

Cranio-cervical posture: a factor in the development and function of the dentofacial structures*

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SUMMARY Many practitioners will recognize that subjects with a large mandibular plane inclination are characterized by an extended head posture and a forward inclined cervical column, i.e. an extended cranio-cervical posture. It is also typical that subjects with a short-face morphology often carry their heads somewhat lowered, and have a markedly backward-curved upper cervical spine, i.e. cervical lordosis.

The aim of the paper is to link together the findings of a series of studies that attempt to clarify this relationship, and bring into focus cranio-cervical posture, which is a functional factor that seems to be involved in many clinical orthodontic problems.

To provide a background for the article, the concept of standardized posture of the head and the cervical column is developed, and procedures for recording this posture, as well as categories of cephalometric variables that express the different postural relationships, are described.

Findings that relate cranio-cervical posture to upper airway obstruction, to craniofacial morphology, and to malocclusion are surveyed, and a post-natal developmental mechanism that explains the findings and leads to further questions is discussed. Recent findings of a relationship between extended cranio-cervical posture and signs and symptoms of temporomandibular disorders further emphasize the biological importance of this functional parameter.

Introduction

An improved understanding of the co-ordinating mechanisms that contribute to normal cranio-facial development is of importance for diagnosis and treatment of morphological and functional disturbances in the masticatory system and adjoining structures. A factor that seems to be of relevance in this connection is the relationship between craniofacial skeletal development and the posture of the head and neck. There is at this time an explosive development in our insight into molecular and cellular aspects of craniofacial developmental biology, but many control mechanisms in craniofacial development still operate at a macroscopic level where they can be utilized or influenced by the orthodontist.

Many practitioners have recognized that subjects with a large mandibular plane inclination and long-face morphology are characterized by an extended head posture and a forward inclined cervical column. It is also typical that subjects with a short-face morphology often carry their heads somewhat lowered, and have a markedly backward-curved upper cervical spine.

Despite these observations, documentation often remains anecdotal and important questions are left unanswered: is there in fact a statistically significant association between skeletal facial development and the posture of the head and cervical column; and, if so, does facial growth influence the postural relationships or do postural relationships influence facial growth?

In a recent series of studies this relationship has been analysed utilizing a specially developed but simple standardized technique for recording posture of the head and cervical column on

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cephalometric radiographs. The most important aspect of this procedure is that it ensures not only a natural position of the head, but also a natural position of the cervical column. In the definition of this position it is emphasized that natural position of the head is the last link in the posture of the spinal column, i.e. body axis. The reproducible positioning procedure therefore calls for the subject to be recorded in a standing position and this requires that the cephalometric equipment is vertically adjustable.

In discussing head posture, the term 'natural head position' is often used. It is perhaps preferable to describe this as standardized upright posture because the term 'natural' indicates a head posture determined by the patient under certain well-defined clinical conditions, whereas 'standardized' implies a reproducible postural position.

Methodology for obtaining standardized cephalograms

The studies on which the present findings are based took place over the last 30 years and began at the Royal Dental College, Copenhagen to investigate the relationship between head posture and craniofacial morphology (Solow and Tallgren, 1971a,b, 1975, 1976, 1977). Ophthalmology textbooks describe head posture control by two different mechanisms. One is determined by proprio-sensitive nerve inputs from muscles, tendons, joints, and the balancing system of the inner ear. This is a 'crude' positioning system. The other mechanism is determined by input from the visual righting system when the subject fixes the gaze on an external object, and is a postural fine-adjustment system. This mechanism is called the visual righting system. Head posture can therefore be defined in two ways: with or without external reference, i.e. the 'self-balance position' and the 'mirror position', respectively. The self-balance position is obtained by activating the proprioceptive system, and the mirror position by subsequently also activating the visual righting system.

Since many orthodontists are not familiar with the precise procedure for recording cephalograms in standardized upright posture, the following

steps are summarized. The objective is to obtain a posture of the head and cervical column in the sagittal plane that is determined by the subject's own postural systems. This position is reproducible without systematic error, and with a method error that is sufficiently small to make the recording clinically useful (Sandham, 1988). These posturing procedures supplement the conventional requirements for standardized cephalometric records but do not replace them.

The basic conventional requirement of cephalometric radiographs is that the procedure be standardized and reproducible in order to enable superimposition of serial lateral head films for analysis of growth and treatment. These standards require the position of the film holder to be mechanically locked so that the distance to the mid-plane of the head holder remains permanently constant to ensure consistent enlargement. The ear rods must be used to ensure that the median plane of the head is at a constant distance from the film, and head posture must be corrected for rotation and lateral tilt in order to obtain maximum coincidence of bilateral structures.

Recording of standardized posture introduces a few additional requirements, namely a rehearsal stage outside the cephalometer and the actual positioning stage in the cephalometer.

A study of body posture by Møhlave (1958) has shown that the most reproducible standing position, termed the ortho-position, occurs in the transition from standing to walking. Young children usually need no particular instruction about body posture except to place heels together and let the arms hang. Older and tense or tall patients may be instructed to walk on the spot a few times, and asked to raise and lower the shoulders to ease tension.

The self-balance position of the head will normally be achieved in young children without any special instructions. Older and more anxious patients may be instructed to find this position by tilting the head slightly up and down with a decreasing amplitude, and then find the most comfortable position in between.

After this rehearsal the patient is positioned in the cephalometer where the posturing sequence

is divided into four phases: the positioning of the feet, the body, the head, and finally adjustment for symmetry. The patient walks into the cephalometer and is placed under the raised head holder. It is important that the operator does not grab or push the head or neck with the hands since this will change the cranio-cervical angle. Instead the operator places a foot in front of the patient's feet, who is then instructed to move slightly forwards to contact the operator's feet (Siersbæk-Nielsen and Solow, 1982). The body positioning and head positioning that were rehearsed outside the cephalometer are then repeated if necessary.

The mirror position is then defined by instructing the patients to look in their own eyes in the mirror. The head holder is then lowered and the ear rods gently inserted to just touch the inside of the meatus. The final adjustment for symmetry can be carried out with a projected vertical and horizontal light beam on the face if this is available on the cephalometer.

Postural variables

These consist of three main categories: (1) those that relate the posture of the head to a line representing the cervical column, i.e. the cranio-cervical angles (NSL/OPT, NSL/CVT); (2) those that express the cervical inclination in relation to the environmentally determined true horizontal, i.e. the cervico-horizontal angles (OPT/HOR, CVT/HOR); and (3) those that relate posture of the head to an environmentally determined vertical or horizontal line, i.e. the cranio-vertical angles (NSL/VER, NL/VER) (Figure 1) (Solow and Tallgren, 1971a,b, 1975, 1976; Solow *et al.*, 1993).

The first postural study was cross-sectional in design (Solow and Tallgren, 1976). It was a correlation study of 120 Danish male dental students aged 20–30 years. Cephalograms of the students were obtained in the self-balance and mirror positions and variables describing craniofacial morphology were correlated with variables defining head posture. The results showed low but significant correlations with many of the dimensions for craniofacial morphology. It was clear that the cranio-cervical

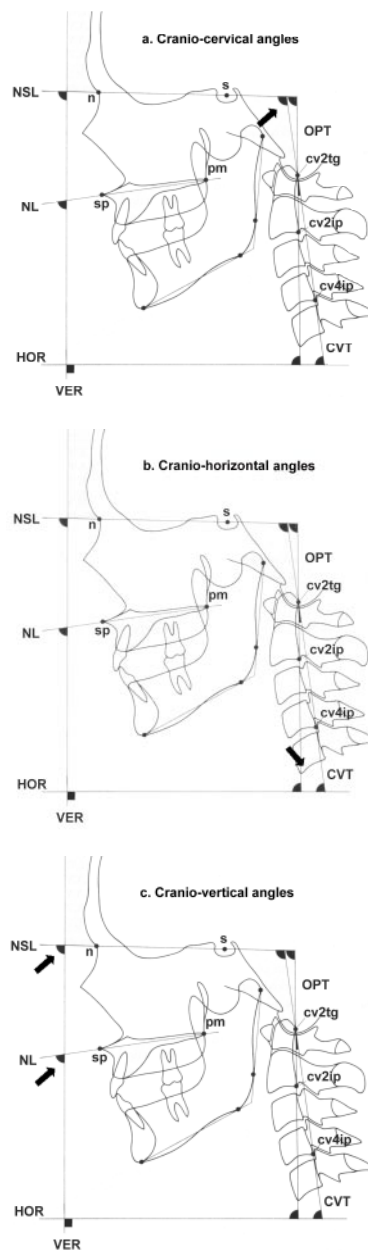


Figure 1 Postural angles: (a) cranio-cervical (NSL/OPT, NSL/CVT); (b) cervico-horizontal (OPT/HOR, CVT/HOR); (c) cranio-vertical (NSL/VER, NL/VER).

angles showed the largest and most consistent set of associations with craniofacial form. Subjects with a small cranio-cervical angle had, on average, a small anterior face height with

increased mandibular prognathism and a small mandibular plane inclination. Subjects with a large cranio-cervical angle had, on average, large anterior face heights, maxillary and mandibular retrognathism, and a large mandibular plane inclination.

Based on these findings, the differences in average craniofacial morphology of subjects with large and small cranio-cervical angles are demonstrated in mean diagrams of the two extreme postural subgroups of 10 subjects, superimposed on the NSL line. A longer, more retruded face was seen in the group with the most extended cranio-cervical posture, and a shorter more prognathic face in those with the most flexed cranio-cervical posture (Figure 2).

The large difference in the craniofacial morphology of the two extreme groups with large and small cranio-cervical angle was in itself surprising, but it also resembled another, well-known difference in morphology between subjects with high and low mandibular plane angles.

To further explore these findings the high mandibular plane angle group was compared with the large postural angle group, and the low mandibular plane angle group with the small postural angle group. The visual agreement was even more striking and it was suggested that the variability in cranio-cervical posture seemed particularly related to mandibular development.

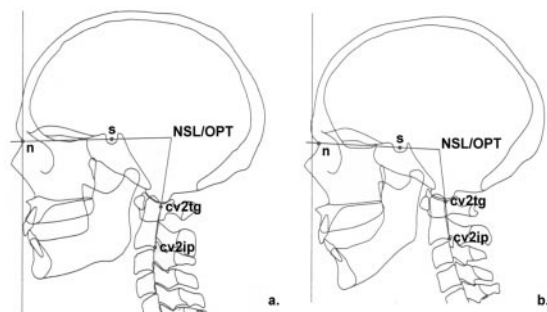


Figure 2 Cross-sectional study: (a) subjects with a small cranio-cervical angle had on average a small anterior face height with increased mandibular prognathism and a small inclination of the mandibular plane; (b) subjects with a large cranio-cervical angle had on average a larger face height, maxillary and mandibular retrognathism, and a large inclination of the mandibular plane.

Analysis of craniofacial correlations in cross-sectional studies is, however, uncertain due to difficulty in eliminating the effect of topographical correlations. In order to further analyse whether the findings reflected growth-co-ordinating mechanisms, a longitudinal study was carried out. The aim of the investigation was to analyse the correlations between growth changes in craniofacial morphology, and those in head and cervical posture (Solow and Siersbæk-Nielsen, 1986). Lateral cephalometric radiographs of 43 children were recorded in the mirror position on two occasions before the start of orthodontic treatment. The mean duration of the period of observation was 2.7 years and associations between growth changes for dimensions representing craniofacial morphology and postural angles were analysed. By focusing on growth changes only, some of the disadvantages of conventional cross-sectional analyses could be avoided.

The results showed that the most conspicuous cluster of associations was between growth rotation of the mandible, assessed by structural regional superimposition, and the change in the cranio-cervical angles. Correlation coefficients of about 0.5 indicated that with flexion of the head, i.e. when the cranio-cervical angle was reduced, there was a more pronounced forward growth rotation of the mandible, whereas extension of the head, with an increase of cranio-cervical angle, was accompanied by a reduced forward rotation or even backward rotation of the mandible.

This supported findings, suggested by the cross-sectional study, that growth co-ordination between changes in craniofacial morphology and postural changes exists, and that the co-ordination is centred on the development of the mandible.

The two extreme cases from the study illustrate these associations (Figure 3). With flexion of the head there was forward rotation of the mandible, whereas with extension of the head the growth was vertical and there was no forward rotation of the mandible.

Longitudinal studies do not provide information about cause and effect, so to further explore this question a predictive study was

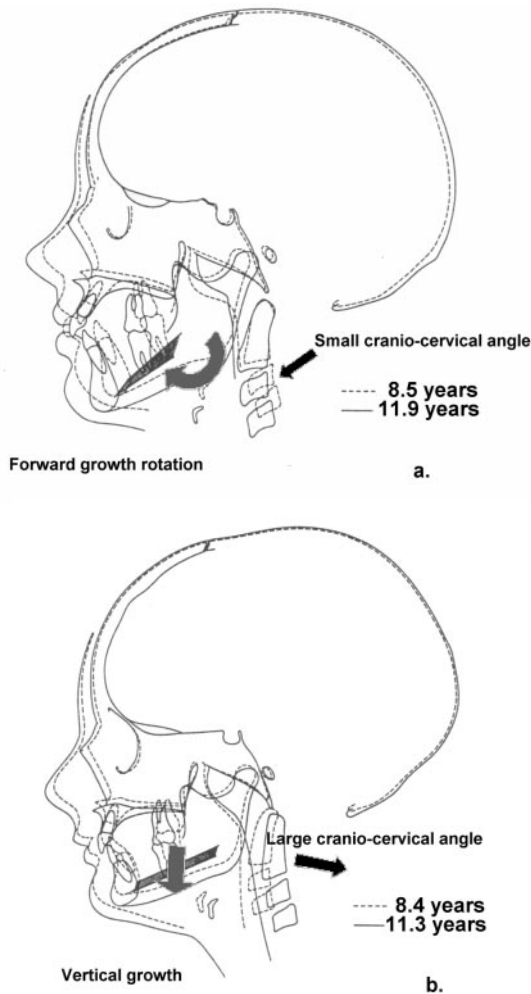


Figure 3 Longitudinal study. Two extreme cases from the study illustrate that with (a) flexion of the head there was forward rotation of the mandible, whereas with (b) extension of the head the growth was vertical and there was no forward rotation of the mandible.

carried out. The aim was to establish whether it was possible to predict postural changes from mandibular shape, or if it would be possible to predict mandibular growth rotation from cranio-cervical posture (Solow and Siersbæk-Nielsen, 1992).

To enhance the sensitivity of the investigation, the children were selected on the basis of their skeletal maturity instead of age and gender. This was assessed from hand radiographs, and those with a skeletal maturity close to the peak height

velocity in growth were selected (Helm *et al.*, 1971).

The first pre-treatment records of these children had been obtained 2–4 years earlier, so the study covered the period 2–4 years before the age of peak velocity in pubertal skeletal growth.

The correlations between the dimensions at the first observation, and the skeletal and postural changes during the study period were examined. There were no associations between craniofacial morphological dimensions at the initial examination and the subsequent postural changes, but the differences in cranio-cervical posture resulted in very different types of facial development. The very small cranio-cervical angle at 9 years of age was followed by a marked forward growth of both maxilla and mandible, whereas the large cranio-cervical angle at the age of about 9 years resulted in a vertical facial development that could also be seen in the vertical position change of the hyoid bone. The cranio-cervical angle 2–4 years before the peak pubertal growth velocity therefore gives predictive information regarding subsequent facial development.

The magnitude of the predictive correlations was about 0.3–0.6, which is low to moderate, and this documents a general average tendency. Prediction of the development in the individual child is only possible for those children with extreme cranio-cervical postural relationships. If ± 2 SD confidence limits are used, it can be predicted with reasonable certainty that subjects with a cranio-cervical angle of less than 79 degrees will have a subsequent forward facial growth direction, and those with a cranio-cervical angle larger than 113 degrees are likely to have a subsequent vertical facial growth pattern.

Cranio-cervical posture (NSL/OPT) is related to craniofacial development, although other cranial and cervical reference lines might, in principle, be used to express this postural relationship. The cervico-horizontal angles (OPT/HOR, CVT/HOR) seem to be important in mediating large changes in the cranio-cervical relationship. These angles usually show the same relationship to craniofacial development as the cranio-cervical angle, but with the opposite sign,

due to the construction of the angle. The cranio-vertical relationship (NSL/VER, NL/VER) is clearly not related to the amount or direction of facial growth (Figure 1).

The above three studies taken together suggest that there is indeed a mechanism that co-ordinates cranio-cervical posture and facial development. It is posture, or factors determining posture, which influence the direction of facial development. The next question concerns the factors that can trigger extension of the cranio-cervical angle (NSL/OPT).

The anatomical and functional complexity of the upper airway offers numerous possibilities for airway compromise, but because of the vital importance of a free airway, some form of counteractive physiological response invariably follows obstruction. It seems that a common type of response is postural in nature, and is seen as an increase in cranio-cervical postural relationship.

Upper parts of the airway can be divided into nasal, nasopharyngeal, and oro-pharyngeal segments, and each may be the site of obstruction. The most common cause of nasal obstruction is rhinitis, with allergic rhinitis being the most common cause of long-term nasal obstruction. The typical clinical appearance of the nasal obstruction is dark rings under the eyes due to an enlarged subcutaneous venous plexus, and a running nose.

Two groups of children with nasal obstruction, one due to asthma and the other due to perennial nasal allergy, have been investigated (Wenzel *et al.*, 1985). In the experimental group there was an immediate reduction of the cranio-cervical angle after administration of a corticosteroid decongestant. This indicated that the nasal obstruction resulted in an extension of the head that was reversible after treatment.

Nasopharyngeal obstruction is usually caused by adenoid hypertrophy. The clinical features are mouth breathing, collapsed nostrils, dark rings under the eyes, and also a generally less than alert expression of the face. A further study was carried out to examine whether adenoidectomy, to eliminate airway obstruction, would have an effect on head posture (Solow and Greve, 1979). Airway resistance can be measured by

rhinomanometry (Solow and Greve, 1980; Solow and Sandham, 1991). In all children whose airway resistance was reduced, there was also a reduction in cranio-cervical angle, and the head again came down over the tongue (Solow *et al.*, 1984; Solow, 1992).

In a study of cranio-cervical posture in subjects with and without enlarged tonsils, Behlfelt (1990) showed that those with enlarged tonsils had cranio-cervical angles on average 4–8 degrees larger.

Oro-pharyngeal obstruction also occurs in obstructive sleep apnoea (OSA), which is characterized by repeated collapses of the oro-pharynx. A study was carried out to determine head posture in OSA diagnosed by polysomnography in 50 subjects (Solow *et al.*, 1993). The average cranio-cervical angle was found to be approximately 10 degrees larger than that in six different reference samples without OSA; in all cases highly significant.

It can therefore be demonstrated that obstruction of the upper airway can lead to extension of the cranio-cervical angle, but an explanation is required as to how extension of the cranio-cervical angle produces a change in craniofacial development.

Hypothesis for the observed changes in craniofacial growth and development

To provide this explanation all the available evidence was considered and an attempt was made to link the chain of events. There was an association between head posture and craniofacial morphology, and cranio-cervical posture influenced subsequent craniofacial growth. Obstruction of the upper airway could lead to a postural change resulting in extension of the cranio-cervical angle. The precise mechanism of coupling is not known, but it was assumed that it must be present, and it was given the general designation 'neuromuscular feedback'.

The next link in the chain posed a bigger question. The mechanism was intuitively derived from the results of the first cross-sectional study of associations between head posture and craniofacial morphology (Solow and Tallgren, 1976), and was termed 'soft-tissue stretching',

which was also used to designate the name of a hypothesis that was proposed (Solow and Kreiborg, 1977) (Figure 4).

In the studies described in this paper, the cranio-vertical angles showed little or no association with craniofacial development, so the force of gravity was excluded. The differences in craniofacial morphology could be explained in terms of forces that the soft-tissue layer of facial skin and muscles exert on the facial skeleton. The idea was that this layer would be passively stretched when the head was extended in relation to the cervical column. This would

increase the forces on the skeletal structures, and such forces would restrict the forward growth of the maxilla and the mandible, and redirect it more caudally.

This final link in the chain could be termed 'differential forces on the skeleton' in relation to postural changes (Figure 5).

The idea was lacking in evidence, but some years later Hellsing and L'Estrange (1987) reported precisely such forces. In a sample of dental students a tiny pressure transducer was glued to the labial surface of an upper central incisor and the pressure recorded when the subject tilted their head 5 degrees up from natural head posture then 5 degrees down. The changes in head posture resulted in a difference of several grams being recorded on the pressure transducer when the head was tilted through 10 degrees. Such differences could easily influence dentofacial and skeletal development.

This is seen most clearly when dramatic disturbances in craniofacial growth occur such as in juvenile rheumatoid arthritis affecting both condyles (Kreiborg *et al.*, 1990). Application of the soft-tissue stretching hypothesis even leads to an explanation of the development of the antegonial notching, which no other hypothesis has explained satisfactorily.

Soft-tissue stretching hypothesis

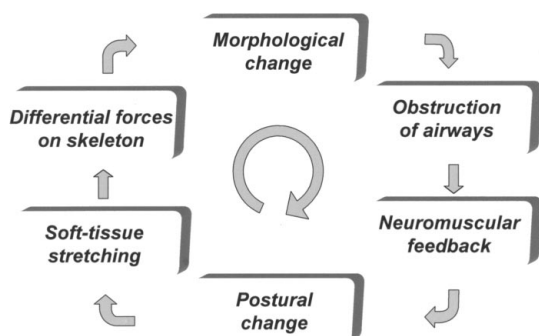


Figure 4 The soft-tissue stretching hypothesis.



Figure 5 Soft-tissue stretching. The morphological change induced by passive stretching of the soft tissues when the head was extended in relation to the cervical column. This increases the forces on the skeletal structures, and such forces restrict the forward growth of the maxilla and mandible and redirect it more caudally. Figure 2 from Solow and Kreiborg (1977) *Scandinavian Journal of Dental Research* 85: 505–507, reproduced with permission.

The direction of the chain of events can probably be reversed, but when this has been operating over a long period of time it becomes a vicious circle of events that should be at least interrupted or prevented.

It is easy to find confirmatory evidence for such a hypothesis. Scientifically, however, hypotheses are not confirmed by corroborative evidence, but by testing predictions derived from the hypothesis. In this respect the hypothesis is of special interest because a number of refutable predictions can be derived. For each of the components of the sequence, it is easy to think of conditions that could initiate the chain of events, and studies can be planned to test this. Pathological craniofacial conditions that prevent the normal development of the upper airway would be expected to result in upper airway obstruction. Numerous other conditions can also lead to upper airway obstruction and thus act as triggering factors at this site of the chain of events. Pathological and functional disturbances in the proprioceptive, visual, utricular, semi-circular canal, or other neural components of postural control could lead to postural changes, and spinal column anomalies could influence cranio-cervical and cranio-horizontal posture. Scar tissue after burns or accidents also exerts soft-tissue pressure on skeletal structures, and lastly, but certainly not least, dentofacial orthopaedics and orthognathic surgical intervention might encroach on upper airway adequacy, and thus trigger an undesirable sequence of events, which should be taken into account in treatment planning.

In view of the wide range of associations between cranio-cervical posture and craniofacial morphology, the question of an association between posture and malocclusion is of interest. This problem was examined recently (Sonnesen, 1997; Solow and Sonnesen, 1998; Sonnesen *et al.*, 1998). Pre-treatment cephalometric records, taken in the mirror position, were obtained from 96 children, and nine postural angles were measured on lateral cephalometric radiographs. Malocclusion was classified and diagnosed clinically, and mean postural differences were calculated between subjects with and without each malocclusion trait. One group of traits involving crowding showed a consistent set of associations

with cranio-cervical angles. The results demonstrated that subjects with crowding of more than 2 mm in the upper or lower anterior or lateral segments had cranio-cervical angles that were on average 3–5 degrees larger than those without crowding in these segments. None of these associations was due to the effect of age or sex.

These findings follow the predictions of the soft-tissue stretching hypothesis, according to which an increased dorsally directed soft-tissue pressure in subjects with an extended cranio-cervical posture restricts the 'normal' forward development of the dentoalveolar arches. On the other hand, the results should be considered with caution as the assessment of space conditions was made by visual inspection. A new study using a new sample is now taking place to help confirm these data.

Further work has now shown that cranio-cervical posture is related not only to craniofacial morphology, but also to dysfunction of the temporomandibular joint. The study related craniofacial morphology to temporomandibular dysfunction (TMD), but head posture variables were also included in the analysis (Sonnesen *et al.*, 2001). A series of remarkable associations were found between a group of temporomandibular variables, namely symptoms and signs of TMD and cranio-cervical (NSL/OPT) and cervico-horizontal variables (OPT/HOR, CVT/HOR).

It was found that TMD, in the form of clicking and reduced mobility was associated with a marked forward inclination of the cervical column and a marked increase in the cranio-cervical angulation, and the strongest associations were found for the cervical inclination, expressed by the CVT/HOR variable (Figure 1).

Subjects with difficulty in opening, clicking assessed by stethoscope auscultation, locking of the jaw, and asymmetrical opening movement also had cranio-cervical angles that were 5–7 degrees larger than those without these traits.

These findings are interesting in themselves, but also because they provide us with a link to a neighbouring clinical profession that is rarely referred to in the orthodontic literature, namely physiotherapists. Signs and symptoms of TMD, to a certain extent overlap signs and symptoms

of cervical spine disorders, and clinical observations of a forward head posture in subjects with cranio-mandibular dysfunction have also been reported. The present study (Sonnesen *et al.*, 2001), using a more accurate technique of cephalometry recorded in the standardized upright posture, has been able to confirm clinical observations by physiotherapists of a relationship between symptoms and signs of TMD and posture of the head and neck.

The finding is clinically valuable for both orthodontists and physiotherapists. Perhaps lateral cephalometric radiographs recorded in the standardized upright posture should be used by physiotherapists for a more differentiated assessment of cranio-cervical postural relationships, and perhaps co-operation with a physiotherapist could also be an option for the orthodontist in the analysis and treatment of orthodontic patients at risk for, or in the treatment of TMD.

Conclusion

The importance of good body posture and function of the airway is of considerable importance in orthodontics and the concept of 'functional and postural competency' in dentofacial development cannot be overlooked in treatment planning and the management of a broad range of craniofacial conditions.

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