiction of bone age, using Cervical vertebrae morphology, in male and female subjects. Earlier Mito et al[41] in 2002 determined a formula to obtain skeletal age, however, the sample used to derive the formula consisted of Japanese girls only. Although, cervical maturity indicator has not taken into consideration that growth is a gradual process, it is an ordinal method consisting of various stages explaining the different timings of growth. Obviously, the change is size and shape occur gradually with time. In cases where the characteristics of both stages are present in a single stage radiograph i.e. an intermediate stage, saying that someone is in late CS 3 or early CS4 is appropriate, depending on the transitional morphology of the third and fourth vertebrae.[42]

Regarding the Treatment Planning, it has been observed that significant mandibular growth occurs at pubertal age i.e. CS 2 and CS 3 stages. So, most of the my functional appliance provides better results when given at those stages. In particular, the detection of CS2 indicates that the growth spurt is approaching, and it will start at CS3, which is approximately 1 year after CS2. Thus the 'Class II' treatment is usually indicated when there is peak in mandibular growth. Whereas, 'Class III' treatment including maxillary expansion and protraction usually done before the peak pubertal stage (CS1 or CS 2). Clinical support of histological finding by Melson[43] explained the stages of maxillary suture growth during development have proved that 'Transverse maxillary intervention' should be done at prepubertal stage. lastly, deficiency of 'Ramal height' can be enhanced significantly when orthopaedic intervention done at CS 3 stage where the peak in mandibular growth occur.[37] So many studies have been done to find the accuracy and correlation of CVMI maturation index with other skeletal age indicators. As, O'Reilly and Yanniello found, on the evaluation of annual lateral cephalometric radiographs, statistically significant increases in mandibular length, corpuslength, and ramus height in association with specific maturation stages in the cervical vertebrae.[44] Cohen investigated the growth of intermaxillary space and the timing of orthodontic treatment in relation to growth and established the fact that, to achieve success, treatment should be instituted early, well before the growth

Table 1. Presenting various stages of cervical vertebra maturation and the significance of each stages

Cervical vertebrae stages	Evaluation of inferior border of all the three cervical vertebrae.	Evaluation of shape of body of C3,C4 vertebrae.	Importance
CS1	Inferior surface of all the three vertebrae is flat. (sometimes slight convex)	C3 and C4 vertebrae shape is trapezoid (wedge of cheese) stage	Occurs approximately the time of eruption of deciduous dentition until about 2 year before the peak in craniofacial growth.
CS2	Notched inferior border of C2 where as inferior border of C3 and C4 still flat.	C3 and C4 vertebrae shape is trapezoid.	The "Get ready" stage because the peak interval of mandibular growth should begin within a year after this stage is evident.
CS3	Notched inferior border of C3 and C3 Vertebrae, C4 inferior border is flat.	Most of C3 and C4 vertebrae is trapezoid, some instance either C3 or C4 has more rectangular horizontal shape.	Stage of maximum craniofacial growth.
CS4	Visible concavities of inferior border of all the three vertebrae.	Both C3 and C4 has rectangular horizontal (bar of soap) stage	Stage of continued accelerated growth can be anticipated.
CS5	Visible concavities of inferior border of all the three vertebrae.	One of the C3 or C4 body shaped square if not then the other body shaped rectangular horizontal	At this stage, considerable craniofacial growth has been achieved.
CS6	Visible concavities of inferior border of all the three vertebrae.	One of the C3 or C4 body assumed rectangular vertical shape if not then other body shaped squared.	Stage of corrective jaw surgery or the placement of end osseous implants in the aesthetic region.

rate peak occurs.[45] Studies done by Uysal et al[46],Chang et al,[47]Lai et al.[48] found high degree of correlation between CVM and HWM methods. Thus keeping all the points in the mind as stated by Houston et al., the use of individual ossification events is of limited use during pubertal growth-spurt prediction, and analysis that includes bone stages as well as ossification events is recommended.[30]

Future work: The application of CVM method can be improved by addition of advance computer intelligence techniques. E.g. First, additional efforts and testing need to be made in order to replace the manual cervical vertebrae contour tracing by an automatic one. This technique should not only includes the single digital image further segmentation of digital images or if possible implementation of augmentation reality can improve the clinician experience adding on to treatment time preservation.[49] Secondly, a mathematical model of shape evolution could be developed, therefore the proposed CVM method would represent just discrete cases of such models.

Conclusion

In conclusion, as the Cervical vertebrae maturity indicator has come out to be more effective method in term of lesser evaluating landmarks in radiograph as compare to hand and wrist skeletal age indicator, also on the bases of radiograph used (lateral cephalogram). Great work have been done by bacceti et al, McNamara et al[37]to provide the information regarding the applicability of this method. Our effort was to briefly review the method and its application. In future, further studies are needed to evaluates its applicability over the children of different population.

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