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Measurement Properties of the Sagittal Craniocervical Posture Photogrammetry

by

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DEDICATION

I would like to dedicate this thesis to all my family who supported me on achieving my PhD, especially to my amazing parents Clara Orzechowski and Moacir Gadotti who I love, admire, and miss so much (you are the best parents in the world!), to my great stepfather Renato Orlando Pereira, to my brilliant and adorable brother Dimitri Gadotti, and to my wonderful parents-in-law Jussara Ramos Vieira and Jair Vieira Filho. I love you all so much! To my beautiful husband Edgar Ramos Vieira who is essentially responsible for my happiness in Canada. I admire you every day. You are everything to me! To my grandfather Fortunato Gadotti that just passed away after 95 years of a great life! I will miss you.

ABSTRACT

Commonly in clinical settings, the patient's posture is visually evaluated by the clinician using anatomical landmark references. However, this measurement is subjective and not quantifiable. Photogrammetry to assess posture was thought to be a possible good clinical alternative to the other methods because it is non-invasive, quantifiable, and less expensive. However, more tests were needed to determine its validity. This study tested the reliability and the validity of five angles measuring craniocervical posture using photogrammetry. Radiographs and photographs of the craniocervical posture of 39 healthy-female subjects were taken in a standardized sagittal standing position. Markers were placed on the back of the subject's neck and ear. A second photograph and radiograph was taken 1 week later using 21 of the 39 subjects to test reliability. The angles were analyzed using Alcimage® software. Intraclass-correlation coefficient and standard error of measurement was used to test the reliability. Concurrent validity was tested using Pearson correlation and regression analysis. Discriminant analysis was used to test the discriminant validity. Sensitivity/specificity and predicted values were also calculated. The results showed that photogrammetry ICC values were good to excellent when assessed by 2 raters (ICC=0.89-0.99). The posture of the subjects was reproducible when tested using radiographs (ICC=0.89-0.98). One rater was reliable in reattaching the markers (ICC=0.71-0.91) and precise in locating the reference spinous processes (87.8%). Craniovertebral angle (CVA) appeared to be valid in measuring the position of the head in relation to the cervical spine (r=0.84) and to be able discriminate subjects with aligned posture, slight forward head posture (SFHP), and forward head posture (FHP) assessed by 1 rater (84.6% correctly classified). Cervical inclination angle (CIA) appears to be valid in discriminating subjects with aligned and FHP (86% and 88% respectively) but moderate to predict the cervical spine inclination. The cervical lordosis angles were not able to discriminate postures and predict the cervical lordosis. CVA and CIA were able to detect postural differences through the sensitivity/specificity and predicted values analysis. This study supports the validation of CVA and CIA to assess craniocervical posture which may improve the ability of the clinician to detect and quantify craniocervical postural alterations.

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CHAPTER 1. INTRODUCTION

POSTURE AND ITS MEASUREMENT IMPLICATIONS

The Posture Committee of the American Academy of Orthopaedic Surgery defined good posture as, "that state of muscular and skeletal balance that protects the supporting structures of the body against injury or progressive deformity irrespective of attitude (i.e. erect, lying, squatting, stooping) in which these structures are working or resting. Under such conditions the muscles will function most efficiently and the optimum positions are afforded to the thoracic and abdominal organs." (1) (p. 168)

According to Kendall (2), body segments are arranged in the ideal posture so that the demands created by gravity are minimized. A vertical line through the body's centre of gravity serves as a reference point for analyzing the effect of gravity on body segments. Good posture is achieved when the center of gravity of each body segment is placed vertically above the segment below.

The effort required to balance the head against the forces of gravity increases when posture is altered. The change stresses the cervical structures, triggering pathological responses to abnormal tissue positioning and stretch which can cause pain. (3) Forward head posture (FHP) has been thought to affect the muscular biomechanics in the neck-head region, causing referral of symptoms from the cervical spine to the head and face region. (4-6) Neuroanatomical and physiological mechanisms for such pain referral to the head have been recognized. (7,8) The mechanism for the pain response is convergence between the trigeminal afferents and afferents of the upper three cervical nerves in the trigeminocervical nucleus in the neck. (8) (for details see Chapter 2).

Forward head posture is one of the common types of poor posture seen in patients with neck pain, (3,9) temporomandibular disorders (TMD), (10-12) and headache. (13,14) Women appear to be more affected by pain syndromes in the craniocervial region such as TMD, (15) neck pain (16,17) and headache (15) when compared with men. Pain in the temporomandibular region is approximately twice as common in middle-aged women as in men. It has been reported that cervicogenic headache (CEH) and tension-type headache is present in 79.1% and 86% in female population respectively. The mean age was reported to be 42 years old for CEH and between 20 and 40 years of age for tension-type headache. (15,18) Similarly, the incidence of neck pain has been found to be slightly higher in women than men and it increased slightly with age having its peak between the ages of 30 and 45 years. (19)

The association between pain and postural alteration is discussed below.

Postural Alterations and Neck Pain

Neck pain has become one of the most commonly reported complaints of the musculoskeletal system for which health care is sought. (20) The position of the forward head posture for a prolonged period of time is considered to be one of the risk factors for neck pain. (21)

In a study by Falla et al (22), subjects with chronic neck pain were found to have a reduced ability to maintain the head in an upright neutral posture when distracted by a computer task. According to the authors, sustained forward head posture associated with prolonged sitting could initiate and aggravate neck pain.

McAviney et al (9) investigated whether the amount of forward head posture was related to neck complaints. These authors found that subjects with cervical pain had less cervical lordosis measured in cervical radiographs using the ARA (absolute rotation angle). Patients with straight or kyphotic cervical curves were 18 times more likely to present with cervicogenic symptoms. A statistical significance was found between cervical pain and lordosis of less than 20º (the cervical lordosis range of 31 º to 40 º was considered "clinically normal" according to the authors). The result was consistent over all age ranges and no trend linking cervical lordosis with age was found. The authors concluded that the maintenance of lordosis in the range of 31 º to 40 º might be a clinical goal in the treatment of patients with cervical posture alteration and pain. Similarly, Kristjansson & Jonsson (23), studied lateral cervical x-rays in a seated position for 3 groups of women with chronic neck pain: whiplash group, insidious neck pain group, and those who were asymptomatic. Angles of the upper and lower cervical curvatures and angles between each pair of vertebra were measured. The whiplash group was in a significantly more flexed position at the C4-C5 level compared with the asymptomatic group (mean difference of 3° (95% CI, 0.8–5.2)). The difference was not statistically significant but the authors concluded that it might be clinically important.

The incidence of postural abnormalities in the thoracic, cervical, and shoulder regions in two age groups of healthy subjects and whether these abnormalities were associated with pain was investigated by Griegel-Morris et al. (24) Subjects with more severe postural abnormalities had a significantly increased incidence of pain. Subjects with kyphosis and rounded shoulders had an increased incidence of interscapular pain, and those with a forward head posture had an increased incidence of cervical and interscapular pain and headache.

Postural Alterations and Temporomandibular Disorders

Temporomandibular disorders (TMD) is a broad term that contains several clinical problems involving the stomatognathic system which is responsible for phonation, deglutition, breathing and mastication functions of them uscular/masticatory/cervical complex and the temporomandibular joint. (25) TMD is characterized by signs and symptoms such as pain in the temporomandibular joint (TMJ), limitation of the mandibular movements, headache, sounds in the TMJ during mandibular function, tinnitus, otalgia, and fatigue of the masticatory, cervical and scapular muscles. (26,27) The etiology of TMD is complex and consists of neuromuscular factors such as bad posture and bruxism; anatomical factors (dental occlusion); and psychological factors such as stress that increases muscular activity. (28)

Some publications have stated that the forward head posture can cause TMD. (6,29-31) Head posture and its relationship to occlusion, to the development and function of the dentofacial structures, and its relationship with TMD, have been studied. Head posture alterations have been associated with changes in the stomatognathic system, influencing the biomechanical behavior of the TMJ and associated structures. It has been suggested that the position of the head affects the resting position of the mandible, (6,32) increases muscular activity (29), and alters the TMJ internal relationships. (33)

Some studies have evaluated postural alterations in TMD patients. Lee et al. (10) analyzed the head posture of TMD patients, comparing them with age-and gender-matched controls and verified a smaller craniovertebral angle in TMD patients than in control subjects (3 degrees of difference), suggesting that TMD patients have a more forward head position than non TMD patients when using the craniovertebral angle to measure posture. Visscher et al. (34) reported that signs and symptoms of cervical spine alterations were significantly greater in both myogenous and/or arthrogenous TMD patients in relation to healthy controls. On the other hand, Hackney at al. (35) evaluated head posture in patients with internal derangement of the temporomandibular joint (i.e. TMD of articular origin) compared with control subjects using radiographs. These authors found there was no significant degree of FHP in the patient group compared with control subjects. Despite the contradictions in the literature, postural training has been one of the interventions recommended in order to restore and optimize the alignment of the craniomandibular system in patients with myogenic TMD (36) based on two randomized controlled trials. (37,38) However, more good quality randomized controlled trials are needed to substantiate the significance of postural treatment for these patients.

The connection between TMJ dysfunction and forward inclination of the upper cervical spine with an increase in the craniocervical angulation was found by Sonnesen et al. (significant differences between -4.88° to -8.04°). (39) Solow and Sonnessen (40) felt that extension of the craniocervical posture led to a passive stretching of the soft tissue layer (i.e. skin, muscles and fascia that cover the head and neck). They felt this condition created a dorsally directed force that impeded the forward directed component of the normal growth of the face. This hypothesis may explain the influence of the forward head posture on the development of the facial skeleton, including the mandible. Two randomized controlled trials (RCTs) also found a close relationship between head and cervical posture improvement and the relief of symptoms of myogenous TMD. (37,38)

In a systematic review looking at the association between head and cervical posture and TMD performed in 2006, (41) out of 12 papers included in the study, 9 reported that postural alteration was associated with TMD. However, the studies included in the review were of poor methodological quality (related to randomization, sample size, outcome measures, and blinding procedure). Most of the papers considered patients with a mixed TMD diagnosis, and just a few publications were found that addressed muscular and intra-articular TMD separately. According to the authors, it was not clear that head and cervical posture were associated with intra-articular and muscular TMD because of the level of evidence in the studies. Visscher et al. (42) investigated the differences in head posture between TMD patients with or without a painful cervical spine disorder and healthy controls, concluded that there was no indication of development of a chronic pain complaint in the masticatory system as a result of an abnormal head posture. In addition, no differences in head posture were found between the subgroups of TMD classified according to a clinical examination. However, the sample size of the study was not appropriate (small and unbalanced) and the method used to assess head posture was not validated. Therefore, more studies with higher quality methodology are necessary to determine whether the head posture can behave differently in TMD patients.

According to Grossi and Chaves, (43) despite the evidence of correlation between the cervical spine alteration and TMD signs and symptoms, there have been only a small number of studies that have established a correlation between these signs and symptoms and craniocervical posture alterations using quantitative methods in TMD patients. (10,35,37,42) Thus, further studies using quantitative techniques to evaluate craniocervical posture are necessary to support the evidence of a relationship between the two systems. In addition, using a good clinical diagnostic technique to assess craniocervical posture should lead to a reasonable and effective treatment for patients with TMD.

Postural Alterations and Headache

The International Headache Society recognizes that some forms of headache can be attributed to pain referred from the cervical spine. (44)

Headaches can be the result of stress, muscle tension and nerve compression in the cervical spine. (13) The group of headaches caused by disorders in the neck is defined as cervicogenic headache (CEH). (8,44) Cervicogenic headache is commonly precipitated by sustained neck postures or neck movements and sometimes relieved by posture changes. (45) Some authors suggest that patients with cervical pain and headache can present with FHP. (14)

A systematic review and a meta-analysis was conducted to investigate the evidence concerning cervical musculoskeletal impairments in subjects with CEH. (5) The evaluation of musculoskeletal impairments of the cervical spine can help in the diagnosis and treatment of CEH. (46,47) From 10 articles included in the study, three addressed the association between FHP and CEH. (46,48) Two of these studies (48,49) found that patients with CEH had greater FHP (smaller angle measured on photographs) than the control subjects. Watson & Trott (48) concluded that clinicians should be aware of a possible relationship between CEH and poor craniocervical posture and that postural treatment should be part of the prevention and management of patients with CEH. On the other hand, one study (46) found no significant difference in head posture between patients with CEH and control patients. The results from the meta-analysis combining all the studies obtained a weak effect but favoring a decreased craniovertebral angle for patients with CEH. A relationship between FHP and CEH has been proposed although the evidence is not definitive. (50) More studies are needed to confirm this relationship.

Despite of the need of further studies to investigate the association between postural alterations and the presence of many head-face pain syndromes such as temporomandibular disorders and, neck pain and, headache (5,41), an indication of relationship needs to be considered. Therefore, the assessment of the craniocervical posture in the sagittal plane may be an important diagnostic tool for the evaluation of these patients in relation to the presence of forward head posture. This assessment has been shown to be an important clinical outcome of care (51) as it can detect possible postural alterations that could be related to the presence of pain in these patients. If the presence of forward head posture is detected by the clinical assessment, postural treatment could be performed and then the patient could be reassessed to determine if the pain level has been altered. If pain decreased with treatment, postural treatment is more likely to be a factor in the patient's improvement.

Even though good posture is well defined in the literature, a variety of postures exists in the population and the definition of a normal posture is still questionable. (52) Therefore, "normal posture" may not be the appropriate definition to be used when classifying different postures. Because the good posture is defined based on the alignment of the anatomical landmarks, the "aligned posture" will be used in this study instead of "normal posture".

APPROACHES FOR MEASURING POSTURE

Upright standing positions are frequently used to measure postural alignment. (3) However, some studies had investigated craniocervical posture in a sitting position. (53,54) Sustained and poor sitting postures, especially in front of the computer, have been identified as important risk factor for back pain. (53,54) Craniocervical posture in standing or sitting position is believed to be influenced by the position of the trunk, pelvis, arms, and legs. Therefore, the evaluation of the craniocervical posture requires a standardized approach in relation to the different aspects of the body. (3,53)

Constant small adjustments are made by healthy subjects instinctively for the maintanence of posture to counterbalance the effects of gravity against the erect human body in terms of balance, postural sway, and motor planning. Therefore, the advantage of using the sitting position instead of the standing position is that in sitting position, postural sway may have a decreased influence. Sitting posture may provide more reliable measures of repeated cervical posture than upright standing postures because postural sway may be reduced. Possible differences between repeated measurements in standing may not reflect a lack of “within subject” reliability but may provide information about usual individual patterns of postural correction. (55)

The upright standing posture is normally used as a diagnostic approach to guide clinical treatments and exercise programs. (56) In the present study, the standing posture was used instead of sitting in order to understand how the cervical spine supports the weight of the head against the forces of gravity (3) when the trunk, pelvis, arms, and legs are also influenced by these forces so the small adjustments for the maintanence of the overall posture such as the postural sway could be also present in the investigation of the craniocervical posture assessment.

Among the techniques used to assess craniocervical posture, the radiographic method has been considered the gold standard for assessing the position of the cervical vertebrae (i.e. vertebral alignment) and the position of the head in relation to the cervical spine. (53,57) However, non-invasive measurements are also of value for clinical purposes (such as the assessment of head posture by a physical therapist in a clinical setting). The benefits of a non-invasive technique over radiographic methods are that it is less expensive, there are fewer technical difficulties, and there is no risk of radiation exposure. (58)

In practice, most clinicians visually evaluate posture using anatomical landmarks as reference points as described by Kendall et al. (2) Kendall recommended the use of a postural grid with a plumb line for alignment. In terms of craniocervical posture, the traditional vertical reference line in a lateral view should pass through the lobe of the ear and the tip of the shoulder. (2) The advantages of using visual assessment to classify head posture include the fact that it is an easy and a fast method. However, the visual assessment is more subjective and therefore less sensitive. The intra- and inter-rater reliability of the visual assessment of the cervical lordosis was found to be fair (kappa= 0.50). (59) According to the authors, the visual assessment should not be discarded because of the poor reliability, but other tools that are more accurate and reliable should be used in combination with visual assessment in order to improve the quality of the cervical posture examination. According to Grimmer-Somers et al, (3) "there is no standard method of describing or objectively measuring habitual cervical resting posture" (p. 510). A more quantifiable method for assessing posture in a clinical setting is necessary in order to improve the clinical evaluation.

Given the advances in technology, digital photographs are now more feasible to use in clinical practice. Measurements of head posture from photographs is believed to provide more reliable data to quantify postural changes (e.g. before and after postural treatment). Computer software has been developed to calculate distances and angles on digital photographs. (3) The use of photogrammetry has been shown to be more sensitive for measuring head posture than simple visual assessment. (60) Several studies have used the photogrammetry (measurements in photographs) to quantify postural measurements. (33,48,56,61-63) The degree of forward head posture has also been investigated using sagittal photogrammetry. (10,32,35,64,65) Most of these studies evaluated the posture of patients with TMD. Other studies have investigated the correlation between superficial non-invasive measurements and radiographic measurements of cervical posture. (42,66,67) However, several authors failed to support their claims with information related to experimental methods.

Lack of Measurement Properties

Reliability, validity, and responsiveness are measurement properties that are used to evaluate the quality of a measurement. These measurement properties should be considered when doing a study but they are not often reported in rehabilitation studies. Ideally, any measurement should be reliable, valid, responsive, practical, and easy to obtain. A gold standard measurement should fulfill several requirements in order to be justifiable and clinically useful. (68) However, several studies investigating craniocervical posture using photogrammetry failed to support their claims with information related the experimental methods including the quality of the measurements. (42,66,67,69) Invalid, unreliable, incorrect findings from postural assessments could lead to errors in diagnosis and consequently improper selection of treatment.

A standard non-invasive surface technique for measuring craniocervical posture (i.e. an indicator of the position of the cervical spine in relation to the head position) has yet to be accepted. (70) Given the lack of agreed standards for measuring posture, it appears that there are opportunities for further research into posture measurement. (3) Measurement properties of the craniocervical posture have not yet been tested in relation to their reliability, validity, and sensitivity.

THESIS OBJECTIVES

The objectives of this thesis are:

1) To test the reliability of craniocervical angle measurements;
2) To test the validity of the craniocervical angle measurements.

Part 1: "Reliability of Measurements of Craniocervical Posture"

- Objectives:

1. To test the intra and inter-rater reliability of craniocervical postural angle measurements using the photographs and radiographs;
2. To test the intra-subject reliability (reproducibility) of the craniocervical postural angle measurements;
3. To test the precision of surface markers positioning in relation to the cervical spinous processes;
4. To test the reliability of repositioning the surface markers on the cervical spine one week later.

- Hypotheses:

The following hypotheses were tested:

1. The intra-rater reliability will be higher than inter-rater reliability;
2. The subject's posture will be reproducible since the posture is standardized;
3. The precision of surface markers positioning in relation to the cervical spinous processes will be good;
4. The repositioning of the surface markers on the cervical spine by the evaluator will be reliable.

<u>*Part 2*</u>*: "Validity of Measurements of Craniocervical Posture"*

- Objectives:

1. To test the concurrent validity of measurements of the craniocervical postural angles using photogrammetry (to determine the ability of the

measurements to actually predict alterations in the craniocervical spine measured using radiographs);

2. To test the discriminant validity of the measurements of craniocervical postural angles using photogrammetry; and
3. To test the sensitivity/specificity and predicted values of the measuremenst of craniocervical postural angles using photogrammetry in comparison to the radiographic postural evaluation.

- Hypotheses:

The following hypotheses were tested:

1. A good and positive correlation will be found between photogrammetry and radiographic postural angle measurements since the measures being compared assess the same aspect of posture;
2. The postural angle measurements will be able to predict clinical observation assessment of craniocervical posture;
3. The measurements will be able to discriminate different postures.

RESEARCH AND CLINICAL IMPLICATIONS

This is the first study in which certain measurement property tests of craniocervical posture using photogrammetry were analyzed. Reliability and the ability of the measurements to detect differences (sensitivity/specificity and predicted values) are prerequisites for validity and these tests have been lacking in previous studies.

A photogrammetry technique to assess craniocervical posture is of clinical importance. If a non-invasive photographic technique can be shown to be effective in assessing craniocervical posture (i.e. reliable, valid, and responsive), it would be less expensive to use than the radiographic method, and there would be no risk of radiation exposure for the patients.

Considering that visual assessment of the craniocervical posture is still a common approach among clinicians, the use of photogrammetry to assess craniocervical posture in clinical settings may improve the ability of the clinician to detect and quantify posture alterations and treatment effect. For example, a patient may be classified as having FHP after treatment by visual assessment even though improvement has occurred. The improvement might be better detected by quantifying craniocervical posture so that the clinician can be reassured that the treatment strategy is correct even though further treatment may be required. A reliable and valid method to assess craniocervical posture provides the physical therapist with the confidence to trust the measures determined during the diagnostic process. In addition, a method used to assess craniocervical posture that is sensitive or, in other words, that can discriminate different craniocervical postures, is of value for the assessment of the effect of postural treatment. Quantitative measurements of the craniocervical posture can be carried out before and after treatment and the effect compared.

This research will contribute to the improvement of the craniocervical posture evaluation using a non-invasive and quantitative approach. If effective, the use of photogrammetry may help in the search for more evidence of relationship of craniocervical postural alterations with neck pain, TMD, and headache.

DELIMITATIONS AND LIMITATIONS

Delimitations

The study was delimited to:

1. A female sample with no pain in the head and cervical spine;
2. Craniocervical postural angle assessment in an habitual upright position;
3. Two dimensional measurements of the craniocervical posture in a sagittal plane.

Limitations

The limitations of this study were:

1. The craniocervical postural measurements using the seventh cervical vertebra (C7) as a reference may be difficult to see in the radiographs because of the position of the shoulders.
2. The subjects of the study needed to be exposed to radiation which represented some risks to the subjects.
3. It was not possible to analyze the inter-rater reliability concerning the placement of the landmarks on the cervical spine of the subjects because the same subjects would need to be exposed to radiation a

second time for the second evaluator. Therefore, only 1 evaluator placed the marks on the cervical spine for the x-ray and photographs images. Only the measures of the angles (drawing) in the digitalized images were analyzed between raters.

4. Since the number of radiographs per subject needed to be limited in order to limit the exposure of the subjects to radiation, the repetitions of the measurements for the reliability analysis were also limited.

DEFINITIONS OF TERMS

Operational Definitions

In order to clarify and standardize the terms used in this research, the following definitions are described:

1. Angles of the craniocervical posture using photographs and radiographs

- **Craniovertebral angle** (line from tragus to the skin over the spinous process of C7 with the horizontal): angle that represents the position of the head in relation to the cervical spine measured on photographs;
- **Cervical inclination angle - CIA** (line from C2 to C7 with horizontal): the angle that represents the inclination of the cervical spine measured on photographs (using skin) and radiographs - (using center of the body vertebrae - CIAr or spinous process - spCIA);

- **Adapted cervical inclination angle - ACIA** (line from C2 to C6 with the horizontal): the angle that represents the inclination of the cervical spine measured on photographs (using skin) and radiographs (using center of the body vertebrae - ACIAr or spinous process - spACIA);
- **Cervical angle - CA** (line from C2 to C4 and from C4 to C7): the angle that represents the lordosis of the cervical spine measured on photographs (using skin) and radiographs (using center of the body vertebrae - CAr or spinous process - spCA);
- **Adapted cervical angle - ACA** (line from C2 to C4 and from C4 to C6): the angle that represents the lordosis of the cervical spine measured in photographs (using skin) and radiographs - (using center of the body vertebrae - ACAr or spinous process - spACA);
- **NSL/OPT** (nasion-sella line with odontoid process tangent): the angle that represents the position of the head in relation to the cervical spine measured on radiographs;
- **NSL/CVT** (nasion-sella line with cervical vertebra tangent): the angle that represents the position of the head in relation to the cervical spine: measured on radiographs;
- **OPT/hor** (odontoid process tangent with horizontal): the angle that represents the inclination of the cervical spine measured on radiographs;
- **CVT/hor.** (cervical vertebra tangent with horizontal): the angle that represents the inclination of the cervical spine measured on radiographs;

- **ARA** (Absolute rotation angle): the angle that represents the lordosis of the cervical spine measured on radiographs;
- **Am/C7/hor** (line from auditory meatus to spinous process of C7 with horizontal): the angle that represents the position of the head in relation to the cervical spine measured on radiographs (using the spinous process) measured on radiographs;

2. Postural definitions

- **Cephalostat:** An instrument used to position the head for measurement and radiographic examination.
- **Craniocervical Posture:** Posture of the cranium (head) in relation to the cervical spine (neck).
- **Forward Head Posture (FHP):** A position in which the head is forward of the vertical reference line that passes through the lobe or tragus of the ear and the tip of the shoulder in a sagittal plane.
- **Lordosis:** Normal ventral convexity curvature of the neck in the sagittal plane.
- **Natural Head Posture (NHP):** Standardized and reproducible orientation of the head in space when one is focusing on a distant point at eye level.
- **Radiation**: Energy that is transmitted in the form of rays or waves or particles.

- **Radiographic Measurement:** Measurement on the image produced on a radiosensitive surface by radiation (x-ray).
- **Sagittal Plane:** The plane that splits the body into right and left halves.
- **Standardization:** The procedure of maintaining methods and equipment as constant as possible.
- **Surface Measurement:** External measurement using the skin as a reference.

3. Statistical definitions

- **Concurrent validity:** A measure that substantiates whether measurements taken using different instruments agree with each other. It is used to test whether a new instrument is interchangeable with an established "gold standard".
- **Correlation:** A statistical measure referring to the relationship between two or more variables.
- **Effect Size:** Effect size (ES) is a measure of the magnitude of difference or correlation between variables.
- **Generalizability:** The ability of values found in a sample population to be applied to a larger population.
- **Gold Standard:** A method, procedure, or measurement that is widely accepted as being the best available.

- **Intra-rater reliability or intra-tester reliability:** The repeatability of measurements taken by the same rater at different times. It demonstrates the consistency of the rater to measure the same "thing" repeatedly.
- **Inter-rater reliability or inter-tester reliability:** The reproducibility of measurements taken by different raters. It is used to detect whether the recorded values change when different raters measure the same "thing".
- **Intra-subject reliability:** The reproducibility of the subjects' performance. It demonstrates whether the measures of the same subject taken at two or more times by the same rater performing the measures are the same or similar.
- **Measurement:** Measurement is the act or process that allows quantitative comparison of results.
- **Measurement Properties:** Concepts related to the process of measuring: reliability, validity, and responsiveness.
- **Power:** Probability of an investigation detecting meaningful difference, or effect, between variables when a difference exists or the probability of correctly rejecting the null hypothesis when the null hypothesis is false.
- **Reliability:** The degree to which a measure is free of random error (measurement mistakes by chance). It is quantified by the degree to which measurements are consistent (constant/stable) and reproducible (repeatable).
- **Sensitivity:** The ability of an instrument to detect meaningful differences in the variable under study, when they occur.

- **Validity:** Quality that is attributed to those measurements that quantify what they are supposed to and that provide a true depiction of what is being measured.

ETHICAL CONSIDERATIONS

This research was approved by the Radiation Safety Committee (Appendix A) and by the Health Research Ethics Board (Appendix B). Posters were placed around the campus of the University of Alberta to recruit subjects (Appendix C). The researcher explained the details of the study (including benefits and risks) to all subjects interested in participating in the study (Appendix D and E). Upon agreement to participate, the researcher asked each subject to sign an informed consent form (Appendix F).

Benefits to the subjects

The subjects were provided with an evaluation of their cervical posture. Postural recommendations were also given to the subjects who demonstrated postural alteration.

Risks to the subjects

The subjects included had either 2 radiographs (Part 1) or 1 radiograph (Part 2) taken which exposed them to radiation. The radiation exposure was considered low for the region being x-rayed. The radiographs were taken at the Glen Sather Clinic at the University of Alberta. A meeting with the radiology technician and with the director of the clinic was held and they agreed to collaborate with the study (Appendix G). The radiographs were taken using the recommended radiation protection guidelines. (71) The thyroid shield was not used on the subjects of this study because there is no consensus in the literature whether the thyoid shield should be used in cephalometry radiographs (72) and therefore, its use was not mandatory according to the guidelines.

Confidentiality

All information was kept confidential, except when professional codes of ethics or legislation (or the law) require reporting. The information provided by the subjects will be kept for at least five years with the author of this study. The information will be kept in a secure area (i.e. locked filing cabinet). Subject's names or any other identifying information will not be attached to the information that is given. Subject's names will also never be used in any presentations or publications of the study results. The information gathered for this study may be looked at again in the future to help the author answer other study questions. If so, an ethics board will first review the study for the consideration of granting permission.

[1]CHAPTER 2. REVIEW OF THE LITERATURE

CONCEPTS OF MEASUREMENTS PROPERTIES

With the increasing awareness of the importance of evidence based practice, researchers and clinicians are interested in objective evaluations of the value and effectiveness of rehabilitation assessment and treatment techniques. These objective evaluations can only be performed by accurately measuring treatment outcomes. Thus, meaningful measurement has become an essential part of the rehabilitation process. Measurement is the act or process that allows quantitative comparison of results. (73) However, the usefulness of measurements in clinical research and in the decision making process depends on the extent to which one can rely on the data as accurate and meaningful indicator of behavior, attribute, or phenomena. (73) The quality of a measurement is often judged by such criteria as reliability, validity, and responsiveness. These measurement characteristics are related to each other and sometimes overlap. In addition, authors frequently disagree on their definitions and sub-classifications. The terms are frequently confused, often used generally (neglecting the sub-classifications) or interchangeably, and sometimes they are used inappropriately or incorrectly. Thus, a review and clarification of the concepts is important.

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[1] *Two versions of this chapter have been published. Gadotti, Vieira, Magee 2006. Brazilian Journal of Physical Therapy, 10: 137-146.; Gadotti, Magee 2008. Physical Therapy Reviews. 13: 258-268.*

A gold standard measurement should be reliable, valid, responsive, practical, and easy to obtain in order to be justifiable and clinically useful. The degree of reliability, validity, and responsiveness necessary for each study (experimental or clinical), the applicability of the intended instrument in each setting, as well as the purposes of the research or clinical assessment should be of concern to both rehabilitation researchers and clinicians in order to choose the most appropriate measurement in specific situations. Thus, the characteristics of a measurement, along with the objectives of measuring the event in question, should guide the decision concerning which measurements properties or its types, are the most important for a specific study. (73,74)

Measurement Reliability

Reliability is defined as the degree to which a measure is free of random error (measurement mistakes by chance). (73) It is quantified by the degree to which measurements are consistent (constant/stable) and reproducible (repeatable). (75) For example, the measurements performed, before and after a treatment, need to be reliable in order to show any differences pre and post treatment. In this case, if there were no changes (the treatment had no effect) the measurements would be the same. If the reliability of the measurements is not reported in a study, the consistency of the measurements performed may be questionable and consequently, the results of the study may also be questioned because differences found (or the lack of them) in the study could have been caused by random measurement errors and not real changes (or the absence of them) in the variable been evaluated. Measurements that are composed of the true value of the variable being assessed along with measurement error are not reliable, (76) unless one knows what the measurement error is and corrects it. Thus, reliability is an essential characteristic of a meaningful measurement because often it is not possible to distinguish between the true value and the amount of measurement error.

The statistical analysis of measurement reliability is frequently performed using the Pearson correlation coefficient and the intraclass correlation coefficient (ICC). Values of 0.0 indicate that all of the variability is due to error, and 1.0 indicates that all of the reliability is due to true between-subject differences. There is no consensus for cut-point values, but it is usually agreed that the values should be greater than 0.75 to indicate good reliability and those below 0.75 indicate poor to moderate reliability. (73) ICC values of radiographic measurements ranged from 0.7 to 1.0 Another form of statistically testing reliability is the non-parametric Kappa test, which is a measure of rater agreement on a discrete outcome (nominal scale of measurement) such as “yes” / “no” for classifying treatment effect, for example. The Kappa test results range from 0.0 to 1.0. Kappa values between 0.61 and 0.80 are considered as demonstrating “substantial” reliability and values greater than 0.80 are considered as demonstrating “almost perfect agreement”. (77) Therefore, the types of reliability analysis vary according to the level of measure (i.e. ratio and nominal meaurements).

Considering the use of ICC or Pearson correlation for testing reliability, ICC is now considered the most appropriate. Correlation reflects the degree of association between two variables, or the consistency of position within the 2 distributions. Pearson correlation is based on regression analysis. It measures if the relationship between two variables can be described by a straight line (the regression line). However, despite a high degree of association between two variables (Pearson correlation almost 1.0), it does not mean that they are interchangeable (the intercept is different from zero and the slope is not equal to one). (78) Therefore, Pearson correlation coefficient is not effective as a measure of reliability as it provides just a measurement of covariance. Statistical approaches to reliability testing should include estimates of agreement in conjunction with correlation. (73)

Another disadvantage of correlation is that they are bivariate. Only two ratings or raters can be correlated at one time being impossible to correlate more than 2 simultaneously. Correlation does not separate the variance components due to error or true differences in the data. Since reliability accounts for the error of measurement, allowing consistent estimation of the true quantity of interest, correlation is not a coefficient of reliability. (73)

The intraclass correlation coefficient (ICC) is calculated using variance estimates obtained through analysis of variance (ANOVA). Therefore, it reflects both degree of correlation and agreement among measurements. (73) The ICC will yield a value of 1.0 only if all the observations on each variable are identical, having a slope of 1.0 and an intercept of 0.0. (78,79) Differently from Pearson correlation, ICC can be used to assess reliability among two or more ratings and it does not require the same number of raters for each subject. These advantages allow more applicability of the ICC analysis for clinical research. However, researches that report reliability on the basis of ICC should still report the results of standard error of measurement (SEM) which indicate the absolute reliability (extent to which a score varies on repeated measurement). In others words, it report how much variability in the score could be expected because of measurement error which is important for a clinical application. (79) Therefore, considering the concept of reliability, we can conclude that the use of ICC for reliability testing is more appropriate to use when comparing to Pearson correlation coefficient.

There are different types of measurement reliability. They are influenced by errors introduced by the rater (e.g. lack of proficiency, non-standardization of procedures), the instrument (e.g. technical problems), and/or by the subjects being measured (e.g. changes in performance, lack of cooperation or comprehension, and misrepresentation of capabilities due to pain, fear, and psychosocial issues).

Intra-Rater Reliability

Intra- rater reliability, or intra- tester reliability, is related to the repeatability of measurements taken by the same rater at different times (stability over-time). It demonstrates the consistency of the rater to measure the same "thing" repeatedly. The subject, the performance level (see intra-subject reliability), and the instrument remain the same.

Inter-Rater Reliability

Inter- rater reliability, or inter- tester reliability, evaluates the reproducibility of measurements taken by different raters. It is used to detect whether the recorded values change when different raters measure the same "thing". (73) As in the case of intra-rater reliability, the rater is evaluated as a possible source of bias and error, but in the case of inter-rater reliability, possible differences between raters measuring the same thing are assessed.

Intra-Subject Reliability

Intra-subject reliability involves the reproducibility of the subjects' performance. It compares the measures of the same subject taken at two or more times when the same rater performs the measures. In this case, the intra-rater reliability must be high so that any possible variations in the measurements can be attributed to the subject's performance variation. (80) Low intra-rater reliability (<0.75) can be a confounder for the intra-subject reliability assessment and the reverse is also true. Thus, high intra-rater reliability is a pre-requisite for testing intra-subject reliability and vice-versa.

Instrument Reliability

Instrument reliability, or test-retest reliability, evaluates the ability of the measuring instrument or test (e.g. device, tool, scale, questionnaire, or interview protocol) to give the same consistent measurements or results. It is tested by taking repeated measures of the same "thing" using the same instrument or test.

(80) Low intra-rater reliability can be a confounder for the instrument reliability assessment. Thus, high intra-rater reliability is a pre-requisite to assess the instrument reliability and vice-versa. Many other studies do not report or consider the intra-rater reliability when assessing the instrument reliability making it impossible to separate the two. In addition to high intra-rater reliability, high intra-subject reliability is needed to test the instrument reliability with no confounders. In other words, if the instrument reliability is the ability of the instrument to replicate its own measures, the consistency of the subject and rater must be ensured.

Internal Consistency

Internal consistency reflects the degree to which different items or set of questions in a test, scale, questionnaire, or interview protocol are associated to each other. Such instruments are ideally composed of questions or items that measure particular parts or attributes of a greater question. The most common approach to testing the internal consistency of questionnaires and interview protocols involves the calculation of the correlation between different items of the instrument. (73) In this case, high internal consistency depends on good correlation ($r>0.75$) among the items of the instrument.

Parallel Reliability

Parallel reliability, or equivalence reliability, is determined by comparing the values or results taken by different instruments or tests at the same time. It evaluates whether measurements or results from different devices or tests are similar or the same. (74) Thus, parallel reliability is used when one wants to provide an alternative and/or similar measurement instrument or test. (80) Therefore, the measures taken should be highly correlated or not differ significantly when the same variable is assessed at the same time. It is important to note that for the parallel reliability analysis, the referential tool needs to have been previously tested and reliable.

Overall, the inter-rater and the parallel reliability tend to be respectively lower than the intra-rater and the instrument reliability because the former involve measurements of different raters or different devices which are susceptible to greater variation. Confounders could affect most of the reliability measures, such as instrument vs. subject reliability, for example, and should be discussed in the studies.

Measurement Validity

Validity is a quality that is attributed to those measurements that quantify what they are supposed to and that provide a true depiction of what is being measured. (74,80) In other words, does the instrument truly measure what it says it does? When a measurement is valid, the inferences made from the results are appropriate. In other words, a valid measure allows one to rely on the study (test) results and interpretations when making clinical decisions. Therefore, validity deals with accuracy (correctness), with the ability to make inferences (conclusions reached on the basis of evidence), and also with the presence of no systematic errors (lack of consistent measurement mistakes). (74) A systematic error of 15%, for example, occurs when the measurements are consistently 15% lower than the actual value.

The Pearson correlation and ICC tests are statistical methods often used to analyse the validity of measurements. The difference between the Pearson and ICC tests is that the latter not only tests the correlation between variables, but also the agreement between them. If the Pearson correlation is used to assess the validity of a measurement, then the regression equation that the Pearson correlation coefficient relates to needs to be evaluated to assess possible systematic errors. ANOVA and T-tests may also be used to test if there are significant differences between the variables. If there are significant differences between the variables under study, the measurements are not valid. ICC, T-test, and ANOVA should only be used when the units (e.g. cm, degrees, kg) of the variables under study are the same or are normalized, meaning that the numbers need to be directly comparable.

Face Validity

Face validity, the lowest level of validity, is related to the intuitive "feeling" that a measurement seems to be valid. (81) The evaluator accepts the assumption that the measurement is valid at "face value". It offers no evidence on which to base the assumption.

Construct Validity

Construct validity is similar to face validity, but it includes a theoretical framework and reasoning to support that the measurement is valid. Construct validity is divided into convergent validity and discriminant validity:

- *Convergent validity*: supports those measurements that are believed to reflect the same variables that yield similar results and are comparable.
- *Discriminant validity*: indicates that measurements that are supposed to assess different characteristics yield different results (ability to discriminate between different constructs). (73) Thus, discriminative validity depends on the fact that measurements that lack a relationship should not be related.

Content Validity

Content validity is usually applied to study questionnaires rather than to evaluate devices or measurement tools. (80) It deals with the scope of the evaluation method and with how well the information gathered fully reflects the variable under study. (81) An example of a question that deals with content validity is “Do the questions in this independence for daily activities’ assessment questionnaire fully cover the problems that a disable person will face in his/hers daily life activities?” In this case, the measurements of pain included in the questionnaire (for example) will have a higher “content validity” if the questionnaire includes an assessment of different characteristics of pain such as location, type, duration, and intensity. (73)

Criterion-Related Validity

This type of validity can be determined by comparing a measurement with a particular factor or criterion, and it can be divided into predictive, concurrent, and prescriptive validity:

- *Predictive validity*: can be assessed by determining whether the predictions originating from the measurements come true. In this case, the outcomes act as the criterion. (74) The predictive value of a positive test is the number of true positives divided by the total number of positive responses (true and false positives). The predictive value of a negative test is the number of true negatives divided by the total number of negatives responses (true and false negatives).
- *Concurrent validity*: evaluates whether measurements taken using different instruments agree with each other. (81) It is used to test whether a new instrument is interchangeable with an established "gold standard". (80) Concurrent validity and parallel reliability are similar. The difference is that concurrent validity requires the reference measurements to come from a valid instrument, while parallel reliability only requires reliable measurements from the criterion instrument. (81) Thus, reliability is a pre-requisite for validity.
- *Prescriptive validity*: is related to how appropriate it is to use a measurement to recommend a treatment. (81) It is determined by the positive or negative outcome of a prescribed treatment. (73,74)

Measurement Validity vs. Study Validity

In addition to “measurement” validity discussed in the previous section, there is another concept called “study” validity that is related to the study in general. Study validity refers to the internal and external validity of the study. The external validity of a study is related to the extent to which the results of a study can be generalized outside the experimental situation. In other words, how much the research findings and conclusions of the study on a given sample are applicable to a larger population. On the other hand, internal validity of a study refers to the degree to which the relationship between the independent and dependent variables are free from the effects of extraneous factors and/or confounders. (73) Internal and external validity are related to the study itself and not specifically to the validity of the measurements taken.

Instrument Responsiveness

Instrument responsiveness is the ability of the instrument, device, tool, test, or scale to accurately detect meaningful changes. (82) The measurements of an instrument used for clinical evaluation need to identify clinically significant differences between and within patients over time. (83) The measurements should show changes in the variable being assessed, but they should not be influenced by changes in other variables if the one under study remains stable (does not change). (84) Instrument responsiveness includes the concepts of sensitivity and specificity.

- *Sensitivity*

The ability of an instrument to detect changes in the variable under study, when they occur, is defined as the instrument's sensitivity to change.

- *Specificity*

The stability or ability of an instrument measure not to change when no changes in the variable under study occur is defined as the instrument's specificity. Note that changes to other variables may happen, but if the variable of interest remains stable, the measurement taken should not change (specificity). Thus, specificity is related to the actual testing of the discriminate validity of a measure (see construct validity). In other words, specificity evaluates if the variable under study is not influenced by changes in other variables. It can be considered as the actual analysis of the discriminant validity (see construct validity).

Sensitivity and Specificity of Diagnostic Tests

In studies involving a diagnostic test, the assessment of the instrument's sensitivity corresponds to the probability that the measures will detect a positive test among patients with disease or injury (i.e. true positive test). When a test incorrectly identifies a problem as positive or negative, this is referred to as a false positive or false negative respectively. The sensitivity of a diagnostic test is calculated as true positive tests divided by true positives plus false negatives. (73) If the test detects several positive tests in subjects without the dysfunction, the false positives increase and consequently, the credibility of the test decreases and it may not be useful for what it is trying to measure.

Instrument specificity is evaluated by the probability of a negative test among patients without disease or injury (i.e. true negative test). The specificity of a diagnostic test can be calculated as true negative tests divided by true negatives plus false positives. (73)

When a study evaluates instrument responsiveness in a sample of subjects with a disease or dysfunction, only sensitivity can be tested because only false negatives can be found. Without including normal subjects (i.e. those without the disease or dysfunction), it is impossible to analyze whether the test has false positives. Both sensitivity and specificity of a test need to be known because a test should have low frequency of both false positives and false negatives in order to be useful in the decision making process.

Interactions between Measurement Proprieties

The measurement properties can be presented and tested separately; however, they are inter-related and affect each other. Table 1 presents the different measurements properties. Selected interactions between measurements properties are presented in the following sections.

Table 1. Overview of measurement reliability, validity and responsiveness.

Concept	Types	Subdivisions
Reliability	Intra-rater	NA
	Inter-rater	NA
	Intra-subject	NA
	Instrument	NA
	Internal consistency	NA
	Parallel	NA
Validity	Face	NA
	Construct	Convergent/Discriminate
	Content	NA
	Criterion-related	predictive
		concurrent
		prescriptive
Responsiveness	sensitivity	NA
	specificity	NA

NA=Not Applicable

Reliability and Validity

Reliability is a pre-requisite for validity. (74) A measure can be reliable but not valid, (80,81) however, a measurement cannot be valid if it is not reliable. (82) A measurement can only be considered valid when it has no systematic error or random error (reliability). Consistent and reproducible measurements do not indicate that the variable of interest is in fact being measured. For example, a questionnaire can have internal consistency (i.e. homogeneity among items), but not content validity (i.e. the items do not reflect the variable under study). High reliability (i.e. low random errors) along with low systematic error results in validity (assuming that the measurement in fact reflects what it is supposed to measure). (80,81) It is important to note that the measurement properties can be tested separately, but they depend on each other to provide useful measures.

Validity and Responsiveness

A measure that is valid at one point in time should also be valid at a different point in time. Consequently, in order to provide valid measurement, an instrument should be responsive to changes over time. (82) Thus, a valid measure needs to be responsive (and have high reliability as discussed before). However, some measures can be valid only at one point in time.

According to Portney and Watkins (73) and Hays and Hadorn, (82) responsiveness is one aspect of validity rather than a separate characteristic. Hays and Hadorn (82) stated that the fact that an instrument's measurements are responsive to a clinical intervention supports the hypothesis that the instrument's measurements are valid. The instrument responsiveness adds longitudinal information (i.e. the ability to capture changes over time) into the process of evaluating measurement validity. When selecting an instrument for evaluation, one should extend his or her concern for measurement validity beyond the face and construct validity to the discussion of the responsiveness of the instrument. (73) On the other hand, Guyatt et al. (85) proposed that responsiveness is distinct from reliability and validity. They stated that an instrument's measurements can have reliability, but not responsive; have responsiveness, but no validity; and have no reliability, but be responsive. Despite this, all measurement characteristics that may affect the findings should be addressed in a study's discussion section in order to provide a full understanding of the strengths and weaknesses of the results and conclusions. The measurement properties may need to be evaluated separately depending on the objectives of the study.

Reliability and Responsiveness

A measurement can have high reliability (i.e. consistency), even when the instrument is unresponsive (i.e. not able to detect meaningful differences). Conversely, a measurement can have low reliability, yet the instrument may be responsive. (85) For example, a measure can detect change or difference of patients performance after treatment (being responsive) even though the measurements were not consistent when measured by different raters (low inter-rater reliability). The measurements might not be reliabile when repeated measures are performed by the same rater (low intra-rater reliability), and in this case, the differences found after treatment might not be a real difference but have occurred by chance. Both reliability and responsiveness are pre-requisites of validity, but responsiveness is not a pre-requisite for reliability.

Implications of Neglecting Measurement Properties

Many published studies fail to report the validity, reliability, and responsiveness of the measurements taken. Some instruments are often used but their measurement characteristics are frequently overlooked and assumed to be adequate. However, this may not be true, and the measurements may have low quality resulting in insufficient statistical power. The power of a study is the extent to which an investigator can detect a difference when a true difference exists. It may also be stated as the probability of correctly rejecting the null hypothesis that there are no differences when null hypothesis is false. (73) Thus, the power of a study relates to how capable the measurement is in detecting differences between or within groups. Every study should have sufficient ability (power) to detect the effect caused by the application of an independent variable (e.g. treatment technique). It should also have a low probability of a type I (alpha) error, which corresponds to rejecting the null hypothesis, when it should not be rejected (for example: finding differences before and after a treatment when, in reality, there were no changes). The determinants of the power of a study include:

- *Sample size:* the larger the sample, the greater the power, because with a large sample, the general population is more likely to be represented. This means the study has greater external validity. Therefore, the results can be generalized to a larger population, and the true differences between groups are more likely to be recognized.

- *Effect size:* the larger the effect size, the greater the power. Effect size is the magnitude of the difference before and after treatment, or between groups. (73) Thus, the power is influenced by the size of the effect of the experimental variable (e.g. treatment). The larger the effect produced by a treatment on a given dependent variable (e.g. knee stability), the more likely it is that the differences before and after will be statistically significant. (86)
- *Statistical significance level used (α-level):* the higher the α-level (i.e. higher than 0.05), the greater the power, but also the higher the chances of making a type I error. The α-level is the probability that the researcher is willing to accept that he or she might be wrong in rejecting the null hypothesis, or the extent to which the researcher could be wrong in saying that there are differences in the finding of the test. The most common α-level used is 0.05 which means that the researcher is accepting that he or she could be wrong in rejecting the null hypothesis 5 times out of 100 or 5% of the time. Lowering the α-level reduces the chances of a type I error by requiring stronger evidence to demonstrate significant differences. Increasing the α-level makes it easier to find differences (it may increase the power), but the probability that one will find a difference that actually does not exist (type I error) also increases.
- *Variability of the data:* the lower the variance, the greater the power. Variance is a measure of the variability within the group (e.g. injured vs. non-injured; before vs. after treatment). The ability to detect a difference

between groups is enhanced when the groups are distinctly different. When the variability within groups is large, the difference between groups will be less evident because the measurements may overlap. This, in turn will lower the power or the ability to detect a difference. (73)

Most of the determinants of power described above depend on the quality of the measurements. If the measurements' reliability, validity, and responsiveness are not adequate the study's ability to detect the effect of an independent variable (e.g. treatment) will be low or inexistent. For example, the amount of variation in the scores obtained for a particular sample or group (i.e. the standard deviation) depends on the variation in the scores and the amount of random measurement error. When the measurement error is large (e.g. the measurements have low reliability), differences between groups and changes over time may become undetectable. Thus, the effect size will be small decreasing the power of the study. (87) The responsiveness of a measurement instrument is also related to the effect size and will also influence the power of a study. If the instrument measurements are not precise enough to capture meaningful changes (i.e. the instrument has low responsiveness), then the differences may be too small to be identifiable. This, in turn, will cause the effect size and the power of the study to be small.

Studies with limited power do not always yield erroneous conclusions but their findings are questionable. The chances that such studies will detect differences rejecting the null hypothesis are small. In other words, studies with low power may not be able to identify differences that exist between groups, leading to erroneous results and conclusions. Many studies in the literature fail to achieve statistical significance which is often related to the low power of the study and not to an actual lack of difference between groups or sample populations. (73) It is relevant to state that the power of the study may be a problem only when no significant differences are found between groups. But, the measurements properties are important even when differences are found because they may be related to inadequate measures. In general, the power of a study will be big enough if the statistical techniques, study design, including sample size and measurements are adequate. (86,88) Thus, assessing and reporting the measurement properties should be a standard procedure in order to increase power and to allow readers to rely on the presented results. Unfortunately, this procedure is still an exception rather than the rule in the rehabilitation field.

Measurement Properties in the Critical Analysis of Rehabilitation Research

A critical analysis of the rehabilitation research found common methodological limitations that resulted in weak studies. (89) Flaws were found in the experimental design, measurement techniques, procedures to control for confounding variables, sample size, and in the statistical analysis of the studies. Thus, there is a need to improve the quality of rehabilitation research studies. The following are examples of questions that should be asked when designing, presenting and analyzing the quality of published studies. The answers to these questions are essential if one is to accept the results and conclusions of a study.

1) Did the study report the reliability, validity, and responsiveness of the measurements used?
2) Did the study control the sources of measurement error?
3) Did the study have sufficient power to detect possible difference between groups?

Final Considerations

Not all measurements properties and their types need to be tested in one study. Independently, the measurement properties that are important for a study should always be reported. One alternative to actually testing measurement characteristics in a study is to use previous studies that used these measurement characteristics to justify the use of specific procedures or instruments. A word of caution must be added, however. To use measurement characteristics from another study, the researcher must ensure the same “thing” is being measured. For example, visual analogue scales have been show to be valid and reliable for some pain measures, but they have not been showed to be valid and reliable for many of the other variables they are purported to measure. (68)

In conclusion, the report of the measurement characteristics can improve the quality of rehabilitation research and clinical evaluation processes which are fundamental for ideal evidence based practice.

CRANIOCERVICAL POSTURE CONTROL

Habitual head posture is believed to be determined by a dynamic combination of factors such as body build, muscle performance, age-related structural changes, mental state, personality, proprioceptive capacity, occupation, and cultural factors. (3) However, the specific nature of the causal mechanisms for a particular resting head posture is not well known. A wide variation in head posture is observed in the general population which explains the variability in individual equilibrium responses when positioning the head relative to gravity. (3)

Biomechanical Stability

According to Kendall, (90) to have an ideal head posture, the correct vertical reference line in a lateral view should pass through the lobe of the ear and the tip of the shoulder. This line falls anteriorly to the transverse axis for sagittal motion of the head. The location of this line creates a flexion moment of the head on the neck as the major weight and center of gravity of the head is anterior to the supporting occipital condyles. Therefore, the maintenance of head and neck posture requires the posterior cervical muscles to support the head against gravity with less action from the antagonists flexors needed to balance these forces. (91) The posterior cervical muscles must have a constant muscular tone to prevent the head falling forward. This biomechanical craniocervical stability should be constantly maintained. However, the neck muscles only need a slight muscular contraction without exerting a major energetic effort to sustain the head posture. (6) In this position, the cervical spine has a slight curvature that is concave backwards, also known as physiological cervical lordosis. This spinal curve, similar to the lordosis in the lumbar spine, is a compensatory arrangement of the spine in order to support the body with minimal stress and energy expenditure. (92)

Although the criterion for ideal posture is described, it is clear that a small percentage of the population meet the criterion stated. The quantification of "normal" musculoskeletal function still remains speculative. (52)

Neuromuscular Mechanisms

The head posture is regulated through neuromuscular mechanisms. These may be subdivided in peripheral and central mechanisms. Kraus (93) describe three peripheral control mechanisms: 1) the vestibular system; 2) the ocular system; and 3) the proprioceptive system. The nervous centers process information from the peripheral mechanisms (sensory input) that generate a response in the form of muscular activity that controls the posture.

The vestibular system involves the internal part of the ear organ. The sensory receptors, located in the semi-circular channels, detect the position of the head and its change in space as a balance organ. The system provides excitatory influences to the extensor, antigravity musculature, especially in the spinal and proximal limb muscles. It also has an inhibitory influence on the flexor muscle groups. The vestibular system, in response to linear and angular movement, produces an increase in extensor muscle tone and decreases flexor muscle tone in order to maintain an upright posture. (94)

The ocular system gives spatial perception through a visual field generating a synergic activity between neck muscles and eye muscles. Both vestibular and ocular systems play an important role in maintaining the head position, as well as in coordinating the movements of eyes, head, and neck.

The cervical spine has articular capsules around the zygophyseal joints that are highly innervated by mechanoreceptors which contribute significantly to postural and kinesthetic sensation. The proprioceptive system of the cervical spine is formed by neuromuscular spindles and articular mechanoreceptors located in ligaments, muscle and tendons. The articular mechanoreceptors produce the tonic neck reflex (TNR), which is activated by stimulation of the tendinous Golgi organs when the ligaments of the cervical spine are stretched. This produces a reflex contraction of the cervical muscles, allowing one to keep the head in balance. The proprioceptive system provides the basic control of the craniocervical posture. (6)

Gonzalez & Manns (6) described a fourth peripheral mechanism. This mechanism is related to the control of ventilation which provides adequate airflow. This mechanism could influence the cervical muscular activity in such a way as to generate a postural change in order to ease breathing if it has been hampered. However, according to Gonzalez and Manns (6), the neurophysiological basis of this mechanism needs to be further investigated, which is beyond the scope of this study.

ALTERATION OF POSTURE

Broadly, poor posture is defined by The Posture Committee of the American Academy of Orthopaedic Surgery as "a faulty relationship of the various part of the body, which produces increased strain of the supported structures and in which there is less efficient balance of the body over its base of support". (90) (p. 51)

Forward Head Posture

Poor head posture is often described as "forward head posture" (FHP). FHP is the most common postural impairment of the cervical spine. (95) Variations concerning the definition of FHP exist in the literature. However, the head being forward of the vertical reference line described by Kendall, (2) is more likely to be a more common description of FHP. (48) Forward head posture may cause the cervical musculature to change their length/tension relationships. (31) In terms of what happens to the cervical spine, FHP is described by Gonzalez & Manns (6) as an extension of the head and upper cervical spine (C1-C3), accompanied by flexion of the lower cervical spine (C4-C7), so that the cervical curvature is increased, a condition called hyperlordosis. However, according to Roccabado (4) and Ayub et al. (96), FHP involves extension at C0-1 and C1-2 levels, a decrease in the mid-cervical lordosis and an increase in the upper thoracic kyphosis. According to Roccabado (4), a reversed physiological curvature (i.e. a decrease of the cervical lordosis) may occur in the FHP when radiographs are analyzed. Because of the variability of posture among subjects, a definitive description on what changes occur to the cervical spine when the head is forward is still contradictory.

Causes of forward head posture

The possible causes of developing forward head posture are: 1) altered neuromuscular feedback due to a failure to achieve and maintain the straight postural position of the individual; 2) postural changes due to bad habit, labor activity, cervical macro or micro-trauma, and/or inheritance; 3) tissue scar (adhesions causing restricted movement and tension on tendons, ligaments); and, 4) the mouth breathing which can cause changes in the head position. (6,31) The mouth breathing will cause the hyoid bone to fall downwards and backward, reducing the air passage. The head needs to assume a forward and more extended position in order to move the hyoid bone forward and upward to ease breathing. (6) Mouth breathing may also cause increased activity in the accessory anterior and lateral cervical muscles (i.e. scalene, sternocleiodomastoid, trapezius, and pectoral muscles) that pull the middle and upper cervical vertebrae forward and down. With the occiput in a position more anterior to the center of gravity, the posterior cervical muscles contract and exert a backward-bending force on the occiput that causes the patient’s gaze not to be horizontal. In order to keep the gaze horizontal, the lower cervical and upper thoracic of the spine bend forward, producing a cervicothoracic kyphosis. (31)

It must be pointed that the head posture alteration is adopted gradually as a consequence of adaptation or compensatory posture. For example, many occupations and activities involve a more anterior positioning of the head and arms with respect to the trunk that is neither ergonomically sound nor comfortable, and in many instances, these postures are held for long periods. This forward positioning magnifies the effect of gravity, increasing the flexion moment of the head and may cause changes in the length-tension relationships of the anterior, posterior and lateral cervical musculature. (31) In this adaptative state, patients lack the cognitive ability to be aware of their poor posture and interpret it as normal. Consequently, they do not self correct their posture. (97)

Consequences of forward head posture

- Zygoapophyseal joints compression

The forward head posture leads to some physiological/functional consequences. The alteration in the cervical spine position can lead to early degenerative and spondylogenic changes, especially in the zygoapophyseal joints. The space between the upper cervical segments is decreased and with the resulting compression, the greater and lesser occipital nerves may also become involved. If the compression occurs, noxious mechanoreceptor activity could possibly lead to a convergence of impulses, which could stimulate the trigeminal nerve. This condition could lead to symptoms associated to the trigeminal nerve such as facial pain and headache. (31)

- Cervical muscle tension

Forward head posture may also lead to thoracic outlet syndrome symptoms because of increased tension in the anterior and lateral cervical muscles. This condition causes the elevation of the first and second ribs and may compress the neurovascular components (i.e. suclavian artery and vein and the brachial plexus). The symptoms include hyper- and hypoesthesia in the lateral aspect of the neck and down the shoulder and arm. Another problem associated with forward head posture is tension in the scalene muscles. The dorsal scapular nerve can be vulnerable to increased tension because this nerve penetrates the middle scalene muscle that may stress the nerve when it contracts. This could lead to a neuropathy that could cause weakness in the rhomboids and levator scapulae. This condition could lead the scapula and shoulder girdle to protract leading to tightness in the pectoral muscles which, in turn, could lead to a neuropathy of the suprascapular nerve. (31)

Cervical Spine Disorders and Referred Pain - Neuroanatomical Mechanisms

The literature is clear that cervical spine refers pain to the head and orofacial regions. (8,98,99) The convergence between the trigeminal afferents and the afferents of the upper three cervical nerves is the neuroanatomical explanation for the referred pain (Fig. 1). Afferent nociceptive input from neck muscles converge with the trigeminal motor neurons in the trigeminocervical nucleus of the upper three cervical nerves. The impulses then travel up to the cortex of the brain. The cortex is unable to distinguish the precise area from which the impulses arose, so information from the C1-C3 neck structures cannot be determined from trigeminal impulses. The trigeminocervical nucleus is located in the upper cervical spinal cord in the spinal nucleus of the trigeminal nerve. This convergence suggests a basis for pain spreading from the cervical to the trigeminal area (the “Kerr principle”) which results in an increase of muscle hyperactivity of the neck and orofacial muscles. (98) Kerr suggested a reflex pathway that could account for the head turning in response to trigeminal stimuli. (100) The trigeminocervical nucleus can be viewed as the nociceptive nucleus for the entire head and neck. (101)

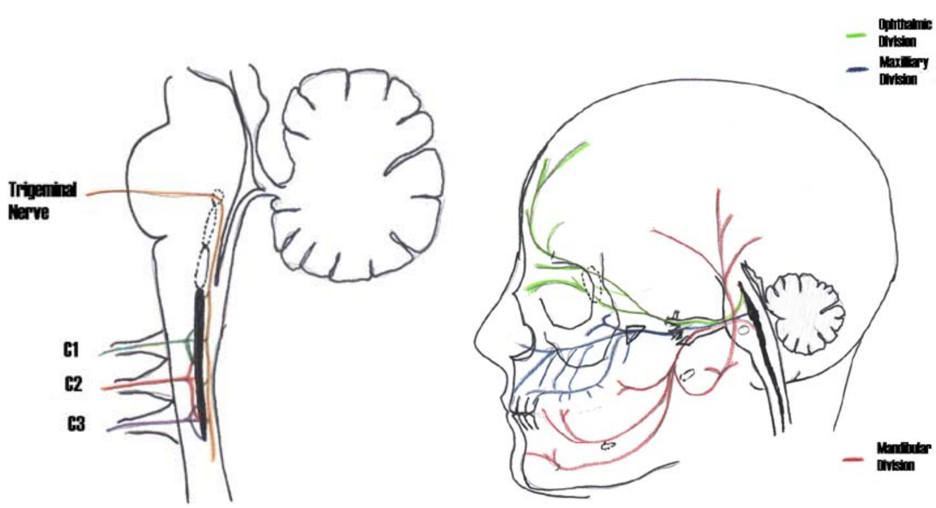

Figure 1. Neurological pathways: Trigeminocervical nucleus by Bogduk

The structures that are innervated by C1 to C3 spinal nerves are the primary sources of pain referred to the head and neck areas. Sources of pain from the cervical spine may originate from disc disorders, cervical nerve root irritation, peripheral nerve irritation (e.g. greater and minor occipital nerve), spinal cord compromise secondary to spinal stenosis, facet joint dysfunction, and myofascial pain. (98,100) According to Kraus, the lower segmental levels (C4-C7) also may contribute to head and orofacial pain through the trigeminalcervical nucleus. (98)

When the head posture is altered, proprioceptive information becomes abnormal because of the loss of mechanoreceptor activity (in the joints, muscles, and tendons). (93) In addition, the suboccipital muscles become short and the central nervous system from this region becomes nociceptive. Proprioceptive input from the trapezius muscle refers pain to the temporal and retro-orbital region and the angle of the mandible. The neuroanatomical connection might explain the possible association between postural alterations and the presence of many head-face pain syndromes such as temporomandibular disorders, neck pain and headache.

MEASUREMENTS OF THE CRANIOCERVICAL POSTURE IN THE SAGITTAL PLANE

Several invasive and radiological methods used for measuring craniocervical posture are described in the literature, although many of these are of little practical value in a clinical situation, due to technical difficulties, special equipment needs and cost. (52,70) Radiographs are considered the standard criterion to measure cervical spine position. However, the radiation exposure limits the use of radiographs for screening posture in the clinical setting and even in research studies. Other forms of medical imaging to assess cervical spine such as magnetic resonance imaging and computed tomography are limited because most of them assess posture in a supine position and not in an upright standing position. (3)

Most commonly, clinicians visually evaluate craniocervical posture in a sagittal plane and in an upright standing position by using a postural grid with a plumbline for alignment as proposed by Kendall. (90) This line, as described previously, should pass through the lobe of the ear and the tip of the shoulder. However, Woodhull et al. (102) considered the mastoid process as the reference landmark for the alignment of the head on the shoulders instead of the lobe of the ear. The clinical evaluation of the craniocervical posture can also be performed by measuring from a vertical tangent line (a plumbline can be used) that runs through the apex of the thoracic spine to the surface of the mid-cervical spine. According to Rocabado (4), this distance averages 6 cm in aligned head posture or "normal" as stated by the author. Poor posture is considered when the distance is greater than 6 cm (Fig. 2).

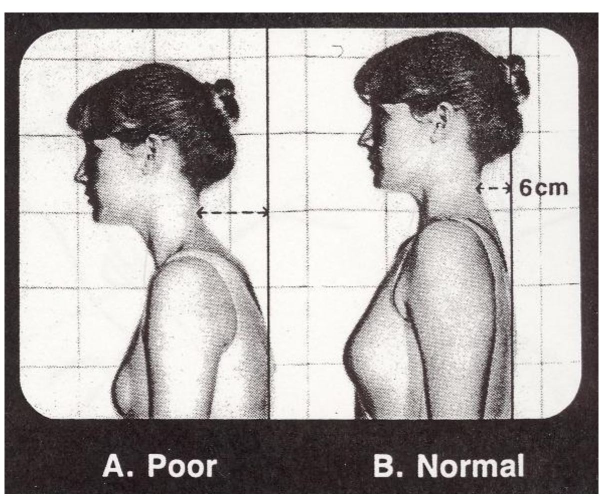

Figure 2. Clinical evaluation of the craniocervical posture using a method developed by Rocabado

Other methods of assessing craniocervical posture in clinical settings include the use of the flexible ruler that is molded to the contour of the lordotic curve by placing it against the back of the subject's neck. (103) However, this method is considered subjective and consequently its use is limited for taking repeated individual measures and for describing the population range of cervical resting postures. (3,64) The use of 3-dimensional measures to assess cervical posture has been increasing used in research. However, this approach may still not be affordable and accessible to many researchers and clinicians, especially those from developing countries. (3)

Measurements using photographs (i.e. photogrammetry) has been used increasingly in research in the last decades especially because of the ability to take digital photographs with surface reference points which make the calculation of posture a measure more time-efficient and more accurate. The disadvantage of using surface references is that they are external bony landmarks used to estimate spinal posture and without a comparative measure of the relative position of the spine, the validity of any external spinal posture is difficult to establish and may not give an accurate interpretation of true spinal alignment. (53) Measurements using radiographs should be used to compare with the surface measurements since radiographs are considered the only trustworthy measure of spinal position (i.e. gold standard). However, there is little research regarding the validation of surface measurements of the craniocervical posture with radiographs because of the ethical and health implications of subjecting healthy spines to radiation. (53)

The dynamic posture has also been studied as a measure of posture during movement. This method is frequently used to investigate balance and how the center of body mass behaves during dynamic tasks such as walking. Because the aim of this study was the assessment of posture in a static position detailed information about this method is beyond the scope of this study.

The craniocervical posture in the sagittal plane can be evaluated based on three different constructs (66,104):

1) The posture of the head in relation to the cervical spine;

2) The inclination of the cervical spine; and

3) The lordosis of the cervical spine.

These 3 constructs may be influenced by postural alteration such as forward head posture. Each construct represents an aspect of posture that may be altered when the head is forwarded. One may be more interested in investigating the forward head posture alteration in relation to the lordosis of the cervical spine, for example. (33,51) These constructs will be further used and tested in the present study.

Radiographic Measurements

In 1948, a method for measuring sagittal spinal curves in lateral radiographs was introduced by Cobb. (105) This has been the method of choice for measurement of overall lordosis and kyphosis of the sagittal spinal curves on lateral radiographs. Figure 3 shows the method used to measure this angle in the cervical spine, described as the angle between the lines intersecting the inferior vertebral body margins of C2 and C7.

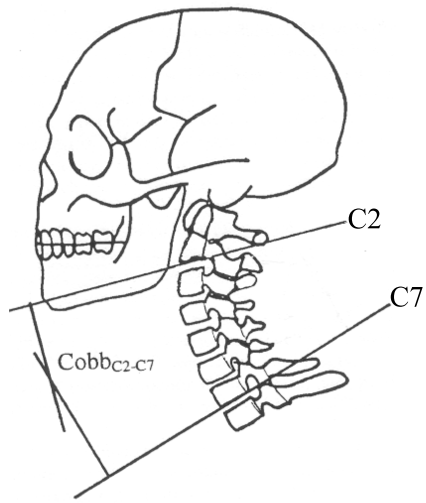

Figure 3. Cobb angle applied to cervical curve

Good to high inter- and intra-rater reliability has been found in some studies using this method. However, this method underestimates the amount of lordosis because of the hooked shape of the anterior inferior body of C2. (106) The underestimation of the lordosis angle is caused by the angles between the inferior endplate and the posterior body margins of C2 and C7. According to Harrison et al., (106) the Cobb angles do not represent the arc of curvature along the anterior and posterior vertebral body margins.

Harrison et al. (106) investigated and compared the reliability of the Cobb method and the Harrison posterior tangent method in assessing cervical lordosis. The Harrison method was described by the absolute rotation angle (ARA), formed by the intersection of tangents drawn at the posterior body margins of C2 and C7

(Fig. 4). These authors found good intra-rater reliability for both methods (ICC=0.7 to 1.0). However, the standard error of measurement (SEM) was higher for the Cobb analysis than the Harrison method. The authors suggested that the Harrison posterior tangent method of analyzing lateral cervical radiographs was superior to the Cobb method.

Figure 4. Absolute rotation angle (ARA)

In 1976, Solow and Tallgren (104) described the following references in radiographs related to spinal curvature (Fig. 5): NSL (nasion-sella line), NL (nasal line), OPT (odontoid process tangent), CVT (cervical vertebra tangent), VER and HOR (true vertical and horizontal lines). These references consisted of three main categories: those that related the posture of the head to a line representing the cervical column (NSL/OPT, NSL/CVT, NL/OPT, NL/CVT); those that expressed the cervical inclination in relation to the true horizontal (i.e. the cervico-horizontal angles – OPT/HOR, CVT/HOR); those that related posture of the head to environmentally determined vertical or horizontal line (the cranio-vertical angles – NSL/VER; NL/VER); and the cervical curvature (OPT/CVT). These references are commonly used in orthodontic studies including craniofacial morphology and to investigate the relation of the cervical spine to the head. These references are considered the clinical standard for measuring the craniocervical position on radiographs. The intra-rater reliability of the Solow and Tallgren measurements was found to be excellent [intraclass correlation coefficient (ICC) values from 0.97 to 1.00]. (40)

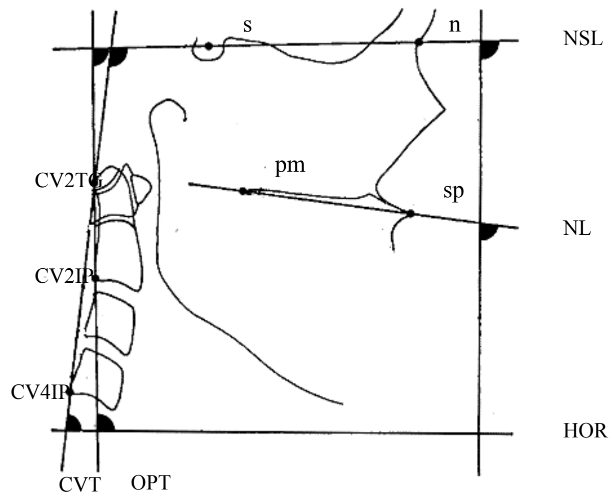

Figure 5. References points by Solow and Tallgren: NSL (nasion-sella line) formed by a line through n (nasion) and s (sella); NL (nasal line) formed by a line through sp (anterior nasal spine) and pm (posterior nasal spine); OPT (odontoid process tangent) formed by a line trough CV2TG (tangent of the second cervical vertebra, the point most superior and posterior of the odontoid) and CV2IP (the most inferior and posterior point of the second cervical vertebra), CVT (cervical vertebra tangent) formed by a line trough CV2TG and CV4IP (the most inferior and posterior point of the fourth cervical vertebra), VER and HOR (true vertical and horizontal lines respectively).

Rocabado (4) from his cephalometric studies considered the craniovertebral position to be the posterior angle produced by the intersection of McGregor's plane (MGP) and the odontoid plane (OP). The MGP was represented by a line connecting the basi-occiput with the posterior nasal spine

(PNS) and the odontoid plane (OP) by a line crossing from the antero-inferior angle of the odontoid to the apex of the odontoid. He claimed this angle in aligned craniocervical cervical posture should be in 101 +/- 5 degrees (Fig. 6).

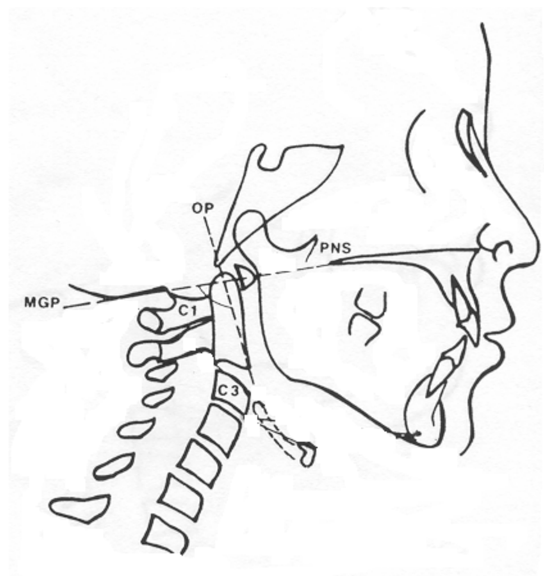

Figure 6. Adapted Rocabado's cephalometric tracings for head and neck posture from radiographs: McGregor's plane (MGP); odontoid plane (OP); posterior nasal spine (PNS).

The angle described by Rocabado involves only one reference point in the second vertebra in the cervical spine for its measurements. Therefore, it provides less information about the position of the cervical spine.

Visscher et al (33) used a method to assess cervical spine posture using the cervical posture line (CPL), using reference points on the upper six cervical vertebrae, with the horizontal axis. The 4 edges of each vertebra were used as references points to establish their position. The co-ordinates of these reference points were digitalized and the centre of each vertebra was determined. Based upon the least squares method, the linear equation of the line running as close as possible along the centers of the upper six cervical vertebrae bodies, the CPL, was calculated (Fig. 7).

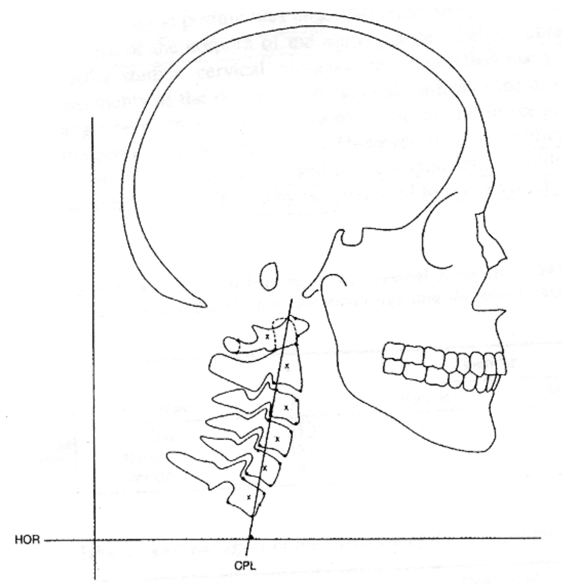

Figure 7. Cervical posture line (CPL) with horizontal (HOR).

In the Visscher et al study (33), a relationship between cervical posture and curvature of the cervical spine was found. Greater forward head posture (FHP) was related to a partly reversed curvature; and a more upright posture was related to a lordotic curvature. In this study, a visual postural assessment including the 3 cateories (lordodic curvature, predominantly straight, and partially reversed curvature) was performed, instead of a quantitative measure such as angle measures, to compare to the radiographic findings. A quantitative measurement of the FHP is necessary for better comparison with the radiographic measurement. The 3 categories used by the authors to assess posture were related to one construct of posture (lordosis of the cervical spine).

Superficial measurements

The most commonly reported angle used in studies that investigate the craniocervical posture using photogrammetry is the craniovertebral angle (CVA). (10,35,42,48,67) This angle refers to the degree of forward head posture, or neck protraction, and is defined as the angle between the true horizontal through the spinous process of C7, with a line connecting spinous process of C7 with the tragus (the cartilaginous protrusion in front of the ear hole). This angle is the most commonly used to assess head-neck posture in patients with TMD. Therefore, this angle is considered by some the clinical standard for measuring craniocervical posture (Fig. 8). (10,35,42,48,67) The smaller the CVA, the more likely it indicates FHP.

Although the craniovertebral angle is useful for measuring the posture of the head in relation to the cervical spine, it is possible to achieve different cervical spine positions having the same forward head posture. (107) The craniovertebral angle takes into account only the posture of the head in relation to C7; it does not reflect the complex vertebral adjustments within the cervical spine that may occur with the alterations in head posture. Therefore, the studies that used the craniovertebral angle to assess FHP can only apply the results in relation to the study of one aspect of the craniocervical posture – the relationship of the tragus to the C7 surface marker. Statements cannot be made concerning the alteration in the position of the cervical spine with the FHP.

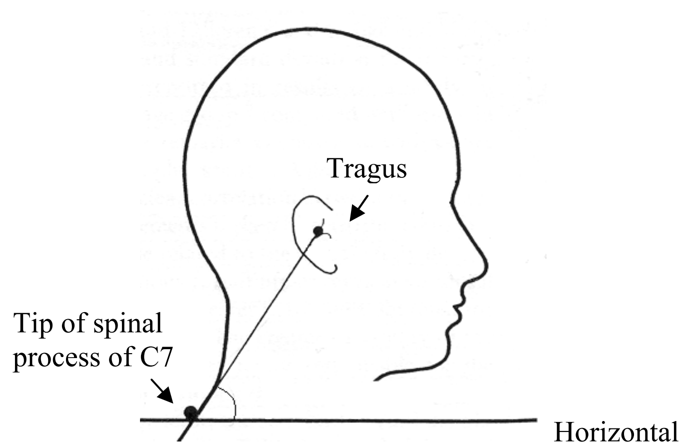

Figure 8. Craniovertebral angle.

The cervical inclination and the cervical lordosis can also be measured using superficial measurements. (66) The inclination angle was determined by a line connecting the spinous process of C2 and C7 with a horizontal line, and the cervical angle was derived from a line connecting C2 and C4, with a line connecting C4 and C7 (Fig. 9). According to these authors, C2 was used to calculate the cervical inclination in preference to the tragus, as described by the craniovertebral angle, because the spinal posture could be quantified independent of the position of the head relative to the cervical spine. (107) The spinal posture can be measured independently of the head position; however, if there is no reference point in the head, the position of the head in relation to the cervical spine cannot be inferred, only the position of the cervical spine can be determined. Therefore, the use of C2 is not a substitute for the use of the tragus, but it changes the construct of the angle measured. (70)

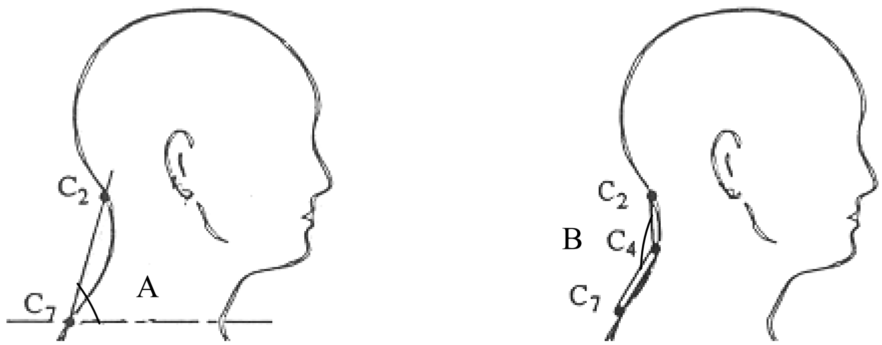

Figure 9. Cervical inclination (A) and Cervical angle (B)

COMPARING PHOTOGRAMMETRY AND RADIOGRAPHIC MEASUREMENTS: VALIDITY STUDIES

Validity studies of postural measurements on photographs such as those involving the lumbar spine have been based on radiographic measurements (108). The concurrent validity of the craniocervical posture photogrammetry is based on radiographic measurements, since the radiographic technique is considered the gold standard for analyzing the position of the cervical spine in relation to the position of the head. However, a valid photogrammetric method to assess craniocervical posture has not yet been established.

Only three studies were found that compared photogrammetry of overall cervical posture with radiographic measurements in the cervical spine in the sagittal plane in an upright position. (42,66,67) One study tested the validity of craniocervical angles using photographs including the craniovertebral angle but the subjects were measured in a sitting position. (53) The validity of the craniovertebral angle was tested by Johnson, (67) and Visscher et al. (42) in the standing position, and by Van Niekerk et al. (53) in sitting position. The validity of the cervical inclination and cervical angles were tested by Refshauge et al. (66)

Craniovertebral Angle

Johnson (67) examined the association between the external measurement of head and neck posture and the anatomical positions of the upper four cervical vertebrae in 34 female subjects. In this study, the craniovertebral angle (C7/Tragus/horizontal) was used as the surface measurement and was compared with the OPT/HOR and CVT/VER (104) in the radiographic measurement (Fig. 10).

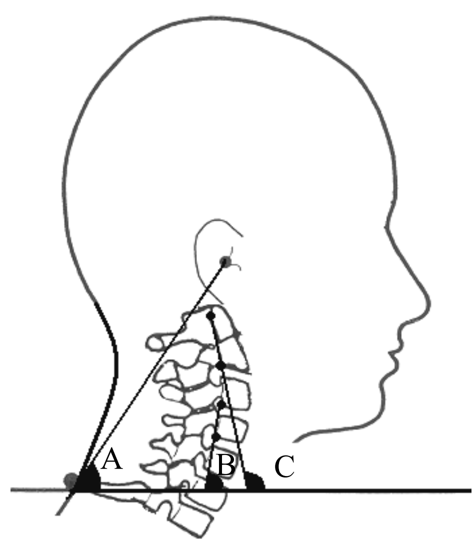

Figure 10. The craniovertebral angle (A) was compared with CVT/HOR (B) and OPT/HOR (C)

Johnson's description of the CVT line differed from that of Solow and Tallgren. (104) The former described the CVT line as being formed by a line through CV2TG (tangent of the second cervical vertebra, the point most superior and posterior to the odontoid) and CV4IP (the most inferior and posterior point of the fourth cervical vertebra), while Johnson described the CVT as being formed by a line through CV3IP (the most inferior and posterior point of the third cervical vertebra) and CV4IP. Since there was no literature reference in Johnson's study when the CVT reference points were described, it is not possible to know whether the author was referring to the CVT line as a modified CVT, or whether there was an error when the reference point was used. The CVT reference point difference can influence the comparison of its measurements among studies.

In the Johnson study, the subjects posture was standardized in the natural head posture (NHP) position using the spirit-level method. The spirit-level, also called fluid level, was first developed by Showfety et al. (109) The spirit-level was attached with adhesive tape to the temple of the subject. A horizontal plane of the spirit-level needed to be establishing to achieve the natural head position. According to the author, this method provided an additional measure of reliability because it provided the same postural pattern for the measurements for all subjects. However, the spirit-level can influence the NHP of the subjects since the posture that needs to be achieved in order to get the horizontal plane of the spirit-level might not be the NHP of the subject. In other words, the real NHP of the subject might be achieved when the spirit-level is not in the horizontal plane. In addition to the spirit-level method, the subjects were also encouraged to move their shoulders up and down to induce relaxation if they appeared tense. The relaxation was believed to be important in order to achieve the NHP without the influence of muscle stress. Alterations in head posture have been described to be directly related to stress on the cervical region. (40)

In order to standardize the posture for the radiographs procedures in Johnson's study, a cephalostat (an instrument used to position the head for measurement and radiographic examination) was used. However, it has been shown by Greenfield et al. (110) that subjects extend their heads and cervical spines when using this device. Therefore, this standardization may not express the natural posture of the subjects analyzed.

The intra-rater reliability was tested in Johnson's study for the measurements in 15 randomly selected unmarked radiographs and photographs. The craniovertebral angle in the photographs and the cervical angles in the radiographs were measured twice. The intraclass correlation coefficient (ICC) was considered excellent (ranged from 0.96 to 0.99). However, the intra-rater reliability tested in the photographs could have been influenced by the markers placement by the investigator, and this was not taken into account for this analysis because the test was performed on the same picture. The intra-rater reliability should also be performed on two different pictures in order to test the consistency of the placement of the landmarks because they influence the measurements. If the placement of the landmarks is not consistent, the intra-rater reliability can be altered. Two photographs were taken from the subjects at 2 different sessions (1 week apart) to measure the craniovertebral angle. An ICC of 0.88 was obtained.

The authors concluded that the 2 sessions showed consistency of posture in the subjects studied. However, an ICC value does not distinguish whether the consistency is from the rater in measuring the angle, or from the subjects' posture. Ideally, the reproducibility of the subjects' posture should be tested with the repeated measurements using different radiographs to decrease the error related to the placement of the markers by the investigator. If the placement of the markers on the neck of the subjects is not reliable, the real measurements of the subjects' posture will be influenced. In other words, the measurements of the subjects' posture may be altered by how the markers are placed. The only restrictions on doing repeated measurements in different radiographs are the additional radiation exposure to the subjects and additional the costs of the study. The risk and cost-benefit ratio of any study needs to be analyzed in order to justify the methodology of the study. The inter-rater reliability was not measured in Johnson's study. Therefore, the reproducibility of measurements taken by the different testers was not provided which would be important to know if the reliability changes among raters.

In order to correlate the angles on the photographs and radiographs in Johnson's study, Pearson correlation coefficient was used. A low correlation was found between the craniovertebral angle and CVT/HOR angle (r=0.11 to 0.23). A statistically significant but low positive correlation was found between the OPT/HOR and the craniovertebral angles (r=0.39). In order to compare the two methods of measuring posture, the same posture needs to be used. The possible alteration in posture between the two methods, which gives one measurement error, can be avoided by taking the picture and radiograph simultaneously. Whether this was done was not mentioned in the study. The author concluded that the anatomic position of the upper cervical vertebrae could not be inferred from the variation of surface measurements of head and neck alignment according to his methodology since the correlation between surface and radiographic measurements was low. The angle comparisons used in his methodology must have contributed to the low correlation. In his study, the surface craniovertebral angle was compared with OPT/HOR and CVT/VER in the radiographs. As discussed previously, the craniovertebral angle represents the measure of the posture of the head in relation to the cervical spine. On the other hand, OPT/HOR and CVT/VER take into account only the position of the cervical vertebrae (i.e. inclination of the cervical spine) without using any reference to the head. Therefore, different constructs of craniocervical posture were compared between photogrammetry and radiographic measurements in Johnson's study which could be the reason for the low correlation. In order for the surface and radiographic measurements to be comparable, the craniovertebral angle should be tested using the radiographic angles that relate the posture of the head to a line representing the cervical column as described by Solow and Tallgren (NSL/OPT, NSL/CVT). (104) Future studies are needed to test this hypothesis.

Visscher et al (42) compared the craniovertebral angle (C7/Tragus/horizontal) with the cervical posture line (CPL) (Fig. 11). The CPL is composed of reference points on the upper six cervical vertebrae, using the horizontal axis. In order to determine the CPL, the 4 edges of each vertebra are used as reference points to establish their position. The co-ordinates of these reference points are digitalized and the centre of each vertebra is then determined. (109) Based on the least squares method, the linear equation of the line running as close as possible along the centers of the upper six cervical vertebrae bodies, the CPL was calculated.

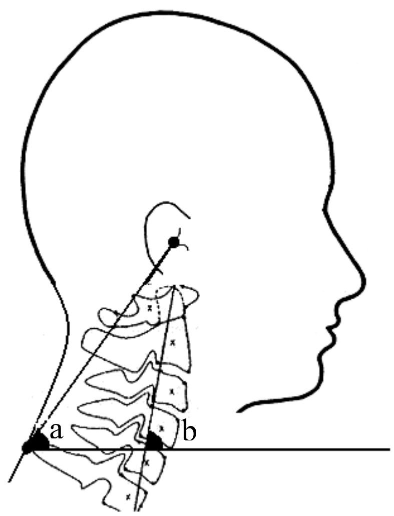

Figure 11. The craniovertebral angle (a) was compared with CPL/horizontal angle (b).

In order to standardize the craniocervical posture of the subjects in the Visscher et al. study, a mirror was placed in front of them. The use of the mirror is purposed to activate a visual righting system that is determined by input from an external object. (111) The use of another technique to standardize the posture, such as the self balance position described by Solow and Tallgren (112) is suggested. The self-balance position is obtained by activating the proprioceptive system (i.e. unconscious perception of the posture by sensory feedback mechanisms) and does not involve an external reference, such as a mirror, which can provide feedback on the subjects posture and consequently influence the NHP. The self balance position is achieved by asking the subjects to perform a large amplitude of cervical flexion and extension, gradually decreasing to rest in the most comfortably balanced position. The cephalostat was not used in the radiographic procedure so as not to influence the posture.

The reliability of the surface and radiographic measurements was tested by Visscher et al. Ten subjects volunteered to have both radiographs and photographs taken on two separate occasions. The ICC of the radiographic measurements was 0.96 and the ICC of the picture measurements was 0.83 in a standing position. The authors also applied a paired t-test to evaluate whether there was a measurement difference between the two separate occasions, and found no significant differences ($t = -0.81$ and -1.43; $P = 0.19$ and -0.44 respectively). For the radiographs, the method error of the differences in head posture among the repeated images was 2.1º and for the photographs, it was 2.5 º. However, a sample of 21 subjects is necessary to test reliability using two repetitions in order to have a power of 80% and an ICC value of 0.85. (113) Therefore, more subjects needed to be included for the reliability analysis in this study. The inter-rater reliability was not tested in this study.

The authors found a positive Pearson correlation coefficient but no statistically significant differences between the two angles measured ($r = 0.43$). The authors concluded that the two techniques, the craniovertebral angle and the CPL angle, were not interchangeable. Similar to Johnson's study, the angle comparisons in the methodology of Visscher et al. must have contributed to the low correlation. Two different constructs were compared: the CPL angle evaluated the inclination of the cervical spine, and the craniovertebral angle evaluated the position of the head in relation to the cervical spine.

The validity of the craniovertebral angle was also tested with radiographic measurements in adolescent healthy subjects. (53) However, the subjects' posture was assessed at a simulated computer workstation and therefore, they were analyzed in a sitting position. Subjects were randomly allocated to one of three sitting positions: slouched, upright, and habitual. The craniovertebral angle was measured in the photographs and radiographs using computer software. The surface markers were detected by the software and used to calculate the angle on the radiographs. Good to excellent Pearson correlation values were found (r=0.79-0.89). Reliability of the subjects posture was calculated using 5 repeated photographs (subjects sitting 5 times consecutively in the same day). ICC values were between 0.78 and 0.98. The authors concluded that the subjects posture was reliable when measured using repeated photographs. However, repeated measures were performed on the same day which is not the ideal method for assessing the reproducibility of craniocervical posture. In addition, the reliability of the markers position was not analyzed. Photographs and radiographs were not taken simultaneously in their study. The authors concluded that photographs provided valid and reliable representation of the position of the underling spine in sitting.

Cervical inclination angle and cervical angle

Refshauge et al. (66) investigated the relationship between the surface contour and the vertebral alignment in the cervical spine in 24 healthy subjects. In this study, the cervical inclination angle (formed by a line connecting the skin over the spinous process of the vertebrae C2 and C7 with the horizontal line) was compared to the cervical inclination angle (formed by a line from the center of the vertebrae C2 and C7 with the horizontal line) on the radiograph. According to the authors, these angles represented the forward inclination of the cervical spine, and therefore, the forward position of the head relative to the cervicothoracic spine. The more acute the angle, the more forward was C2 relative to C7 (Fig.12).

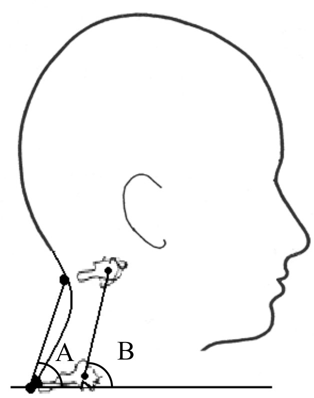

Figure 12. Cervical inclination angle with surface measures (A) and with radiographic measures (B).

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The authors found a moderate correlation (r=0.55) for the cervical inclination between the superficial and radiographic measurements. In the same study, the cervical angle derived from surface measurements (spinous processes of C2, C4, and C7) was compared with the line connecting the center of the vertebrae of C2 and C4, and C4 to C7 in the radiographs (Fig. 13). The authors felt these angles represented the cervical spine lordosis: the smaller the magnitude of the cervical angle, the larger the cervical lordosis.

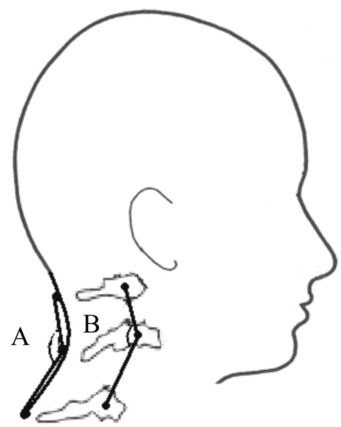

Figure 13. Cervical angle with surface measures (A) and with radiographic measures (B).

A moderate correlation was found for the cervical angle (r=0.65) between radiographic and photographic measurements. Further analysis was performed in the same study, and revealed that the correlation between the spinous process with both the vertebral body (r = 0.63–0.85) and surface parameters (r = 0.80) was better than the previously observed correlation between the vertebral body and surface parameters. According to the authors, the difference between the surface and vertebral curvature appeared to be due to the length of the spinous processes and the depth of the soft tissues, which decrease the correlation between these two references. However, this further analysis was described in the discussion section of their paper, and was not a main objective. Therefore, additional studies are necessary to replicate this methodology. In addition, the authors found that the greatest difference between vertebral body and surface curves occurred near the cervicothoracic junction (C7). The fact that C7 has the longest spinous process in the cervical spine may contribute to the smaller correlation between vertebral body and surface curves, because the surface reference using the spinous process of C7 underestimates both angles (cervical inclination and cervical angle) for the surface measurements as compared with the vertebral body. The use of C6 as a reference instead of C7 when studying the cervical part of the spine may increase the correlation between the measurements, as the C6 spinous process does not present such a distinctive characteristic in relation to the rest of the cervical spinous processes. However, more studies are needed to investigate this hypothesis.

In the study of Refshauge et al., (66) the surface measurements better represented the radiographic measurements. In other words, they measured the same construct or aspect of posture (cervical inclination and cervical lordosis) in both surface and radiographic measures. However, the standardization of the head posture was not described in this study, and only a moderate correlation was found.

Final considerations

Several authors failed to support their conclusions because of the lack of information about experimental methods in validity studies of craniocervical posture using surface techniques. Important issues are missing in the literature concerning these studies (Table 2).

Table 2. Issues to be addressed when evaluating craniocervical posture in sagittal plane.

Issues	Examples
Standardization of posture	Is the posture of all subjects being standardized in the same way? What procedure is being used?
Reliability of the measurements	How reliable is the investigator? (Intra-rater reliability). Is there a difference of measurements among investigators? (Inter-rater reliability). Is the posture of the subject reproducible? (Intra-subject reliability).
Comparisons of the same construct of posture for validity studies	Are the measurements that are being compared between different methods (i.e. surface and radiographic) representing the same construct of posture? (inclination of the cervical spine, lordosis of the cervical spine, or position of the head in relation to the cervical spine).
Sensitivity of the measurements	Are the measurements able to detect differences among different postures? (i.e. between natural head posture and forward head posture).

- Standardization of posture

The head posture needs to be standardized in order to decrease the chance of variation in the head position to increase the consistency of the subject's postural measurement. This is important for the comparison of posture among subjects, or within subjects. In the literature, there have been various methods employed to establish natural head posture (NHP) when assessing a subject's posture. The objective is to obtain a posture of the head and neck in the sagittal plane that is determined by the subject's own postural systems. This can be achieved if the procedure is standardized among all subjects being evaluated.

Some studies have attempted to define the NHP, however, a number of different methods have been used to determine NHP in the literature, which demonstrates a conflict of opinion and lack of consensus among researchers. The differences for each standardization procedure need to be tested and compared in order to determine which one better represents the NHP and is more reproducible.

The zero point (between flexion and extension) has been variously described as: the posture of the head when standing erect, and looking at a visual target at eye level; the posture of the head and neck when standing erect and looking at a visual target 15° below eye level; and 'normal erect posture'. (65)

Standards for assessing craniocervical posture are described in the literature. In Showefty et al's study (109), the subjects were instructed to look at the horizon, while in Braun and Amundsen's study (64), the subjects simply focused on a point directly ahead on the wall of the room. The Frankfurt plane parallel to the ground is another concept frequently used in the literature. This is a standard position of reference in which the upper border of the external auditory meatus is on a horizontal plane with the lower border of the eye. The use of the spirit-level (also called fluid level), first developed by Showfety et al., (109) was also used to standardize NHP. (67)

The visual righting system is a mechanism introduced by Solow and Tallgren (112) that is determined by input from the visual righting system when the subject fixes his or her gaze on an external object. The authors investigated the reliability of the method using a mirror in front of the patient's eyes, and the method of self-balance position (achieved by a large amplitude of cervical flexion and extension, gradually decreasing to rest in the most comfortably balanced position). Therefore, head posture could be defined with or without external reference: the mirror position and the self-balance position respectively. According to Solow and Sandham, (111) the self-balance position is obtained by activating the proprioceptive system, and the mirror position by subsequently also activating the visual righting system. Solow and Tallgren (112) demonstrated that with both methods, head postures were reproduced without systematic error. However, they also found that when using the mirror, there was a tendency for the head to be held in a significantly more extended position than with the use of the self-balancing system. In addition, Cooke and Wei (114) investigated NHP in Chinese school children using the same methods. They found that boys extended their heads more in the mirror reference position than in the self-balance position.

Therefore, the mirror should not be used if one wants to assess the habitual head posture of subjects.

When comparing craniocervical posture using surface and radiographic measurements, the postural positioning needs to be the same for both methods. If postural positions derived from the surface and radiographic techniques are not the same, the validity analysis will not be accomplished. Therefore, it is recommended that the photograph taken for the surface technique and the radiographic image be taken simultaneously. (63) The standardization of head and neck posture was not described in the Refshauge et al. study. (66)

- Reliability

Posture is considered reproducible (consistent/reliable) if no significant changes in posture occur when repeated postural evaluations are performed. The posture needs to be reproducible to be sensitive enough to detect systematic changes to treatments (56) or to be able to be compared among different subjects. If posture is not reproducible, posture measurements become unreliable and therefore non-valid. Reliability is a prerequisite for the validation of a measurement. (68) Lack of standardization and low intra-rater reliability are possible confounders that need to be considered when assessing reproducibility. If these confounders are controlled, the more reproducible posture will be. More studies need to address these subjects when investigating posture reproducibility.

Evaluators also need to be reliable in terms of finding the position of the landmarks used for the surface technique, and from these landmarks, the drawing of the angles or lines for the craniocervical posture (intra-rater reliability). If the measurements are to be compared between raters, the inter-rater reliability needs to be considered. The inter-rater reliability was not tested by any of the validity studies described previously. (42,66,67) The Refshauge et al. study did not report any reliability analysis. The lack of reliability analysis leads the readers to question the precision of the measurements described.

- Validity

When testing the validity of surface measurements with radiographic measurements, both measurement techniques need to represent the same construct of posture (i.e. inclination or lordosis of the cervical spine, or position of the head in relation to the cervical spine). The Refshauge et al. study (66) was the only study found that compared the same construct of posture in both photographs and radiographs.

Other radiographic measurements described in the literature, (106) such as the absolute rotation angle (ARA), can also be compared with surface measurements. The ARA can be compared with the cervical angle for surface measurements; however, future studies are necessary to test whether they are correlated and whether the correlation would be different from the correlation using the cervical angle in the radiographs instead of the ARA. Further investigation of the correlation of the measurements using the spinous process of the cervical spine with the surface and cervical body measurements as discussed by Refshauge et al. (66) are also needed.

- Sensitivity

Another measurement property that should be tested is the sensitivity. In the case of the craniocervical posture in the sagittal plane, the measurements need to be able to discriminate different postures (e.g. FHP and aligned posture). This is important when investigating the postural treatment effect. Therefore, improvement in posture can be evaluated by comparing the posture before and after treatment. The sensitivity analysis was not tested by any of the studies comparing surface and radiographic measurements.

RADIOGRAPHIC CONCEPTS

Radiation quantities and their units of measure

There are four basic radiation quantities (115):

1. Exposure: the amount of radiation that expresses the concentration of radiation delivered to a specific point, such as the surface of the human body. The conventional unit is the roentgen (R) and the International System of Units (SI unit) is the coulomb/kg of air (C/kg of air).

2. Absorbed dose: the amount of energy per unit mass by radiation in the subject's body tissue. The rad (radiation absorbed dose) has been used as the unit of absorbed dose.

3. Equivalent dose: the product of the average absorbed dose in a tissue or organ in the human body and its associated radiation weighting factor chosen for the type and energy of the radiation in question. The equivalent dose is expressed in sieverts (Sv) (SI unit) or in rems (traditional unit).

4. Effective dose: the measure of the overall risk of exposure to radiation. It considers that some tissues are more sensitive to radiation than others. Effective dose is expressed by sieverts (Sv) (SI unit) or in rems (traditional unit).

Radiation Risks versus the Risk Benefit Ratio

Every diagnostic and interventional procedure can lead to potential risks to the patient. (116) The biologic damage produced by ionizing radiation includes molecular damage, leading to abnormal cellular function, or loss of cellular function. However, if an imaging procedure for health purposes is needed, the patient may decide to assume the risk exposure to ionizing radiation to obtain the diagnostic medical information. (115)

According to Holm et al. (117), the risk for patients being x-rayed is low because they are not frequently exposed to x-rays. In addition, only a small part of the body is exposed for each picture. The authors also reported that the greatest risk from x-rays is for the operators who may be exposed repeatedly if no shield is used. From a population health perspective, the relative risk for patients who receive x-rays is minimized by a potential medical benefit of the test. For patients for whom an x-ray can be diagnostic, to not take an x-ray can provide a higher medical risk than the risk of radiation exposure. For healthy subjects, for whom x-rays are taken for research purposes, the radiation exposure from the x-ray will not provide them with any direct benefit such as a medical diagnosis. Therefore, the research needs to bring some benefits to society in order to make it ethically acceptable and to justify the risk of the healthy subjects being exposed to radiation (i.e. risk benefit ratio). In the present study, the benefit to society is to contribute to the improvement of the craniocervical posture clinical evaluation using a non-invasive and quantitative approach. A non-invasive technique that is effective for the assessment of craniocervical posture is less expensive to use than the radiographic method, and there is no risk of radiation exposure for the patients with its use. Therefore, the risk of the healthy subjects being exposed to radiation is justified by the benefits that this research brings to society.

Radiation Protection

The radiographs need to be produced under recommended radiation protection guidelines. Recommendations are described in the National Council on Radiation Protection and Measurement's Report and the International Commission on Radiological Protection's Publication. Radiation exposure should always be kept at the lowest possible level for the patient. When the radiation is safely and prudently used in the imaging of patients, the benefit of the exposure can be maximized while the potential risk of biologic damage can be minimized. (116,118)

Protection of x-ray operators and office personnel is provided by the patient protection practices and by operator wall shielding and the maintenance of proper operator distance. In addition, radiographic equipment must be installed according to governmental standards and periodically tested for safety by state and/or local heath public officials. (118)

Quality of the Radiographic Image

There is always a varying amount of magnification of an object in any radiography because of the divergence pattern of x-ray photons originating from the tube x-ray source. The larger the distance from the source being imaged to the film plane, the greater the magnification. To minimize this effect, the distance from the x-ray source to the patient should be no more than 5 feet or 1.5 meters. (118)

Another important characteristic to ensure in a radiographic image is the good visualization of the anatomic structures. If the radiation is scattered, the quality of radiographs image can be affected. To reduce the amount of scattered radiation, an x-ray grid is recommended. The grid consists of small leads strips either parallel to each other or in a converging pattern with radiolucent spacers in between. The grid is placed in between the object being imaged and the x-ray film as close as possible to the film. Thus, the scattered radiation hit the strips and is absorbed. This technique increases the contrast of the film and provides more detailed images such as bony structures. (118)

Lateral Radiography of the Cervical Spine

When the radiologist assesses a lateral radiography of the cervical spine, he/she makes sure the whole cervical spine is seen; then he/she looks at the configuration of the spine (e.g. curves, pathological changes) and the harmonic course of the auxiliary lines along the anterior and posterior edges of the cervical bodies, the posterior margin of the spinal canal, and the spinal process (Fig. 14). The radiologist studies the intervertebral joints, the intervertebral disk spaces, the vertebral body configurations, and the prevertebral soft tissue stripe. (116)

Figure 14. Radiographic image of the cervical spine showing the lines (harmonic course) along the anterior and posterior edges of the cervical bodies, and the contour of posterior vertebral arches.

In general, the amount of radiation received by a patient from a diagnostic radiologic procedure is indicated in terms of entrance skin exposure. The permissible skin entrance exposure for the cervical spine examination is between 35 and 165 milliroentgens (mR) per projection.

The typical effective total body dose for radiography of the cervical spine is 0.1 mSv (millisievert) which is equivalent of 5 chest radiographs and equivalent of 2 weeks of natural background radiation (116) such as terrestrial radiation, cosmic radiation from the sun and beyond the solar system, and internal radioactive atoms that make up a small percentage of the body's tissue. (115) The dosage of 0.1 mSv is considered low (less than 1 sv).

Limitations of Radiographic Technique

The limitations of radiographs are well known. They include possible image magnification and distortion, and exposure to radiation. Another limitation is that it provides analysis in only two dimensions. In cephalometric analysis, for example, the ideal diagnostic analysis of the craniofacial complex would be performed in three dimensions. The analysis of the soft tissue is very important to determine the esthetics and balance of orthodontic patients. The best that can be accomplished using radiographic data is to combine a lateral cephalometric radiograph with a radiograph taken in the frontal view thus creating a more comprehensive analysis. (119).

For analysis of head and neck posture, the disadvantage of using lateral radiographs is that a possible rotation or inclination of the head is not assessed. A 3D analysis of the posture would be ideal. However, if the objective of the study is the assessment of forward head posture which is being evaluated in a lateral view, rotation and inclination of the head may be controlled when taking the radiographs by using a standard posture. In addition, there is a limitation of 3D analysis when comparing the natural head posture assessed with surface and radiographic measurements. The 3D radiograph of the subjects needs to be taken in supine position or in sitting position which limits the study of the natural head posture (in standing position).

CHAPTER 3. METHODOLOGY – PART 1

This chapter describes the methodology of Part 1 of the study: "Reliability of Craniocervical Posture Measurements".

STUDY DESIGN

This study uses an exploratory design to test the relationship and prediction among certain variables (i.e. angle measurements and posture). More specifically, this is a methodological research designed to test a measuring technique (photogrammetry) for use in research or clinical practice. (73)

SUBJECTS

Considering that women are more affected by pain syndromes in the craniocervial region as discussed in Chapter 1, a convenience sample of healthy female volunteers between the ages of 20 and 50 years old were included in this study. Healthy subjects were selected in this study to prevent potential counfounding factors, such as pain, since this was an initial, baseline study of the measurements tested. (108)

The sample size calculation was based on an estimate for reliability studies. (113) Twenty one subjects are needed for the reliability analysis using 2 repetitions in order to achieve a power of 80% with alpha of 0.05 for ICC 0 = 0.6 and ICC 1= 0.85 (Appendix H).

Inclusion and Exclusion Criteria

- Inclusion criteria:
    1. Normal craniocervical region defined as normal function (i.e. range of motion) and absence of pain.
- Exclusion Criteria
    1. History of cervical trauma, surgery, bone pathology, or arthritic or other inflammatory disorders;
    2. Pain in the craniocervical region including:
        - Frequent neck pain and/or headache (more than 2 episodes per month or 1 episode of more than 3 days of duration) (120);
    3. Body mass index (BMI) more than 30 which indicates obesity.

PROCEDURES

Three sessions were needed to evaluate the subjects:

1) In the first session, the subjects had their craniocervical region evaluated by the first investigator. During this evaluation, the subjects were assessed to determine if they were eligible for the study based on the inclusion and exclusion criteria.

2) In the second session, 1 radiograph and 1 photograph of the craniocervical region in natural head posture was taken for each subject.

3) In the third session, another radiograph and another photograph were taken. This session was used to determine the intra-rater reliability of the

measures in the craniocervical spine, including the replacement of the landmarks in the cervical spine, and the reproducibility of the subject's posture (2 repetitions).

DATA COLLECTION

1) First session

First, an information letter about all the research procedures was given to each volunteer (Appendix D). If the subject agreed to participate, the evaluation started. A physical assessment of the head and neck region including a medical history questionnaire, a visual assessment of the presence of forward head posture (FHP), (2) palpation, and a range of motion evaluation, was included (Appendix I). The duration of this session was approximately 35 minutes.

2) Second session

The subjects included in the study had a radiographic and a photographic image taken simultaneously of the craniocervical region in a sagittal standing position. First, the subjects were asked to wear a tank top. The skin overlying the spinous process of C2, C4, C6, and C7 were located by palpation of the cervical spine (121), and marked with a hypoallergenic pen (specific for surgical procedures). Reference markers made of light metal were placed on the marks and in the tragus of the ear (left side) with a double-side adhesive tape by the first investigator. The markers were visible in the radiographs which were used to check accuracy/agreement of the marker placement in relation to the spinous processes of the cervical spine.

Standardization of the Posture

Subjects were asked to stand relaxed. The position of the head was standardized using the self balance position (112), asking the subjects to look parallel to the ground, keeping the gaze horizontal after performing a large amplitude of cervical flexion and extension. This position was ensured by a reference mark placed in the wall at the same level of the subject's eyes. The level of the subject's eyes was measured using a laser level that was held by the first investigator on the lateral canthus of the subjects left eye (Fig. 15). The laser point was projected on the wall in front of the subjects indicating where the marker needed to be placed. A feedback from the subjects was also used to ensure that the point was centered and in a habitual/comfortable position to look. Additionally, the subjects were instructed to stand in a relaxed upright posture, barefoot, on a sheet of paper in order to trace the position of the feet. This procedure was important for the second photograph when the sheet of paper was used again to assess the reproducibility of their posture one week later. This ensured that the same foot position was achieved in both photographs to eliminate errors induced by alignment changes. (56)

Figure 15. Laser level used to standardize posture

Radiographic Procedures

Lateral radiographs of the craniocervical region with the subjects in a standing position were taken by a radiology technician at the Glen Sather Clinic at the University of Alberta. The area of the images included the nasion-sella line to the seventh cervical vertebra including the body of the vertebrae and spinous processes. Figure 16 shows a radiograph taken from a subject. The radiographic image also includes the markers placed on the skin over the spinous process of the cervical vertebrae C2, C4, C6, and C7.

The structural detail (sharpness) in the radiographic image must be very clear in order to accurately use the references in the image for the measurements being analyzed. In order to have a good image quality and control of the image magnification, the distance between the source and the image was 72 inches (1.83 meters). The object-to-image distance was small (18 cm) in order to decrease the penumbra (fuzzy border around the shadow), which increases the image sharpness. The mid-sagittal plane of the patient's head was parallel to the x-ray film plane. A grid, placed between the subject and the film, was also used to control scatter radiation which further controls the density and contrast of the image. The subjects used a lead belt around the hips for radiation protection of the ovaries. The cephalostat was not used so as not influence the standardization of the posture. (110)

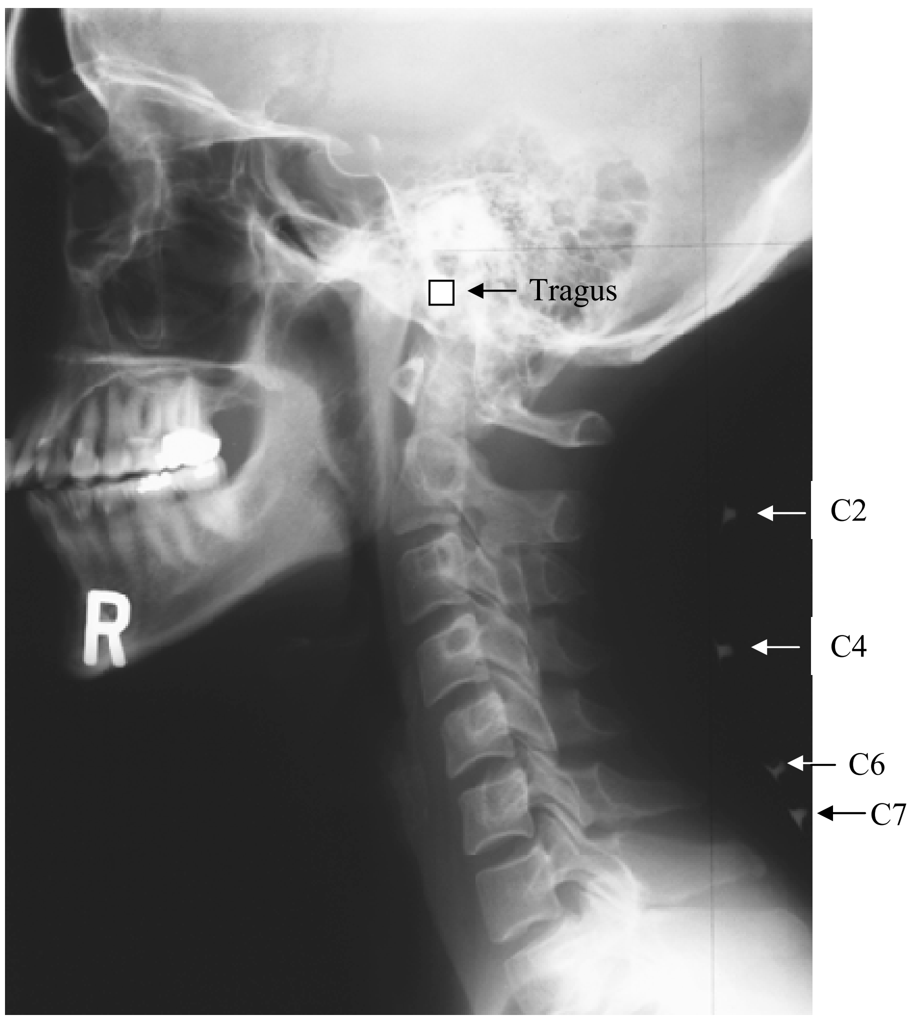

Figure 16. Radiographic image of the craniocervical posture (arrow indicate markers)

Photographic Procedures

A Canon EOS Rebel XT digital camera was used to take the photographs of the craniocervical region. The camera was positioned in the same plane as the x-ray tube (on top) (63) and the same distance from the subject used for the radiograph was used for the photographs (72 inches) (Fig. 17).

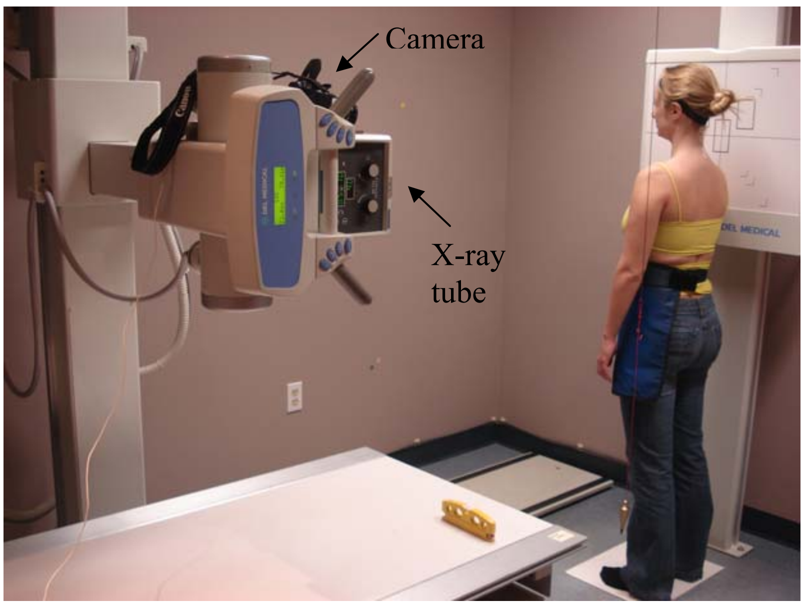

Figure 17. Data collection settings for taking the radiographs and photographs.

A camera remote cable (Remote Switch RS-60 E3) was connected to the camera so the photographs were taken by the first investigator at the same time the radiologist took the radiographs (Fig. 18). The following verbal communication was used to take the images simultaneously: “One, two, three, now”. Using this procedure, the posture of the subjects is the same for both measurements which avoided error when comparing posture measures between the two techniques (radiograps and photographs). The images were taken from the subject's left side.

Figure 18. Remote cable used to take the photographs and radiographs simultaneously.

Figure 19 shows a photograph taken of a subject. Reflective tape was used on the markers positioned on the neck and tragus of the ear of the subjects for better visualization of the markers in the photographs. A plumb for alignment made of metal was positioned beside the subject for a vertical reference. The plumb was also visible in the radiographs. The second visit took about 30 minutes.

Figure 20 shows a close-up of the surface markers and how the surface markers were placed on the cervical spine in a posterior view.

3) Third session

The third visit took place 1 week after the second visit and in the same period of the day as the second visit. Subjects were asked if they had any pain after the first and second sessions to assure absence of pain for the third session.

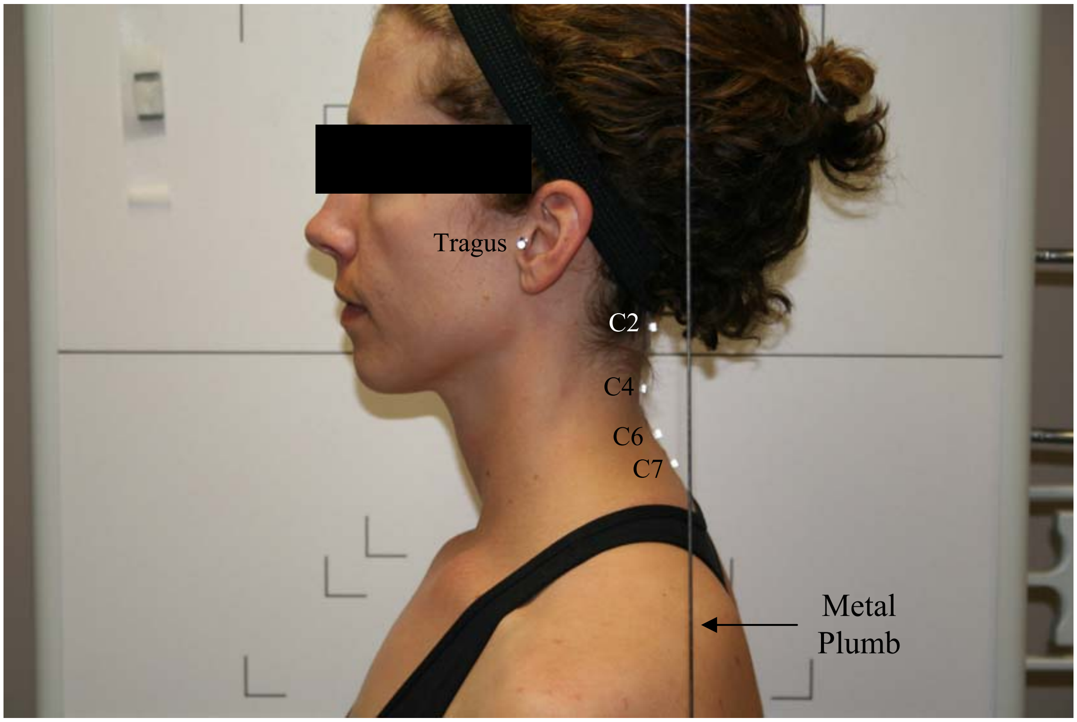

Figure 19. Photographic image of the craniocervical posture showing surface markers on cervical spine and tragus of the ear.

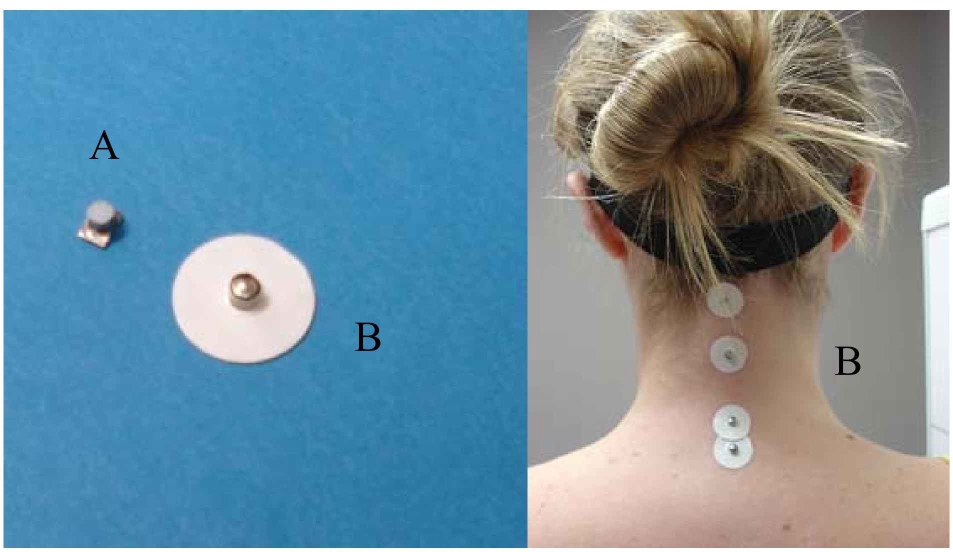

Figure 20. Surface markers placed on tragus of the ear (A) and on the cervical spine (B)

The same time period was used because the reproducibility of the subject's posture was tested and the posture may change according to the time of day. The same procedure used in the second visit was followed for the third visit, including the placement of the landmarks in the cervical spine, the standardization of the posture, and the procedure for the photographs and radiographs. The subjects were asked to step on the same sheet of paper with the position of the feet traced in the second session.

MEASUREMENTS

Blinding Procedure

Codes were placed on top of the subject identification on the radiographs by an independent person using a random digits table (122) so the first investigator was blind in relation to the subject and sessions. The radiographs were scanned (Epson 1680) and transferred to the computer. The faces of the subjects on the photographs were also hidden so possible identification of the subject during the measurements was minimized. Only the area of interest (head and neck) was showed on the screen during the drawing of the angles on the photographs. The shoulder and trunk were not showed in order to reduce the possibility of the rater to know the classification of the subject's posture which is more apparent when shoulder and trunk are visible. Each radiograph and photograph from the same subject was saved with a sequential identification numbers by an independent person. The order of the photographs used to do the measurements was randomized using the random digits table. (122)

Craniocervical Posture

Three aspects of the craniocervical posture were measured in the photographs and in the radiographs: 1) The posture of the head in relation to the cervical spine; 2) The inclination of the cervical spine; and 3) The lordosis of the cervical spine.

The following surface angles were measured:

- Angle that represents the position of the head in relation to the cervical spine:
  - Craniovertebral angle (CVT) (see Figure 8 page 65).

- Angle that represents the inclination of the cervical spine:
  - Cervical inclination angle (CIA) (see Figure 9 page 66).

- Angle that represents the lordosis of the cervical spine:
  - Cervical angle (CA) (see Figure 9 page 66)

The following adapted angles were also measured to assess inclination and lordosis of the cervical spine respectively (Fig. 21):

- Adapted cervical inclination angle (ACIA) represented by the angle formed by a line connecting C2 and C6 with the horizontal line; and

- Adapted cervical angle (ACA) represented by the angle formed by a line connecting C2 and C4 with a line connecting C4 and C6.

A total of five surface angles were measured in the photographs.

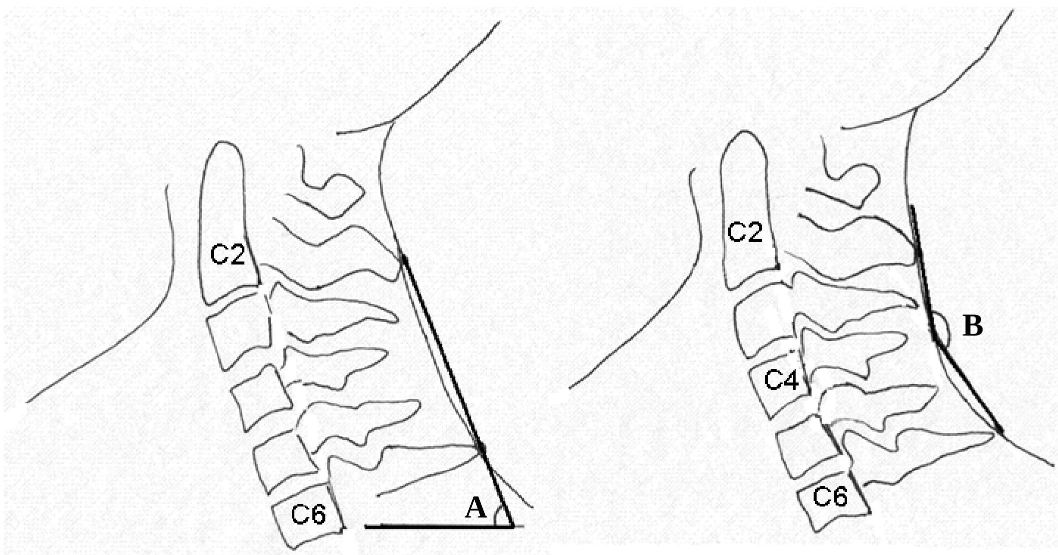

Figure 21. Adapted surface measurements to assess inclination and lordosis of the cervical spine: A) Adapted cervical inclination angle; and B) Adapted cervical angle.

The adapted angles for assessing inclination and lordosis of the cervical spine differ slightly from the angles described by Refshauge et al. The use of C6 vertebra was proposed as a reference instead of C7, as described by Refshauge et al, for the following reasons: 1) a greater difference between surface and radiographic measurements has been found in the cervicothoracic junction; (66) 2) according to Descarreaux et al, (63) the C7 marker did not contribute to the prediction of any of the segmental vertebral inclinations in the cervical spine and

3) the penetration of the x-ray at C7 was sometimes difficult to take because of the shoulder position and consequently, hard to visualize during analysis. Because of these difficulties, it was expected that the adapted angles (ACIA and ACA) were a better representation (concurrent validity) of the inclination and lordosis of the cervical spine respectively. This assumption was tested in Part 2 of the study (Chapter 4).

The following radiographic angles were measured:

- Angles that represent the position of the head in relation to the cervical spine:
  - NSL/OPT (see Figure 5 page 61);
  - NSL/CVT (see Figure 5 page 61).

- Angles that represent the inclination of the cervical spine:
  - OPT/horizontal (see Figure 5 page 61);
  - CVT/horizontal (see Figure 5 page 61);
  - Cervical inclination angle (CIAr) (see Figure 12 page 75);
  - Adapted cervical inclination using C6 instead of C7 vertebra (ACIAr).

- Angles that represent the lordosis of the cervical spine:
  - ARA (see Figure 4 page 60);
  - Cervical angle (CAr) (see Figure 13 page 76);

- Adapted cervical angle using C6 instead of C7 vertebra (ACAr).

- Angles using the spinous process instead of the center of the body vertebrae:
  - Cervical inclination angle (spCIA);
  - Cervical angle (spCA);
  - Adapted cervical inclination (spACIA);
  - Adapted cervical angle (spACA);
  - Angle formed by a line connecting the auditory meatus and the spinous process of C7 with a horizontal line (Am/spC7/hor).

A total of 14 angles were measured in the radiographs.

Angle Analysis

The digital photographs and the digitalized radiographs were analyzed using Alcimage® software. This software uses an angular calculus to accurately quantify the posture through the utilization of an image. (62) Measurements of the head posture in a lateral view in subjects with occlusion class I and II using this software have demonstrated excellent intra-rater reliability (ICC=0.99). (123) During the measurements using the software, the investigator was blind to the angles values measured because they were calculated automatically by the software in a different window in the computer screen which was not seen by the investigator.

Statistical Analysis

The following reliability tests were performed from at least 21 subjects: Intra-rater, intra-subject, inter-rater, and the precision of the marker placement. Each type of reliability tested is described below.

1. Intra-rater reliability

   Two types of intra-rater reliability were tested:

   I. The intra-rater reliability of the tracing of the angles on the photographs and in the radiographs. Two measures repeated a week apart were performed for each image. Intraclass correlation coefficient (ICC) and the standard error of measurement (SEM) were then calculated between the 2 repeated measures of the same image. Only one radiograph randomly chosen from each subject was used for this reliability. The first radiograph was chosen from a subject with even identification numbers and the second radiograph was chosen from a subject with odds numbers. This analysis was performed by two raters (physical therapists who graduated between 10 and 15 years ago);

II. The intra-rater reliability of the placement of the landmarks in the cervical spine. The mean of the 2 repeated measures for each of the 2 photographs for each of the the subject taken a week apart was calculated. ICC and SEM were calculated between the 2 means. This analysis was performed by Rater 1.

2. Intra-subject reliability (reproducibility of the subject's posture):

The mean of the 2 repeated measures in each of the 2 radiographs of each subject taken a week apart was calculated. ICC and SEM were calculated between the 2 means.

3. Inter-rater reliability:

Two types of inter-rater reliability were tested:

I. The inter-rater reliability of the tracing of the angles on the photographs and in the radiographs between the two raters. The mean of the repeated measure on the photographs and radiographs by each rater were compared to calculate ICC and SEM. The raters were unaware of each others measurement values.

II. The inter-rater reliability of the visual assessment of posture using photographs and radiographs between two raters. This reliability was performed using all subjects included in this study (Part 1 and Part 2). Therefore, the methodology and results for this reliability are presented in Chapter 4 (Methodology-Part 2) and Chapter 6 (Results and Discussions-Part 2) respectively.

4. Precision of the markers position on the cervical spine

The precision of the landmarks positions over the spinous process of C2, C4, C6, and C7 were calculated using a percentage agreement. This analysis was performed using the 2 radiographs taking on different days for each subject using percentage agreement. Because only Rater 1 placed the markers on the cervical spine, this analysis was based on this rater only.

Statistical Background

The intraclass correlation coefficient (ICC) was calculated using variance estimates obtained through analysis of variance (ANOVA). The two-way mixed average measures was used to calculate the ICC (ICC 3,k). One ICC measures the proportion of total variability that is due to true between-subject variability. Therefore, it reflected both degree of correlation and agreement among measurements. (73) Standard error of measurement (SEM) was also calculated in order to know how many degrees the angles varied on the repeated measurements because of error. (80) According to Portney and Watkins, (73) ICC values greater than 0.75 indicate good reliability and those below 0.75 indicate poor to moderate reliability.

A 95% confidence interval (CI) was also calculated for the reliability results. CI is the range of values within which a population parameter is estimated to fall, with a specific level of confidence (in this case, 95%). CI evaluates the precision of the reliability estimate values. The boundaries of the CI are based on the sample mean and its standard error. The wider the interval, the more confident we are on saying that the true population mean fall within it. However, when the CI is narrow, the more precise is the estimation. (73)

CHAPTER 4. METHODOLOGY – PART 2

This chapter describes the methodology of Part 2: "Validity and Sensitivity of the Craniocervical Posture Measurements"

STUDY DESIGN

This study uses an exploratory design to test the relationship and prediction among certain variables (i.e. angle measurements and posture). More specifically, this is a methodological research designed to test a measuring technique (photogrammetry) for use in research or clinical practice. (73)

SUBJECTS

A convenience sample of normal females between the ages of 20 to 50 years of age was used in this study. To achieve a power of 80% with an effect size of 0.4, at least 37 subjects were needed (Appendix H). (73) The data from the subjects from PART 1 was included in PART 2 along with data from the additional subjects. Doing the data collection in this manner kept the radiographic exposure to the subjects to a minimum and reduced the number of subjects needed for the study. The same inclusion and exclusion criterion used in Part 1 was used in Part 2.

Inclusion and Exclusion Criteria

- Inclusion criteria:
    1. Normal craniocervical region defined as normal function (i.e. range of motion) and absence of pain.
- Exclusion Criteria
    1. History of cervical trauma, surgery, bone pathology, or arthritic or other inflammatory disorders;
    2. Pain in the craniocervical region including:
        - Frequent neck pain and/or headache (more than 2 episodes per month or 1 episode of more than 3 days of duration) (120);
    3. Body mass index (BMI) more than 30 which indicates obesity.

PROCEDURES

Two sessions were needed to evaluate the subjects:

1) In the first session, the subjects had their craniocervical region evaluated by the first investigator. During this evaluation, the subjects were assessed to determine if they are eligible for the study based on the inclusion and exclusion criteria.

2) In the second session, 1 radiograph and 1 photograph of the craniocervical region in natural head posture was taken for each subject.

OBS: The 2 radiographs and 2 photographs of each subject included in Part 1 (reliability analysis) were randomized (the first radiograph was chosen for each subject with even identification numbers and the second radiograph was chosen for each subject with odds numbers) in order to be included in this part. Therefore, only one radiograph and one photograph taken simultaneously (on the same day) using the subjects in Part 1 were included.

DATA COLLECTION

1) First session

First, an information letter about all of the research procedures was given to each volunteer (Appendix E). If the subject agreed to participate and met the criteria or was not excluded, the evaluation started. A physical assessment of the head and neck region including a medical history questionnaire, a visual assessment of the presence of FHP, (2) palpation, and range of motion evaluation, was included (Appendix I). The duration of this session was approximately 35 minutes.

2) Second session

The subjects included in the study had a radiographic and a photographic image taken simultaneously of the craniocervical region in a sagittal standing position. First, the subjects were asked to wear a tank top. The skin overlying the spinous process of C2, C4, C6, and C7 were located by palpation of the cervical spine (121), and marked with a hypoallergenic pen (specific for surgical procedures). Reference markers made of light metal were placed on the marks and in the tragus of the ear (left side) with a double-side adhesive tape by the first investigator. The markers were visible in the radiographs which were used to check accuracy/agreement of the markers placement in relation to the spinous processes of the cervical spine.

The procedures for standardization of posture, and for taking the radiographs and photographs were the same as described in Part 1 of the study (for detailed see Chapter 3).

MEASUREMENTS

Blinding Procedure

Codes were placed on top of the subject identification on the radiographs by an independent person so the first investigator was blind in relation to the subject and sessions. The radiographs were scanned (Epson 1680) and transferred to the computer. The faces of the subjects on the photographs were also hidden so possible identification of the subject during the measurements was minimized. Only the area of interest (head and neck) was showed in the screen during the drawing of the angles in the photographs. Shoulder and trunk was not showed in order to reduce the possibility of the rater to know the classification of the subject's posture which is more apparent when shoulder and trunk are visible. Each radiograph and photograph from the same subject was saved with a sequential identification numbers by an independent person.

Craniocervical Posture

The same measurements performed in Part 1 for the photographs and radiographs were used in this part (see Chapter 3).

Each angle measured in the photographs in NHP was compared with the angle measured in the radiographs. The comparison was performed only between the angles that represent the same constructs of posture (Table 3). Therefore, the angles representing the posture of the head in relation to the cervical spine, the inclination and the lordosis of the cervical spine measured in the photographs were compared respectively with the angles that represent posture of the head in relation to the cervical spine, the inclination and the lordosis of the cervical spine measured in the radiographs.

Angles analysis

The procedure for measuring the angles were the same as described in Part 1.

Statistical Analysis

The following analysis was performed:

1. Concurrent validity

The measurements from the photographs and the radiographs were compared according to each aspect of posture. Pearson correlation (r) was used to

Table 3. Comparisons between surface and radiographic angles according to the constructs of Craniocervical posture.

Constructs of craniocervical posture in sagittal view	Photograph	Radiograph
Head in relation to the cervical spine	• Craniovertebral angle (CVA)	• NSL/OPT • NSL/CVT • Auditory meatus/spinous process of C7/hor. (am/C7/hor)
Inclination of the cervical spine	• Cervical inclination angle (CIA) • Adapted Cervical inclination angle (ACIA)	• OPT/horizontal • CVT/horizontal • Cervical inclination angle (CIAr) • Adapted cervical inclination angle (ACIAr) • Spinous process of C2, C7, hor. (spCIA) • Spinous process of C2, C6, hor. (spACIA)
Lordosis of the cervical spine	• Cervical angle (CA) • Adapted cervical angle (ACA)	• ARA • Cervical angle (CAr) • Adapted cervical angle (ACAr) • Spinous process of C2, C4, C7 (spCA) • Spinous process of C2, C4, C6 (spACA)

evaluate the correlation between the angles. Correlation reflects the degree of association between two variables, or the consistency of position within the 2 distributions. Pearson correlation is based on regression analysis. It measures if the relationship between two variables can be described by a straight line (the regression line). Pearson correlation coefficient does not measure agreement between variables; it provides just a measurement of covariance. (78) The values for determining clinically significant ranges for the correlation were: <0.25 as little or no relationship; 0.25-0.50 as fair to moderate; 0.50-0.75 as moderate to good; and >0.75 as good to excellent. (73) Coefficient of determination (r^2) was also calculated using regression analysis to determine whether the variability of the angles measured in the radiographs (dependent variable) could be explained by the surface angles (independent variable). Therefore, r^2 is a measure of proportion, indicating the accuracy of prediction based on the surface angles. According to Portney and Watkins, (73) r^2 provides a more meaningful explanation of relationship when a variable is being predicted by another and not only the interpretation for the strength of the association as r means.

2. Spearman Correlation

Spearman Correlation (r_s) was used to test the behavior of the magnitude of the surface angles (if their values increase or decrease) in relation to three posture classifications assessed visually using photographs (without any angle measurements). Even though the subjects included in this study presented with a normal craniocervical region (i.e. absence of pain), possible variability of posture was expected because a large variety of posture is seen in the population. Spearman correlation is a nonparametric analogue of Pearson correlation (r), but used with ordinal data. (73) To determine significance a p-value of 0.05 was used. The following criteria were used to classify each posture using the visual assessment:

- Aligned Posture: Alignment of ear over shoulder (trunk is used as a reference if shoulder is positioned forward); ear over middle of neck; head well positioned in relation to trunk;
- SFHP (slight forward head posture): when head is not perfectly aligned but also not classified as having FHP;
- FHP (forward head posture): Ear in front of shoulder or trunk.

3. Discriminant Validity

A multiple discriminant function analysis (MDA) was performed to determine which of the 5 surface angle measurements would best predict a clinical observation assessment (aligned posture, SFHP, and FHP) and also to determine if the postural classifications could be differentiated on the basis of the angle measurements which tests the ability of the angles to discriminate different craniocervical postures (discriminant validity). Discriminant analysis (DA) is a form of regression used when the dependent variables are categorical (i.e postural classification) and the independent variables are quantitative. However, DA has more statistical power than logistic regression (less chance of type 2 errors - accepting a false null hypothesis). In DA, "the subjects are classified according to their scores, and the model is examined to see if the classification were correct" (p. 603). (73) Because more than 2 categories of dependent variable were used, a MDA was performed.

A cross validation was also performed to determine if the predictive model can be generalized across samples. The cross-validation estimates how well the model is going to perform on future data. It gives a better estimate of what classificiation results would be in the population and therefore, increases the accuracy of validation. (124) If the cross-validation is not considered in validation studies, a reduction on the validity of a test on future applications can be expected. (73)

4. Sensitivity, Specificity, and Predicted Values

The sensitivity and specificity in relation to the visual postural assessment using radiographs were tested to investigate whether the angles were able to detect subjects with aligned posture and FHP in relation to the gold standard (radiographs). This analysis was performed as for a diagnostic test. Therefore, the assessment of the sensitivity corresponded to the probability of the angle measurements to detect a positive test (i.e. presence of forward head posture) among subjects with forward head posture (true positive test). The sensitivity was calculated as true positive tests divided by true positives plus false negatives. The specificity was evaluated by the probability of a negative test (i.e. aligned posture) among subjects with aligned posture (true negative test). The specificity was calculated as true negative tests divided by true negatives plus false positives. (68,73)

In addition to the sensitivity and specificity, the predicted values were also calculated. A positive predicted value (PPV) estimates the probability of a person who tests positive (FHP) actually is positive, and a negative predicted value (NPV) estimates the probability of a person who tests negative (aligned posture) actually is negative. The PPV is calculated as by true positive tests divided by true positives plus false positive. The NPV is calculated by true negative divided by true negative plus false negative.

The cut-off points established from the cross-validation on discriminant analysis were used to calculate the sensitivity and specificity of each of the surface angles in relation to the classification of posture. For this analysis, 2 postural classifications were used: aligned posture and FHP. Subjects classified as having SFHP were grouped together with the subjects presenting FHP. The criterion to classify aligned posture using radiographs was based on the alignment of auditory meatus with the body of the 7th vertebra and on the position of the head in relation to the cervical spine. The last criteria was subjective but provided the rater with more information about how centered was the head in relation to the spine. The plumb was used as a vertical reference since it was made of metal and was visible on the radiographs.

5. Precision of the markers position on the cervical spine

The precision of the surface markers positions over the spinous process of C2, C4, C6, and C7 were calculated using percentage agreement. This analysis was performed using the radiographs. Since subjects included from Part 1 had 2 radiographs taken (sessions 2 and 3), their radiographs were randomized (the first radiograph was chosen for subjects with even identification numbers and the second radiograph was chosen for subjects with odds identification numbers) in order to be included in this part of the study. The information about how the markers were positioned was important for the overall validation analysis. Therefore, only 1 radiograph was included from each subject for this analysis as only 1 radiograph (the same) from each subject was included for the overall validation analysis.

1. Inter-rater reliability

The inter-rater reliability of the visual assessment of posture using photographs and radiographs between two raters (physical therapists) was tested. The posture was classified as aligned posture, slight forward head posture (SFHP), and forward head posture (FHP) using the photographs, and it was classified as aligned posture and FHP using the radiographs. Two classifications were used to assess posture in radiographs because in practice, the position of the head is viewed in radiographs as being forward or not compared to the cervical spine which is different from a visual evaluation in a clinical setting where the slight forward head posture classification is commonly used and therefore applicable to the postural evaluation. Kappa statistic was used to calculate this inter-rater reliability to determine consistency among raters. Kappa statistics is another measure of reliability that may be used when the unit of measurement is on a categorical scale. Therefore, this measure of agreement was also utilized. Kappa statistics not only measure the proportion or percentage of agreement (i.e. how often the raters agree on subjects' scores) but also considers the proportion of agreement expected by chance. For kappa statistics, values above 80% represent excellent agreement; above 60%, substantial agreement; from 40 to 60%, moderate agreement; and below 40%, poor to fair agreement. (73)

The following criteria to assess posture using radiographs were used:

- Aligned Posture: Alignment of auditory meatus over body of C7; head well positioned in relation to the cervical spine.
- FHP: Auditory meatus in front of the body of C7; head forward in relation to the cervical spine.

Since data collection for Parts 1 and 2 of the study were related, the steps for both parts are shown below (Table 4). A total of 2 radiographs were necessary for each subject participating in Part 1, and 1 radiograph was necessary for each subject in Part 2.

Table 4. Chart showing the steps for parts 1 and 2 of the study.

Sessions	Procedures	Measurements	Test used according to each procedure	Number of subjects needed per test	Estimate Time for each session
1	Evaluation for eligibility	Physical assessment (R1)	-	37 subjects (Part 1 and 2)	35 min.
2	Marks placement	C2, C4, C6, C7 located (R1)	Intra-rater-reliability for markers repositioning (1st measurement)	21 subjects (Part 1)	30 min.
			Precision of markers position on spinous processes	21 subjects (Part 1) 37 subjects (Part 2)	
	1 radiograph taken	14 radiographs angles measured (R1 and R2)	- Intra-rater reliability (tracing) - Inter-rater reliability (tracing and visual posture assessment) - Intra-subject reliability (1st measurement)	21 subjects (Part 1)	
			- Validity - Sensitivity	37 subjects (Part 1 and 2)	
	1 photograph taken	5 surface angles measured (R1 and R2)	- Intra-rater reliability (tracing) - Inter-rater reliability (tracing and visual posture assessment)	21 subjects (Part 1)	
			- Validity - Sensitivity	37 subjects (Part 1 and 2)	
3	Marks placement	C2, C4, C6, C7 located (R1)	Intra-rater-reliability for markers repositioning (2nd measurement)	21 subjects (Part1)	30 min
			Precision of markers position on spinous processes	21 subjects (Part 1) 37 subjects (Part 2)	
	1 radiograph taken	14 radiographs angles measured (R1 and R2)	- Intra-subject reliability (2nd measurement)	21 subjects (Part1)	
			- Validity - Sensitivity	37 subjects (Part 1 and 2)	
	1 photograph taken	5 surface angles measured (R1 and R2)	- Inter-rater reliability (visual posture assessment)	37 subjects (Part 1 and 2)	
			- Validity - Sensitivity	37 subjects (Part 1 and 2)	

CHAPTER 5. RESULTS AND DISCUSSIONS – PART 1

RESULTS

A total of 22 subjects were included in this part of the study. From the 22 subjects, 17 (77.3%) were in the range of 22 and 29 years old, and 5 (22.7%) between 30 and 37 years old. Three subjects were excluded: two had body mass index (BMI) equal or more than 30 (31 and 37.5) indicating obesity; and one presented with frequent pain in the craniocervical region. The subject demographic descriptive statistics are given in Table 5.

Table 5. Descriptive statistics of demographic characteristics for 22 subjects (Part 1).

Variables	Mean (SD)	Range
Age (years)	27.73 ± 4.37	22 to 37
Weight (Kg)	62 ± 10.12	43.5 to 85.4
Height (m)	1.67 ± 0.07	1.51 to 1.82
BMI	22.3 ± 3.24	15 to 29.7

BMI: body mass index (weight/height^2)

All participants presented with a normal cervical range of motion during the physical examination (see Appendix I). Pain was observed in 2 subjects: One had mild pain (localized discomfort) in the right upper trapezius muscle region during cervical extension but had normal extension range of motion (54°); and one had mild pain (localized discomfort) in the left masseter during protrusion but had normal protrusion range of motion (6mm). The pain presented in these subjects was not a condition of exclusion because the pain was mild and only triggered by a specific movement. The pain had also no effect on their regular activities.

Intra-rater Reliability

Tracing of the angles

- Photographs

For the photogrammetry intra-rater reliability, the intraclass correlation coefficient (ICC) and standard error of measurement (SEM) were calculated for the repeated measurements on the same picture and radiograph for raters 1 and 2. The ICC values were classified as excellent for both raters: ICC between 0.98 and 0.99, and SEM between 0.01° and 1.25° (Tables 6 and 7).

The true ICC values were in the range of the 95% confidence interval (CI). The CI indicated a range of plausible values for the "true" value of ICC, with a stated level of confidence. (73) As showed in the tables, the CIs were narrow and therefore, considered precise in the estimation. It can be noticed that the ICC values from both raters were above 0.90.

Table 6. Intra-rater reliability of craniocervical posture photogrammetry for rater 1.

Angles	Picture day 1 ICC (SEM)	95% Confidence Interval	Picture day 2 ICC (SEM)	95% Confidence Interval	P-value
CVA	0.99 (0.02)	0.995- 0.999	0.99 (0.04)	0.994 - 0.999	< 0.01
CIA	0.99 (0.07)	0.98 - 0.99	0.99 (0.06)	0.98 - 0.99	< 0.01
CLA	0.98 (0.37)	0.96 - 0.99	0.99 (0.22)	0.97 - 0.99	< 0.01
ACIA	0.99 (0.05)	0.993 - 0.998	0.98 (0.06)	0.95- 0.99	< 0.01
ACA	0.98 (0.35)	0.96 - 0.99	0.99 (0.42)	0.97 - 0.99	< 0.01

CVA= craniovertebral angle; CIA= cervical inclination angle; CA= cervical angle; ACIA= adapted cervical inclination angle; ACA= adapted cervical angle

Table 7. Intra-rater reliability of craniocervical posture photogrammetry for rater 2.

Angles	Picture day 1 ICC (SEM)	95% Confidence Interval	Picture day 2 ICC (SEM)	95% Confidence Interval	P-value
CVA	0.99 (0.01)	0.993- 0.998	0.99 (0.01)	0.997 - 0.999	< 0.01
CIA	0.99 (0.01)	0.98 - 0.99	0.99 (0.03)	0.98 - 0.99	< 0.01
CLA	0.98 (0.22)	0.96 - 0.99	0.98 (0.09)	0.96 - 0.99	< 0.01
ACIA	0.99 (0.03)	0.993 - 0.998	0.99 (0.03)	0.98- 0.99	< 0.01
ACA	0.98 (0.14)	0.96 - 0.99	0.99 (1.25)	0.96 - 0.99	< 0.01

CVA= craniovertebral angle; CIA= cervical inclination angle; CA= cervical angle; ACIA= adapted cervical inclination angle; ACA= adapted cervical angle

Figure 22 shows the scatter plot of CIA measurements representing the intra-rater reliability for the photogrammetry. The scatter plot can visually clarify the strength and shape of a relationship through the interaction of a pair of related observations (i.e. angle measurements). (73) Only one scatter plot was chosen to represent each type of reliability.

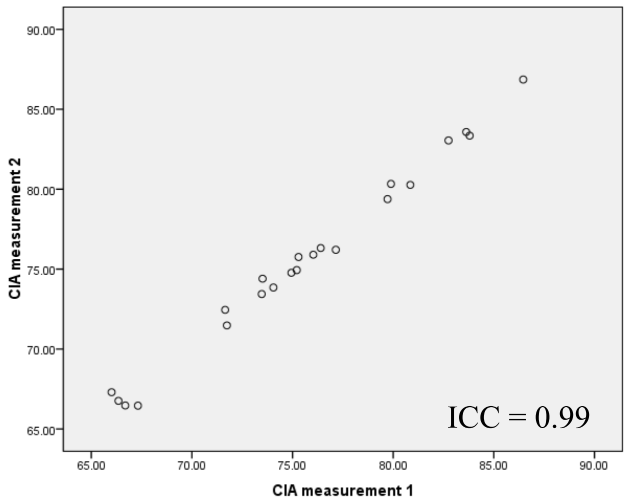

Figure 22. Scatter plot of cervical inclination angle (CIA) measurements for intra-rater reliability (pictures) by rater 1.

The scatter plot in figure 22 shows a strong positive correlation with the data points falling in an almost straight line. Moreover, the positions of the data points are consistent; that is, the data points on the X axis is mostly paired with the data points on the Y axis showing a good level of agreement among the measurements. The higher the ICC value, the straighter is the line and the more paired the measurements are on the plot. The lower the ICC value, the more spread the measurements are in the plot.

- Radiographs

The intra-rater reliability for the radiographic measurements was also good to excellent (ICC between 0.95 and 0.99 by rater 1 and between 0.94 and

0.99 by rater 2) and demonstrated a SEM between 0.01° and 0.38° for rater 1 and between 0.01° and 4.03° for rater 2 (Tables 8 and 9 respectively).

Table 8. Intra-rater reliability of craniocervical posture measurements on radiographs for rater 1.

Angles	Radiograph ICC (SEM)	95% Confidence Interval	P-value
NSL/OPT	0.99 (0.14)	0.989 - 0.998	< 0.01
NSL/CVT	0.99 (0.05)	0.991 - 0.998	< 0.01
OPT/hor	0.99 (0.13)	0.98 - 0.99	< 0.01
CVT/hor	0.99 (0.03)	0.990- 0.998	< 0.01
CIAr	0.99 (0.03)	0.992 - 0.998	< 0.01
Car	0.99 (0.15)	0.98 - 0.99	< 0.01
ARA	0.99 (0.99)	0.98 - 0.99	< 0.01
ACIAr	0.99 (0.01)	0.993 - 0.998	< 0.01
ACAr	0.98 (0.38)	0.95 - 0.99	< 0.01
Am/C7/hor	0.99 (0.01)	0.995 - 0.999	< 0.01
spCIA	0.99 (0.1)	0.98 - 0.99	< 0.01
spCA	0.96 (0.33)	0.91 - 0.98	< 0.01
spACIA	0.99 (0.01)	0.98 - 0.99	< 0.01
spACA	0.95 (0.11)	0.87 - 0.98	< 0.01

NSL= nasion-sella line; OPT= odontoid process tangent; CVT= cervical vertebra tangent; CIA= cervical inclination angle; ACIA= adapted cervical inclination angle; ARA= absolute rotation angle; CA= cervical angle; ACA= adapted cervical angle; r=measured in radiographs; Am=auditory meatus; hor= horizontal; sp=spinous process.

Table 9. Intra-rater reliability of craniocervical posture measurements on radiographs for rater 2.

Angles	Radiograph ICC (SEM)	95% Confidence Interval	P-value
NSL/OPT	0.97 (0.74)	0.93 - 0.99	< 0.01
NSL/CVT	0.97 (0.61)	0.92 - 0.99	< 0.01
OPT/hor	0.98 (0.26)	0.96 – 0.99	< 0.01
CVT/hor	0.99 (0.29)	0.98 - 0.99	< 0.01
CIAr	0.99 (0.06)	0.98 - 0.99	< 0.01
Car	0.97 (0.81)	0.93 - 0.99	< 0.01
ARA	0 .94 (0.50)	0.86 - 0.98	< 0.01
ACIAr	0 .99 (0.01)	0.98 - 0.99	< 0.01
ACAr	0.97 (0.23)	0.93 - 0.99	< 0.01
Am/C7/hor	0.99 (0.07)	0.98 - 0.99	< 0.01
spCIA	0.94 (0.91)	0.85 - 0.97	< 0.01
spCA	0.94 (4.03)	0.85 - 0.97	< 0.01
spACIA	0.97 (0.44)	0.93 - 0.99	< 0.01
spACA	0.94 (2.91)	0.86 - 0.98	< 0.01

NSL= nasion-sella line; OPT= odontoid process tangent; CVT= cervical vertebra tangent; CIA= cervical inclination angle; ACIA= adapted cervical inclination angle; ARA= absolute rotation angle; CA= cervical angle; ACA= adapted cervical angle; r=measured in radiographs; Am=auditory meatus; hor= horizontal; sp=spinous process.

Although the ICC values for spCA and spACA measurements were considered good, they were the lowest values for both raters (0.96 and 0.95 for rater 1 and 0.94 and 0.94 for rater 2 respectively). Figure 23 shows the scatter plot of ACAr measurements representing the intra-rater reliability for the measurements on the radiographs. The scatter plot shows a strong positive correlation.

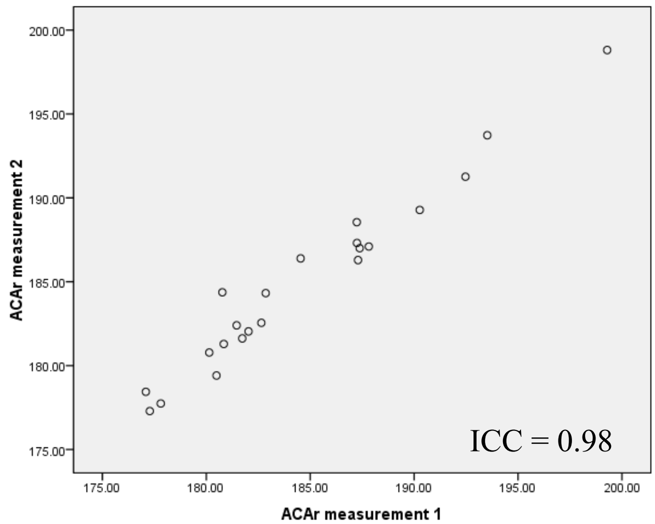

Figure 23. Scatter plot of adapted cervical angle (ACAr) measurements for intra-rater reliability (radiographs) by rater 1.

Replacing the surface markers on the cervical spine

In order to test the reliability of Rater 1 to reattach the surface markers on the cervical spine a week later, the means from the measurements on the 2 photographs taken a week apart were compared (Table 10).

Table 10. Reliability of replacing the surface markers on the cervical spine by rater 1 between photographs taken a week apart.

Angles	ICC (SEM)	95% Confidence Interval	P-value
CVA	0.91 (0.21)	0.79 - 0.96	< 0.01
CIA	0.88 (2.02)	0.73 - 0.95	< 0.01
CA	0.82 (0.23)	0.62 - 0.92	< 0.01
ACIA	0.85 (3.30)	0.66 - 0.93	< 0.01
ACA	0.71 (0.21)	0.43 - 0.87	< 0.01

CVA= craniovertebral angle; CIA= cervical inclination angle; CA= cervical angle; ACIA= adapted cervical inclination angle; ACA= adapted cervical angle

Figure 24 shows the scatter plot of ACIA measurements between days representing the reattaching of the landmarks on the cervical spine.

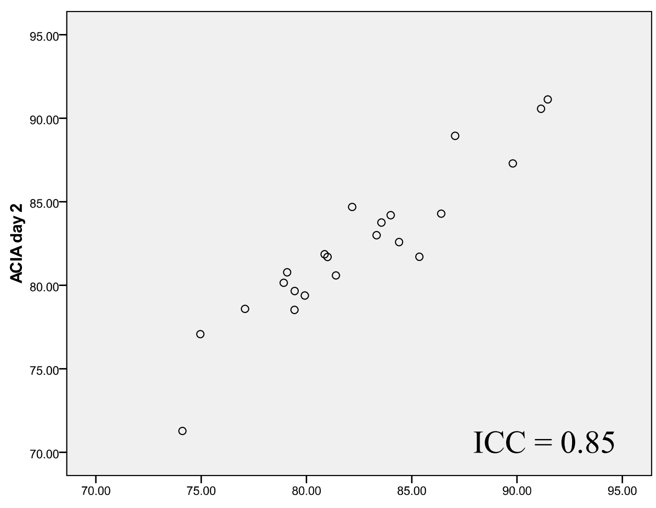

Figure 24. Scatter plot of adapted cervical inclination angle (ACIA) measurements for the repositioning of the landmarks on the cervical spine by rater 1.

In figure 24, more variability among the measurements between different pictures (day 1 and day 2) was observed when compared with the repeated measurements on the same picture as showed previously (Figure 22).

Intra-subject Reliability

In order to test the intra-subject reliability or the reproducibility of the subjects posture, the mean of the measurements from the 2 radiographs taken a week apart were compared (Table 11).

Table 11. Intra-subject reliability (reproducibility of posture) tested between the mean of the 2 radiographs taken a week apart.

Angles	ICC (SEM)	95% Confidence Interval	P-value
NSL/OPT	0.97 (0.80)	0.92 – 0.99	< 0.01
NSL/CVT	0.97 (0.49)	0.92 – 0.99	< 0.01
OPT/hor	0.96 (0.25)	0.90 – 0.98	< 0.01
CVT/hor	0.95 (0.39)	0.88 – 0.98	< 0.01
CIAr	0.94 (0.40)	0.86 – 0.97	< 0.01
CAr	0.90 (0.70)	0.78 – 0.96	< 0.01
ARA	0.98 (0.48)	0.94 – 0.99	< 0.01
ACIAr	0.93 (0.33)	0.85 – 0.97	< 0.01
ACAr	0.89 (1.70)	0.76 – 0.95	< 0.01

NSL= nasion-sella line; CVT= odontoid process tangent; CIA= cervical inclination angle; ACIA= adapted cervical inclination angle; ARA= absolute rotation angle; CA= cervical angle; ACA= adapted cervical angle; hor= horizontal.

Good to excellent intraclass correlation coefficient (ICC) and a small standard error of measurement (SEM) was found for all angles measured. The ACAr presented a higher SEM (1.70) and consequently, a smaller ICC value (0.89). However, the ACAr ICC value is still considered good (ICC>0.75). (73) Figure 25 shows the scatter plot for CIAr measurements between days representing the intra-subject reliability.

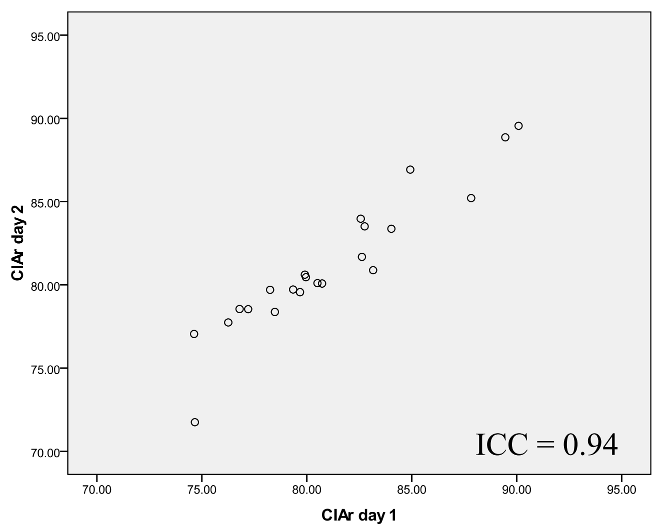

Figure 25. Scatter plot of cervical inclination angle (CIAr) measurements (radiographs) for the intra-subject reliability.

Similarly to Figure 23, Figure 24 shows more variability among the measurements between different radiographs (day 1 and day 2) when compared with the repeated measurements on the same radiographs.

Inter-rater Reliability

Tracing of the angles on the photographs and on the radiographs

The reliability of measuring the angles on the photographs and on the radiographs between raters was tested (Tables 12 and 13 respectively).

- Photographs

Table 12. Inter-rater reliability of 2 raters using craniocervical photogrammetry for the 2 pictures taken.

Angles	**Picture 1**	**95% Confidence Interval**	**Picture 2**	**95% Confidence Interval**	**P-value**
CVA	0.99 (0.01)	0.993 -0.998	0.99 (0.04)	0.995 -0.999	< 0.01
CIA	0.99 (0.03)	0.97 -0.99	0.97 (0.07)	0.93 -0.99	< 0.01
CA	0.96 (1.93)	0.90 -0.98	0.91 (7.06)	0.79 -0.96	< 0.01
ACIA	0.98 (0.13)	0.95 -0.99	0.96 (0.22)	0.90 -0.98	< 0.01
ACA	0.95 (2.18)	0.89 -0.98	0.89 (9.40)	0.75 -0.95	< 0.01

CVA= craniovertebral angle; CIA= cervical inclination angle; CA= cervical angle; ACIA= adapted cervical inclination angle; ACA= adapted cervical angle.

Figure 26 shows the scatter plot of CA photogrammetry of the 2 raters representing the inter-rater reliability.

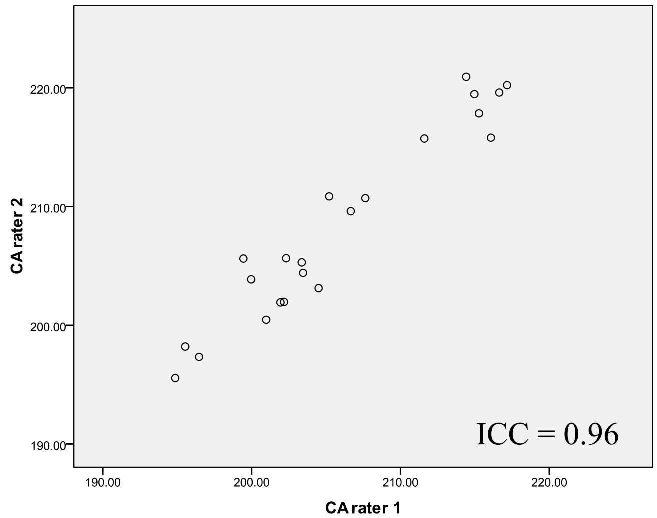

Figure 26. Scatter plot of cervical angle (CA) measurements for the inter-rater reliability (pictures).

- Radiographs

Figure 27 shows the scatter plot of SpCIA measurements on radiographs by the 2 raters representing the inter-rater reliability. Table 13 is shown next.

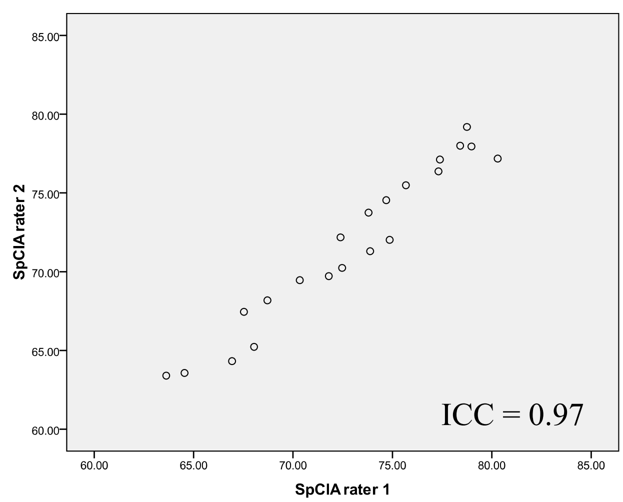

Figure 27. Scatter plot of cervical inclination angle using the spinous process (SpCIA) measurements for the inter-rater reliability (radiographs).

Table 13. Inter-rater reliability of 2 raters for craniocervical posture measurements on radiographs.

Angles	ICC (SEM)	95% Confidence Interval	P-value
NSL/OPT	0.98 (0.15)	0.95 - 0.99	< 0.01
NSL/CVT	0.95 (1.77)	0.89 - 0.98	< 0.01
OPT/hor	0.99 (0.07)	0.98 - 0.99	< 0.01
CVT/hor	0.99 (0.08)	0.98 - 0.99	< 0.01
CIAr	0.99 (0.01)	0.991 - 0.998	< 0.01
CLAr	0.99 (0.01)	0.98 - 0.99	< 0.01
ARA	0.90 (3.78)	0.77 - 0.96	< 0.01
ACIAr	0.99 (0.03)	0.995 - 0.999	< 0.01
ACLAr	0.98 (0.15)	0.96 - 0.99	< 0.01
Am/C7/hor	0.99 (0.09)	0.98 - 0.99	< 0.01
spCIA	0.97 (0.19)	0.94 - 0.99	< 0.01
spCA	0.79 (6.89)	0.56 - 0.91	< 0.01
spACIA	0.98 (0.18)	0.96 - 0.99	< 0.01
spACA	0 .75 (4.02)	0.48 - 0.89	< 0.01

NSL= nasion-sella line; OPT= odontoid process tangent; CVT= cervical vertebra tangent; CIA= cervical inclination angle; ACIA= adapted cervical inclination angle; ARA= absolute rotation angle; CA= cervical angle; ACA= adapted cervical angle; r=measured in radiographs; Am=auditory meatus; hor= horizontal; sp=spinous process.

The inter-rater ICC values for the pictures measurements ranged from 0.91 to 0.99 which is considered good to excellent reliability. (73) For the radiographic measurements, the ICC values ranged from 0.75 to 0.99. The lowest ICC values were found for the SpCA and SpACA (0.79 and 0.75 respectively). These values are still considered good (≥0.75). (73) However, SEM for CA and ACA measured on the photographs (7.06° and 9.40°) and for SpCA (6.89°) were considered clinically significant and therefore not reliable when compared between the 2 raters because the error associated with their measurements were greater than 5 degrees.

Precision of the Markers Position on the Cervical Spine

The ability of Rater 1 to place the surface markers on the skin over spinous processes of C2, C4, C6, and C7 was tested using percentage agreement. This reliability was tested using radiographs since the surface markers were visible on the radiographs and the placement could be assessed. Percentage agreement was used to test this analysis. Kappa statistics was not used since no contingency (2x2) table could be made with this data format.

The criteria used for the agreement was based on the direction of palpation because in order to place the markers on the cervical spine, palpation was performed first. In other words, it was based on the perpendicular direction of the marker on the skin over the spinous process as illustrated below (Fig. 28). As showed in Figure 28, the direction of palpation was not the same for all spinous processes. Because of the natural curve of the cervicothoracic junction, the palpation of C6 and C7 was more caudal. A marker was considered misplaced when the center of the marker did not meet the tip of the spinous process when looking at the radiographs in a sagittal view considering the direction of palpation (see figure 16 for more detail).

Figure 28. Illustration of the direction of palpation for the placement of the surface markers.

From 22 subjects, 44 radiographs (2 radiographs from each subject) were analyzed which represents 176 surface markers placements (44 multiplied by 4 placements on each subject - C2, C4, C6, and C7). From these 176 placements, 22 were misplaced (12.5%). Of the 12.5% of error, 1.7% occurred attempting to find C2; 4.5% on C4; 3.4% on C6; and 2.8% on C7. The misplaced surface markers were placed in between spinous processes or on the spinous process above or below the target. The former condition was mostly seen when placing C7 marker. The total percentage of agreement was 87.5%.

DISCUSSION

The different types of reliability can be presented and tested separately. However, they are inter-related. Studies that investigate craniocervical posture test only one type of reliability (frequently intra-rater) and do not include information about the other sources of variability (error) such as from the patients/subjects or instrument. Reliability analysis was performed in the present study in a way that all possible types of reliability could be tested. The discussion will be presented based on each of the reliability types tested. The inter-relationship among them will also be discussed. Another reliability analysis to test the agreement of the visual assessment of posture using photographs and radiographs between 2 raters was performed in Part 2 of this study and it is discussed in the next chapter.

Intra-rater reliability

Tracing the angles

The good ICC values found for the intra-rater reliability on tracing the angles indicate that both raters were able to reliably repeat their measures for each of the 2 pictures of each subject. This type of reliability does not depend on the subject's posture reproducibility (intra-subject reliability) since the repeated measurements were performed on the same photograph. A period of one week between the repeated measurements was established. This condition was important to avoid rater bias (i.e. when the rater remembers the previous measurement and it can influence the second measurement). (73) In addition to the period between repeated measurements, the order of measurements was randomized for both times using the random table to avoid rater bias.

This type of reliability was expected to be high since the time established to repeat the tracing of the angles (a week apart) is the only factor that varied between measures, and therefore was considered to be the only source of error. According to Karanicolas et al., (125) this form of research design typically results in a higher reliability estimate than other reliabilities. For example, the repeated measurement on the same picture/radiograph from the same subject presents with less possible errors compared to measurements on a picture/radiograph taken a week apart from the same subject. The more sources of error a test has, more influence there is on the measurement variability. Achieving good intra-rater reliability on tracing the angles was considered, in this study, a prerequisite for the other reliabilities because if the rater is not able to replicate his/her own measurements on the same image (picture or radiograph), the other types of reliability will be affected by it.

In a study by Johnson, (67) repeated measurements on pictures and radiographs were tested by one rater. CVA was measured on the photographs and

OPT/hor, CVT/hor, CVT/OPT (Figure 6 for reference), and one angle to measure the position of the atlas (AT/vertical) were measured on the radiographs. Ten subjects were randomly selected and the ICC from these measurements ranged from 0.96 to 0.99. Although the author didn't separate the ICC values from the pictures and radiographic measurements, the result was similar to the results found in the present study (between 0.98-0.99 from the photogrammetry, and between 0.94-0.99 from the radiographic measurements by both raters).

Excellent coefficients of reliability (0.97 to 1.00) were also found for the intra-rater reliability test in Solow and Sonnesen's study. (40) In a study by Solow and Tallgren, (104) twenty six lateral radiographs of the craniocervical posture in the standing position were randomly chosen and nine reference angles were measured (figure 5 for reference). In this study, the reference points were removed and subsequently marked again. The method error ranged from 0.27° to 0.64°. Unfortunately, no more details were given for the reliability methods in this study. In the present study, the SEM for the radiographs intra-rater reliability ranged between 0.01° and 0.99° for rater 1 and between 0.01° and 4.03° for rater 2. Therefore, the error calculation for rater 1 was similar to the findings of the Solow and Sonnesen study. For rater 2, the maximum range was of approximately 3 degrees higher than rater 1. However, the higher SEM was found only for spCA angle (Table 9). Clinically, a SEM of five degrees or higher is considered significant. The cut point of five degrees used was based on the degrees of error found in previous studies when craniocervical angles were measured on repeated radiographs (0.9° to 3.8°) (126) and are based on the SEM from the present study where the majority of the values raged from 0.01° to 4.03°. In addition, in studies using a goniometer, the minimum difference that needed to be exceeded to be certain that a real change has occurred was calculated to be around 4 degrees. (127) Therefore, in the present study, a SEM of more than five degrees was considered clinically significant and therefore, not reliable.

Replacing the surface markers on the cervical spine

In order to test the reliability of placing the markers on the cervical spine in the same position, the measurements on the photographs were used. However, in order to test this reliability, the other sources of variability needed to be controlled first: the rater's measurements and the subjects posture (intra-rater and intra-subject reliability respectively). If the rater could not replicate her own measurements and if the subjects posture was not reproducible, the replacement of the markers reliability would be affected and it could not be tested separately because one does not know where the source of variability is. Therefore, in the present study, the rater and the subject reliability were prerequisite requirements in order to test the marker replacement. As intra-rater reliability and the subjects posture were reliable, the replacement of the markers on the cervical spine could be tested separately. The intra-rater reliability of the repeated angle measurements was shown to be good to excellent as described previously (ICC between 0.98 and 0.99). The intra-subject reliability was also shown to be good when measured on 2 different radiographs (ICC between 0.89 and 0.98).

The reliability of replacing the surface markers on the cervical spine was found to have ICC values between 0.71 and 0.91 and SEM between 0.21° and 3.30°. Therefore, it can be concluded that Rater 1 was able to reliably replace the surface markers on the cervical spine a week later.

Comparing the replacing of the surface markers reliability with the tracing of the angles reliability (both as part of the intra-rater reliability), the former presented with lower ICC values. The lower ICC values for the replacement of the markers reliability is related to the possible sources of error: slight inter-sessions differences in camera and surface marker position, differences in the rater measurements between days, or a real difference in the posture of the subjects between sessions even though the posture was standardized. Although some inter-sessions errors might be present, it is difficult to verify if a change in the angle measurements was true or simply the consequence of measurement variability. (127)

The instrument reliability (ability of the measuring instrument or test to give the same consistent measurements or results) (68) can also be considered when testing the surface markers replacement. The ability of an instrument (i.e. angle measurements using the Alcimage software) to replicate its own measures ensures the testing of the other types of reliability. Without a reliable instrument, the testing of other types of reliability is affected. The instrument reliability can be tested comparing measurements performed on different days and the results compared. However, the intra-rater reliability needs to be controlled to ensure that the rater is able to repeat his/her measurements (i.e. repeated measurements on the same picture/radiograph). The testing of the instrument reliability is associated, in the present study, with the reliability test of the surface markers replacement and with the intra-subject reliability (reproducibility of posture) since different days was used to test them. Since the reliability test of the surface markers replacement and the intra-subject reliability was showed to be good, one can conclude that the instrument was reliable in replicating its own measurements. A previous study (123) demonstrated excellent intra-rater reliability of craniocervical posture measurements using this software in subjects with dental occlusion alterations (ICC=0.99).

The reliability of reflective marker placement was tested measuring knee angles recorded in a standing sagittal plane in Marks & Karkouti study. (128) Reflective markers were placed on the great trochanter, the femoral condyle, and the lateral malleolus of 32 healthy men and women in three different sessions spaced at intervals of 1 and four weeks. In the first session, the surfaces markers were removed and replaced and the angles re-measured. The ICC value for the reliability for this repeated measure within the same session was 0. 87 and the standard error of measurement (SEM) ranged from 1.65 to 2.09. The inter session (1x2x3) reliability ICC ranged from 0.67 to 0.73 and the SEM ranged from 2.09 to 2.34. According to the present results dealing with the cervical spine, ICC ranged from 0.71 to 0.91 and SEM from 0.21 to 3.30 using 2 sessions a week apart (Table 10). The markers placement reliability in the present study was better than that found in Marks & Karkouti study considering that different measurements (different references and region) and number of sessions were performed between the 2 studies.

The reliability of replacing the markers on the cervical spine was never tested alone in any study. If one looks at the replacement of the markers reliability separately, this test can be also considered a test of the intra-subject reliability using photographs because it is impossible to separate the 2 tests if measurements on radiographs were not performed for the intra-subject reliability. However, because the intra-subject reliability in this study was tested in radiographs in order to eliminate the influence of the markers on the measurements, the replacement of the markers was not primarily considered testing the intra-subject reliability but instead it isolated the source of error added by the marker. In the studies that investigated the reproducibility of subject posture using photographs, the influence of the marker replacement reliability on the spine (if markers are used) needs to be considered and discussed. In the intra-subject reliability discussion (presented next), a few studies did not considered the ability of the rater to replace the markers reliably when testing the reproducibility of posture. (67,107,129)

Intra-subject reliability

This study demonstrated that craniocervical posture measured in radiographs taken on 2 different days was reproducible. This means that craniocervical posture can be quantified and compared before and after treatment for the same subject or compared among different subjects.

In order to assure a good intra-subject reliability, the intra-rater reliability has to be high so that any possible variation in the measurements can be attributed to the subject's performance variation. (80) Low intra-rater reliability (ICC lower than 0.75) can be a confounder for the intra-subject reliability evaluation. (68) Therefore, high intra-rater reliability is a precondition for testing intra-subject reliability (68,82). The intra-rater reliability was also tested in this study and it showed excellent ICC values (between 0.98 and 0.99).

In this study, confounders such as the lack of intra-rater reliability and standardization of posture were controlled. (70) Commonly, the intra-rater reliability is not taken into consideration when assessing reproducibility. Low intra-rater reliability can lower the intra-subject reliability. Another confounder is the use of cephalostat to standardize the posture of the subjects for taking the radiographs. According to Greenfield, (110) the use of the cephalostat can influence and change the posture of the subjects (subjects measurably extend their heads and cervical spine when using this device) and therefore the use of the cephalostat is not recommended when assessing natural head posture (NHP). In this study, the cephalostat was not used and the subjects posture were standardized in the self balance position.

Refshauge et al. (107) examined the reproducibility of the cervical and cervicothoracic curvature in a relaxed standing position was examined in 17 volunteers (13 men and 11 women) using surface measurements. Two trials (1 and 2), with 3 photographs each, were performed. One week later, the trials were repeated (3 and 4). The consistency was analyzed within trials, between trials, and between days. All measures of cervical inclination were highly reproducible as was cervicothoracic kyphosis (ICC>0.85). However, cervical lordosis had more variability (ICC between 0.72 and 0.90). Similarly in the present study, more variability in the angles measuring lordosis of the cervical spine was found (CAr = 0.90 and ACAr = 0.89). Therefore the present results are in agreement with Refshauge et al study. (107) In the present study, radiographs were used instead of photographs to measure posture reproducibility in order to eliminate possible errors in placing external markers on the neck of the subjects as used in photogrammetric studies.

According to Dunk et al's study, (56) the reproducibility of the head posture in the sagittal view was different for 10 men and 10 women being measured for the craniovertebral angle at 3 different photograph sessions. The ICC value for women was slightly better (0.84) when compared with the ICC for men (0.75). However, the ICC values for both gender were consider good (≥0.75). (73) As in the previous study, photographs were used instead of radiographs to measure posture reproducibility.

In another study, the reproducibility of the head posture from lateral cephalometric radiographs was investigated in 12 subjects (8 male and 4 female aged between 8 and 15 years old). (126) Two repeated radiographs of the subjects natural posture were performed (1 hour between the first and the second radiographs) and the angles described by Solow and Tallgren (104,126) were measured. The authors concluded that the head posture was reproducible with a method error of only a few degrees (between 0.97 and 3.8°). However, some issues were observed in their study: 1) the cephalostat was used for the radiographic procedure and the mirror for the standardization of posture. In the present study, the cephalost and the mirror were not used so as not influence the posture of the subjects; 2) the time established to re-measure the radiographs in Sandham's study was a very small (1 hour between measurements). In the present study, a week was established to repeat the measurements to see if posture was altered in a period of 1 week which gives more time between measurements and consequently more time for possible changes in posture to occur; 3) twelve subjects participated in their study to test reliability. However, 21 subjects are needed for the reliability analysis using 2 repetitions in order to achieve a power of 80%. (113) Twenty-two subjects were used in the present study to calculate reliability.

In Johnson's study, (67) the reproducibility of posture in 34 young adult women aged 17 to 30 years of age was tested comparing 2 pictures taken at least 1 week apart and comparing 1 radiograph with 1 picture taken approximately 1 week apart. The mean difference between postures was calculated and it was found to be 1.1° between pictures, 2° between the first picture and the radiograph, and 2.7° between the second picture and the radiograph. Unfortunately, no comparisons between radiographs were made in Johnson's study.

As discussed previously, some studies tested the intra-subject reliability comparing measurements performed on different pictures from the same subject. In the present study, this method was considered measuring the reliability of replacing the markers on the spine, and the measurements performed in different radiographs were considered measuring the intra-subject reliability. Even though more variability was found for repeated measurements in photographs (ICC between 0.71 and 0.91) compared to repeated measurements in radiographs (ICC between 0.89 and 0.98), this variability was expected since the markers' positioning adds one more source of variability on the measurements. For this reason, the reproducibility of posture was tested on radiographs instead of on the photographs. The more variability found does not discard the usefulness of the photographs to measure reliability of the measurements over time because the values were still satisfactory and comparable with the gold standard (radiographs) with the exception of the ACA which presented an ICC less than 0.75 which is considered a moderate to good reliability (0.71). (73)

In the present study the craniocervical posture of the subjects was reproducible when measured using radiographs which points out that the clinicians may be able to quantify postural changes over time, given that the evaluator is also reliable in measuring posture over time.

Inter-rater reliability

As previously hypothesized, the inter-rater reliability was found to be lower than the intra-rater reliability of tracing the angles. ICC values from 0.89 to 0.99 and from 0.75 to 0.99 were found for photogrammetry inter-rater reliability and for the measurements on the radiographs respectively. Intra-rater reliability of tracing the angles ranged from 0.98 to 0.99 and from 0.94 and 0.99 for photogrammetry and for the measurements on the radiographs respectively. The possible reasons for the lower ICC values for the inter-rater reliability compared to the intra-rater reliability of angles tracing are the fact that 2 raters were involved instead of one and which can add variability to the angle measurements. In the inter-rater reliability analysis, not only are the measurements affected by the intra-rater variability, but so to is inter-rater variability. (127) SEM was also found higher and clinically significant for inter-rater reliability compared to intra-rater reliability for CA and ACA on the photogrammetry (7.06° and 9.40° respectively) and spACIA for the radiographic measurements (6.89°). Maximum SEM of 4.03° for intra-rater reliability was found for the SpACA measurements by rater 2 (Table 9). Therefore, more errors were found when measuring CA and ACA between 2 raters compared to the other surface angles even though ICC values were still good (0.91 and 0.89 respectively).

In inter-rater reliability analysis, the expertise level of each rater is a factor that can contribute to the variability between raters. Researchers should include a diverse and representative group of raters in their study. Including raters with a variety of expertise levels provides more informative results since a varying level of expertise is seen in the clinical practice. Therefore, the raters need to be representative of the individuals who will apply the instrument in practice. (125) In the present study, 2 raters were used and both were physical therapists who graduated between 10 and 15 years ago. Both have their research focus in orthopedic physical therapy specifically the head and neck area and temporomandibular disorders. Rater 1 had about 4 years of clinical experience and the Rater 2 had about 8 years. Rater 1 practiced doing the measurements on photographs for 2 years before the study and measurements on both photographs and radiographs were also used in a pilot study during the development of this research. The same software used in the present study was used previously by Rater 1 for the photogrammetry, and the protractor method was used for the measurements on radiographs. Rater 2 had been doing measurements on photographs and radiographs since 1996 and all measurements were performed with the use of protractors. Rater 2 was not familiar with the software used in the present study. Therefore, for the present study, the raters presented with similar expertise in their general area however, with different experiences in terms of photogrammetry and measurements on radiographs. Because both raters had some previous experience with the method, the inclusion of a rater with no experience about the method would have been ideal in order to increase the diversity of raters and therefore being more representative to the clinical practice. Nevertheless, the 2 raters included in the present study are still representative of most clinical researchers in the area.

According to Karanicolas et al., (125) if an acceptable level of inter-rater reliability is found in a study, no further intra-rater reliability testing is necessary. However, if a poor inter-rater reliability is found, testing the intra-rater reliability is needed to assist researchers in the identification of sources of error and in making appropriate modifications.

Harrison et al. (130) tested the inter-rater reliability of 2 physical therapists for measurements of head and shoulder posture on 15 healthy subjects using a goniometer. The following ICC values where found for each of the 2 angles measured: 0.68 for the cranial rotation angle (tragus-lateral corner of the eye-horizontal), and 0.34 for the neck inclination angle (tragus-C7-horizontal) or, as called in the present study, the craniovertebral angle (CVA). Lower ICC values were found in the Harrison et al.'s study compared to the present findings. The intra-rater reliability should have been tested to determine if the inter-rater reliability was low because the raters could not replicate their own measurements (low intra-rater reliability). While a goniometer was used to measure the angles in Harrison et al.'s study, photogrammetry was used in the present study. According to the authors, the poor inter-rater reliability for these angles was not a surprise for them because of the difficulty the raters encountered in reading the goniometer while keeping one goniometer arm level with the horizontal. They concluded that further work toward developing a reliable and practical method of measuring these angles was needed. (130) The same angle (tragus-C7-horizontal) used in Harrison et al.'s study was used in the present one. Good inter-rater reliability was found in the present study using photogrammetry. Therefore, the photogrammetry was shown to be more reliable than the use of a goniometer for the assessment of the craniovertebral angle between 2 raters.

No studies were found on the craniocervical photogrammetry inter-rater reliability to compare with the results to the present study. There was a study to test inter-rater reliability for measurements on radiographs by 2 raters to measure thoracic, lumbar, and thoracolumbar scoliosis in 20 subjects. (131) ICC ranged from 0.46 to 0.97. Inter-rater reliability for the craniocervical measurements in radiographs was found to be between 0.75 and 0.99 which is better if compared to Saad et al. study. However, different angles were used in both studies.

Precision of the Marker Positions on the Cervical Spine

The ability to palpate spinous process is considered to be a basic skill for manual therapy techniques. (132) Methods of finding cervical spinous processes are described in the literature and these methods were followed in the present study. (121) However, this study showed that even though the methods of palpating the cervical spinous process were followed and the palpation performed by a physical therapist with about 4 years of clinical practice and 6 years of research practice in orthopedic physical therapy specifically dealing with the head and neck area, errors in finding the spinous processes of the cervical spine were present (total error of 12.5% on marker placement).

In the present study, the markers that had the least error were the ones placed on C2 (1.7%) and C7 (2.8%). On the other hand, the markers placed on C4 presented with the most errors (3.4%). These findings were similar to what is seeing on practice. When descending from the occiput of the skull, C2 spinous process is palpated as the first bump (121) which made C2 spinous process easy to palpate. The spinous process of C7 was identified by asking the subject to flex and extent the cervical spine. While C6 spinous process appears to move in and out, C7 spinous process remains immobile during the movement thus making differentiation between C6 and C7 easier. (121) The spinous process of C4 was palpated by counting the cervical spinous process from occiput. However, because of the large anatomical variety of cervical spines such as size of spinous process, shape of the spinal curve, and amount of tissue covering them, the localization of the spinous process was not constant for all subjects. That might explain the errors on placing the surface markers on the cervical spine by Rater 1.

The inter-rater reliability and the validity of palpating C7 spinous process was test by Robinson et al. (132) Two raters with 16 and 18 years of practice in manual therapy located C7 spinous process based on 3 levels of agreement: within 0mm, 10mm and 20mm of difference between their measurements. The same point was marked in 39%, 61%, and 78% based on each level respectively. In terms of validity, C7 was correctly identified, based on radiographs, in 55% and 72% of the participants based on the 2 raters respectively. The only method used in their study to find C7 spinous process was the passive movement of extending the cervical spine and finding C7 as the first stationary spinous process. The authors felt that, a combination of other palpation techniques, including counting the cervical spinous process from occiput to C7, might have improved the results. In the present study, both methods of palpation were used and that may explain the higher percentage agreement of correctly finding the spinous process (87.5%). Therefore, the use of both techniques (ie. passive movement of extending the cervical spine and counting the cervical spinous process from occiput to C7) is suggested in the clinical setting. (132)

Since the amount of fat varies among subjects, as this might also influence the palpation results, subjects with body mass index (BMI) more than 30 (obese) were excluded from the present study. From 22 subjects included, based on BMI, 16 had normal weight (19.3 - 24.5), 5 overweight (25.2 - 29.7), and 1 underweight (15). The investigation of whether the subjects' BMI and gender influenced the palpation of C7 was tested by Robinson et al. (132) These authors found that neither the height, weight, nor gender influenced the results. For the subjects in their study, 21 had normal weight, 19 were overweight, and 9 were obese. Only C7 marker was tested in their study. The influence of fat tissue on finding less prominent spinous processes such as C3, C4 and C5, compared to C7 spinous process, might be larger. More studies assessing the influence of BMI on the palpation of cervical spinous process are needed in the literature.

Ideally, more than one rater placing the surface markers on the cervical spine should have been included in the present study in order to compare the ability of marker placement by other raters with different amounts of experience. The reproducibility of many manual techniques cannot be assumed if physical therapists are not able to locate the same spinous process. (132) However, only one rater was included in this part of the study (marker placement) so as to avoid the number of radiation exposures to the subject participants. If more raters were included, more radiographs would have needed to be taken for each healthy subject to test the ability of the additional rater on placing the marker on the cervical spine. Therefore, this study tried to limit as much as possible the number of radiographs taken for each subject.

Some studies have assessed the reliability of palpation to locate lumbar and sacral spinous processes. (133,134) However, more information about how accurate clinicians are on palpation of the cervical spine is needed in the literature. The validity of the photogrammetry to assess the craniocervical posture is affected if the clinicians are not able to accurately place the surface markers on the cervical spine.

CHAPTER 6. RESULTS AND DISCUSSIONS – PART 2

RESULTS

A total of 39 subjects were included in this part of the study. The 22 subjects from Part 1 were included in this part plus 17 additional subjects. From the 39 subjects, 17 were in the age range of 22 and 29 years old, 15 between 30 and 39 years old, and 7 between 40 and 50 years old. From the 17 subjects added for this part, 3 were excluded: two had body mass index (BMI) equal or greater than 30 (33.2 and 37.4) indicating obesity; and one had a history of trauma. Therefore, based on the excluded subjects from Part 1 and from the additional pool of subjects in Part 2, a total of 6 subjects were excluded. The subject demographic descriptive statistics are given in Table 14.

Table 14. Descriptive statistics for subject demographic characteristics (Part 2).

Variables	Mean (SD)	Range
Age (years)	32.7 ± 8.03	22 to 50
Weight (Kg)	62.4 ± 8.6	43.5 to 85.4
Height (m)	1.66 ± 0.07	1.51- 1.82
BMI	22.7 ± 2.6	15 to 29.7

BMI: body mass index (weight/height^2)

From the physical examination, all participants presented with a normal cervical range of motion with absence of pain (see appendix I for reference). Pain was observed in 2 of the additional subjects needed for this part: One had mild pain in the left side of trapezius muscle during palpation; one felt a “tension” but no pain during palpation of the right trapezius muscle. The pain presented on these subjects was not a condition of exclusion because the pain was mild and had no effect on their relgular activities.

- Photogrammetry Descriptive Statistics for each Postural Classification

From the 39 subjects included, 14 were classified as having aligned posture (35.9%); 16 were classified as having SFHP (41%); and 9 were classified as having FHP (23.1%) through the visual clinical assessment. For each of the postural groups classified, the mean, the standard deviation, and the range of the 5 photographic angles were calculated and are shown in Table 15. This data was further used for the discriminant analysis from the angles measured.

Concurrent Validity

The concurrent validity was assessed by the relationship between photographic and radiographic measurements. Table 16 shows the Pearson correlation between the measurements, and the coefficient of determination from the regression analysis (see Appendix K for means and standard deviation). Regression analysis was only performed for those who showed at least a moderate correlation ($r \geq 0.50$).

Table 15. Mean, standard deviation, and range for the surface angles measurements according to each postural classification

		CVA	CIA	CA	ACIA	ACA
Aligned Posture (14)	Mean (SD)	56.35 (2.68)	81.69 (4.27)	154.67 (5.50)	85.86 (4.47)	158.68 (5.74)
	Range	52.40-61.46	72.11-87.36	142.7-163.53	74.60-91.13	145.79-167.01
SFHP (16)	Mean (SD)	49.85 (2.01)	74.46 (4.27)	152.76 (8.42)	78.93 (4.55)	156.65 (8.62)
	Range	45.53-53.19	65.36-81.54	143.92-169.95	72.20-87.54	146.93-172.50
FHP (9)	Mean (SD)	46.75 (2.01)	74.65 (1.80)	152.88 (8.24)	79.61 (2.36)	157.98 (7.60)
	Range	42.94-49.82	70.93-76.51	143.36-166.12	75.34-88.27	148.24-167.88
Overall	Mean (SD)	51.47 (4.48)	77.10 (5.12)	153.47 (7.31)	81.57 (5.18)	157.68 (7.32)
	Range	42.94-61.46	65.36-87.36	142.7-169.95	72.2-91.13	145.79-172.50

SFHP=slight forward head posture; FHP= forward head posture; CVA=craniovertebral angle; CIA=cervical inclination angle; CA=cervical angle; ACIA=adapted cervical inclination angle; ACA=adapted cervical angle.

For each of the 5 angles measured on the photographs, the results related to their correlation with the angles measured on the radiographs are described next.

Table 16. Pearson correlation and coefficient of determination between photographic and radiographic angles.

Photographic angles	Radiographic angles	Pearson correlation (r)	Coefficient of determination (r^2)
CVA	NSL/OPT	-0.21	-
	NSL/CVT	-0.34(*)	-
	Am/spC7/hor.	0.84(**)	0.71
CIA	OPT/hor	0.15	-
	CVT/hor	0.33(*)	-
	CIAr	0.63(**)	0.40
	spCIA	0.74(**)	0.55
CA	ARA	0.63(**)	0.39
	CAr	0.66(**)	0.44
	spCA	0.68(**)	0.46
ACIA	OPT/hor	0.24	-
	CVT/hor	0.43(**)	-
	ACIAr	0.63(**)	0.39
	spACIA	0.60(**)	0.36
ACA	ARA	0.53(**)	0.28
	CAr	0.58(**)	0.33
	ACAr	0.57(**)	0.33
	spACA	0.48(**)	0.23

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

- Craniovertebral angle (CVA)

The CVA was better correlated to the angle formed by a line connecting the auditory meatus and the spinous process of C7 with a horizontal line -

Am/spC7/hor. (r=0.84). The correlation was statistically significant at the 0.01 level and therefore, presented a small probability that the observed value occurred by chance. According to the regression analysis for CVA, 71% of the variability of the Am/spC7/hor (dependent variable) can be predicted by the CVA (independent variable). The prediction is good and significant ($p<0.01$). The coefficient of determination is illustrated in Figure 29.

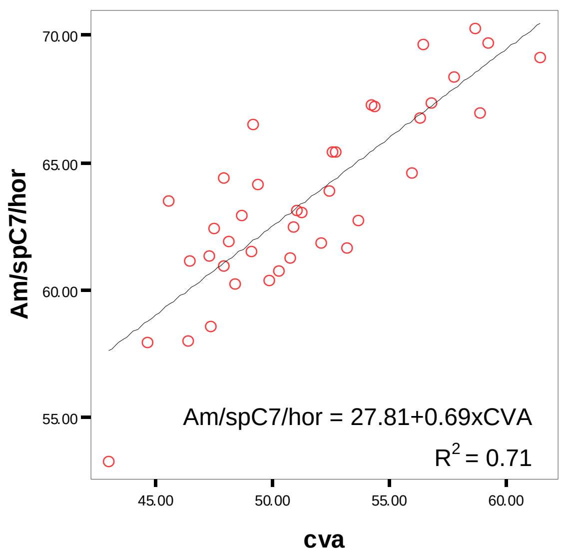

Figure 29. Coefficient of determination between craniovertebral angle measured on photographs (CVA) and auditory meatus/the spinous process of C7 with a horizontal line angle (Am/spC7/hor.)

A poor negative and a fair negative correlation was found for CVA with NSL(nasion-sella line)/OPT(odontoid process tangent) (r=-0.21) and NSL(nasion-sella line)/CVT(cervical vertebra tangent) (r=-0.34) respectively. The negative sign indicates that the angles presented an inverse correlation. Therefore, when one angle increased, the other decreased, and vice-versa. No regression analysis for these correlations was performed since the correlations were less than 0.50.

- Cervical Inclination Angle (CIA)

The CIA was better correlated to the cervical inclination angle using the spinous processes (spCIA) and the cervical inclination angle using the body vertebrae (CIAr) having a Pearson correlation of 0.74 and 0.63 respectively. According to the regression analysis for CIA, 55% and 40% of the variability of the spCIA and CIAr can be predicted by the CIA. The accuracy of the prediction was moderate and significant ($p<0.01$). The coefficients of determination for the best 2 correlations are illustrated in Figure 30.

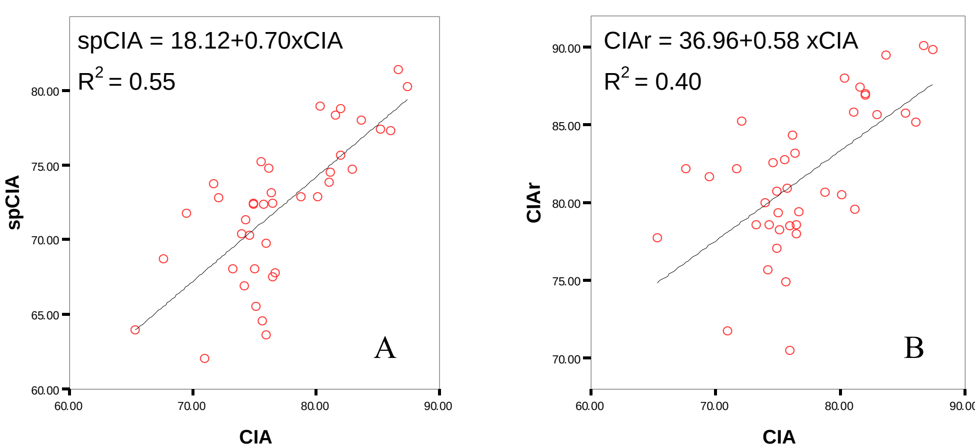

Figure 30. Coefficient of determination between cervical inclination angle measured on photographs (CIA) and cervical inclination angle using the spinous processes (SpCIA) (A), and between CIA and cervical inclination angle using the body vertebrae (CIAr) (B).

▪ Cervical Angle (CA)

The CA had a moderate to good correlation with the cervical angle using the spinous processes (spCA) (r=0.68), cervical angle using the body vertebrae (CAr) (r=0.66), and the absolute rotation angle (ARA) (r=0.63). According to the regression analysis, CA could predict 46%, 44%, and 39% of the variability of the spCA, CAr, and ARA respectively. The accuracy of the prediction was fair to moderate and significant ($p<0.01$). The coefficients of determination for the best 2 correlations are illustrated in Figure 31.

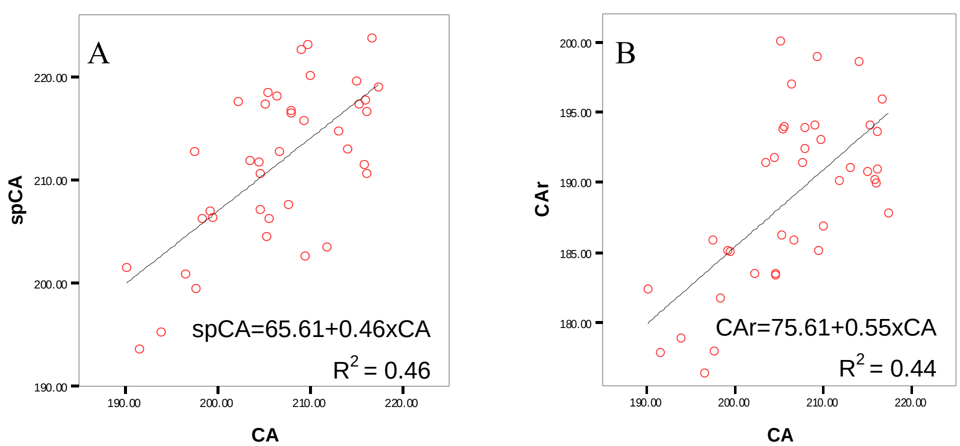

Figure 31. Coefficient of determination between cervical angle measured on photographs (CA) and cervical angle using the spinous processes (SpCA) (A), and between CA and cervical angle using the body vertebrae (CAr) (B).

▪ Adapted Cervical Inclination Angle (ACIA)

The ACIA had a moderate to good correlation with the adapted cervical inclination angle using the body vertebrae (ACIAr) (r=0.63) and cervical inclination angle using the spinous processes (spACIA) (r=0.60), a fair correlation to CVT (cervical vertebra tangent)/hor. (r=0.43), a litlle correlation with OPT (odontoid process tangent)/hor. (r=0.24). According to the regression analysis, ACIA could predict 39% and 36% the variability of the ACIAr and spACIA respectively. The accuracy of the prediction was fair to moderate and significant (p<0.01). The coefficient of determination for each correlation is illustrated in Figure 32.

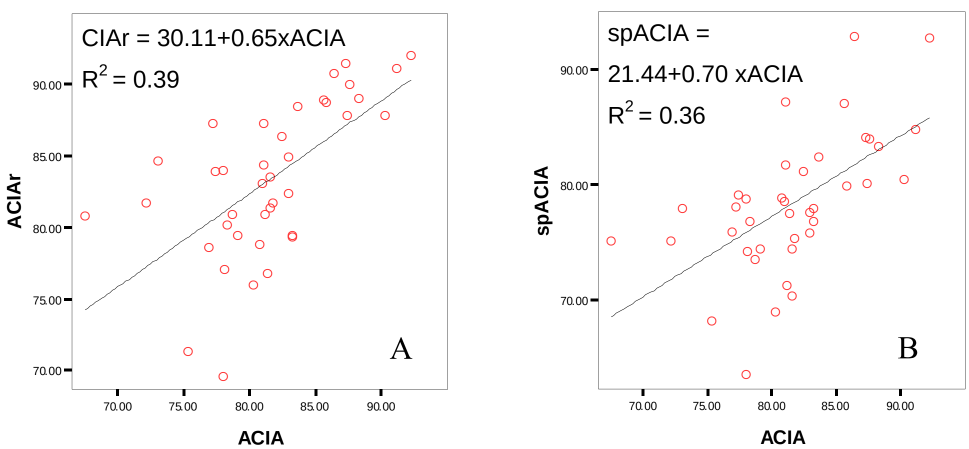

Figure 32. Coefficient of determination between adapted cervical inclination angle measured on photographs (ACIA) and adapted cervical inclination angle using the body vertebrae (ACIAr) (A), and between ACIA and cervical inclination angle using the spinous processes (spACIA) (B).

- Adapted Cervical Angle (ACA)

The ACA had a moderate to good correlation with cervical angle using body vertebrae (CAr) (r=0.58), adapted cervical angle using body vertebrae (ACAr) (r=0.57), and absolute rotation angle (ARA) (r=0.53), and a fair to good correlation with adapted cervical angle using spinous processes (spACA) (r=0.48). According to the regression analysis, ACA could predict 33%, 33%, 28%, and 23% of the variability of the CAr, ACAr, ARA, and spACA respectively. The accuracy of the prediction was fair to moderate and significant ($p<0.01$). The coefficient of determination for each correlation is illustrated in Figure 33.

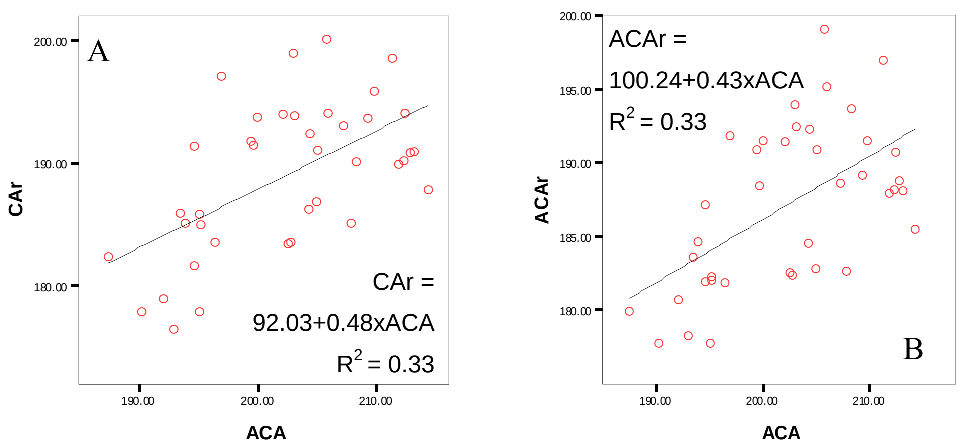

Figure 33. Coefficient of determination between adapted cervical angle (ACA) and cervical angle using body vertebrae (CAr) (A), and between ACA and adapted cervical angle using body vertebrae (ACAr) (B).

For further analysis, Pearson correlation was also performed between each of the surface angles (Table 17). According to this analysis, CVA presented a moderate correlation with CIA (r=0.59) and with ACIA (r= 0.52). The correlation was statistically significant. In addition, CIA and CA were strongly and significantly correlated with ACIA (r=0.95) and ACA (r= 0.94) respectively. A significant and fair to moderate correlation was found for CIA with CA and ACA (r=0.39 and r=0.49 respectively) and between ACIA with ACA (r=0.33).

Table 17. Correlation among surface angles.

	CVA	CIA	CA	ACIA	ACA
CVA	1				
CIA	0.59**	1			
CA	0.16	0.39*	1		
ACIA	0.52**	0.95**	0.19	1	
ACA	0.12	0.49**	0.94**	0.33*	1

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

To further explore the correlation observed between CVA and the angles that represent the inclination of the cervical spine (CIA and ACIA), the correlation of CVA with the angles that represented the inclination of the cervical spine on radiographs (CIAr and ACIAr) were also tested in order to determine if the pattern of correlation was the same for the same angles on the radiographs. The analysis showed that CVA demonstrated moderate to good correlation with CIAr and ACIAr (r=0.71 and 0.66 respectively; p value <0.01).

- Correlation among Vertebral Body, Spinous Process, and Surface Measurements

As previously described in Table 16, the surface angles CVA, CIA, and CA were better correlated to the angles using the spinous processes of the vertebrae (r = 0.68 to 0.84) compared to the angles using the body of the vertebrae (r = 0.15 to 0.66). To further investigate the behavior of the correlations using body vertebrae, spinous process and surface references, the correlation between the angles on the radiographs that use cervical bodies and the angles that use spinous processes was also calculated. The angles CIAr, CAr, and ACIAr were better correlated to the angles using the spinous process spCIA (r = 0.90), spCA (r=0.71), and spCIA (r=0.85) respectively when compared to the angles measured using the surface markers (r = 0.63, 0.66, 0.63 respectively). The correlations were all significant ($p<0.01$). Therefore, in general, the angles using the body of the vertebrae were better correlated to the angles using spinous processes, and the angles using spinous processes were better correlated to the angles using the surface markers.

Spearman Correlation

The values of the surface angles in relation to the posture classification were tested using a Spearman correlation (r_s).

Table 18 shows a significant good to excellent correlation of CVA with the posture classifications (r_s = -0.88). When CVA increases, the classification of posture is closer to the aligned posture category. Conversely, when CVA decreases, the classification of posture is closer to the FHP category. CIA and ACIA presented with the same pattern behavior in relation to the postural classifications as CVA but a significant moderate to good correlation (r_s = -0.60), and a fair to moderate correlation (r_s =-0.40) was found for CIA and ACIA respectively. Little and non-significant correlation of CA and ACA with the postural classifications was observed (r_s = -0.14 and 0.09 respectively).

Table 18. Spearman correlation between the surface angles and the posture classifications.

Surface Angles	Spearman Correlation (r_s)	P-value
CVA	-0.88	0.001
CIA	-0.60	0.001
CA	-0.14	0.39
ACIA	-0.41	0.001
ACA	-0.09	0.59

Discriminant Validity

A multiple discriminant analysis (MDA) was performed in this study to determine the 5 angle measurements' prediction membership in a clinical postural assessment: aligned head posture, slight forward head posture (SFHP), and forward head posture (FHP). MDA also determined if the postural classifications could be differentiated on the basis of the angle measurements. The 5 angles were: CVA (craniocervical angle), CIA (cervical inclination angle), CA (cervical angle), ACIA (adapted cervical inclination angle), and ACA (adapted cervical angle). According to the description of different aspects of posture when measuring craniocervical posture in sagittal plane, (66,104) CVA measures the position of the head in relation to the cervical spine, CIA and ACIA measures the inclination of the cervical spine, and CA and ACA measures the lordosis of the cervical spine. Because the angles were all measured within the craniocervical region, it was likely that these angles were correlated. Hence, 5 different statistical models were developed where the dependent variable is the postural assessment and each angle was a predictor for each model. The descriptive statistics by group for each of the angle measurements are showed previously in Table 15.

- Assumptions

In discriminant analysis, the independent variables (i.e. angle measurements) are assumed to be normally distributed, the variances/covariances are assumed to be homogeneous, and the independent variables should not be highly correlated (multicollinearity). (73,124) These assumptions were tested in the present study.

Violations of the normality assumption are not "fatal" and the resultant significance test is still reliable as long as non-normality is caused by skewness and not outliers. Therefore, the skewness test was calculated. All 5 angles were not significant for the test CVA (p=0.306), CIA (p=0.751), CA (p=0.25), ACIA (p=0.56), and ACA (p=0.738) and no outliers were found. Therefore, the variables were assumed to have a normal distribution. The test of homogeneity was performed using Box's M and the results are shown in Table 19.

Table 19. Box's M test of the homogeneity of variances

Model	Predictor	Box's M	F	P-value
1	CVA	1.420	0.683	0.505
2	CIA	6.519	3.140	0.043
3	CA	2.641	1.270	0.281
4	ACIA	0.401	1.927	0.146
5	ACA	2.216	1.066	0.345

Except for CIA, all tests were not significant so it was concluded that the groups did not differ in their variances, satisfying the assumption of homogeneity. Although CIA violated this assumption of DA, DA is considered robust even when the homogeneity of variance assumption has not been met, provided the data does not contain important outliers.

Because the models involved only one predictor, test of multicollinearity was not necessary. No test for the assumption on the correlations among the independent variables was performed.

- Test of significance

Wilks' lambda is the proportion of the total variance in the discriminant scores not explained by differences among the groups. Wilks' lambda tests which independent variables contribute significantly to the discriminant function. The smaller the value of the variable Wilks' lambda, the more that variable contributes to the discriminant function. Wilks' lambda varies from 0 to 1, with 0 meaning group means differ (thus the more the variable differentiates the groups), and 1 meaning all group means are the same. The F-test of Wilks' lambda showed which variables contributed significantly to the discriminant function. A significance value less than 0.05 indicated that the group means differed, and therefore the function was a significant discriminator. (124)

In the ANOVA table (Table 20), Wilk's lambda was significant by the F-test for CVA, CIA and ACIA, implying that these factors were individually important in discriminating the observation assessment. Therefore, the predictors (angles) varied enough to distinguish the different groups. Because CA and ACA were not significant (both p=0.76), these angles were not able to discriminate posture among groups, therefore, no further discriminant analysis was performed for these angles.

Table 20. Tests of equality of groups means.

Model	Predictor	Wilks' Lambda	F	Sig.
1	CVA	0.244	55.674	0.001
2	CIA	0.542	15.210	0.001
3	CA	0.985	.282	0.756
4	ACIA	0.790	4.793	0.014
5	ACA	0.984	.284	0.755

- Canonical Discriminant Functions

The discriminant analysis develops a statistical model called discriminant function. It provides maximum discrimination among the groups by determining the linear combination of variables that makes the groups as statistically distinct as possible. Because there were more than 2 groups of the dependent variable (3 postural classifications) and there was only one predictor for each model, only one discriminant function was determined for each model (i.e. the lesser of (number of groups-1) and the number of predictors). (73,124) To express the relationship between group membership and the discriminant function, a measure of correlation called canonical correlation was calculated. It is used to determine whether the function is useful in determining group differences. (73)

According to Table 21, a high canonical correlation of 0.869 was found for the function associated with CVA and the canonical correlations were not so high for the functions defined by CIA and ACIA. However, the test of function for each model using Wilks' lambda showed that CVA, CIA and ACIA could each significantly discriminate posture ($p<0.0001$).

Table 21. Cannonical correlation and test of function for each model

Model	Function 1 of model	Canonical Correlation	Test of Function (Wilks' Lambda)	P-value
1	CVA	0.869	0.244	<0.0001
2	CIA	0.679	0.539	<0.0001
3	ACIA	0.629	0.604	<0.0001

The function created for each angle can (now) be named. According to the different aspects of posture described previously when measuring craniocervical posture in the sagittal plane (66,104), each function defined by the angle can represent the aspect of posture that the angles measure. Therefore, for

CVA, the function 1 represents the position of the head in relation to the cervical spine, and for CIA and ACIA function 1 represents the inclination of the cervical spine. Therefore, the aspects of posture were represented by the functions.

- Classification Results

The final step in discriminate analysis was to determine if the discriminant function had correctly classified each individual including the cross-validation analysis. The classification results were performed for each angle separately to determine which angle best classified the subjects according to posture. Tables 22, 23, 24 present a summary of number and percent of subjects classified correctly and incorrectly which evaluated how well the discriminant function worked and if it worked equally well for each of the visual clinical assessments. For further explanation of how these classifications were calculated by SPSS, please see Appendix J.

In Table 22, CVA generally classified 85% of the sample correctly into the observation group. At the individual level, 86% of the patients who had aligned posture, 94% who had slightly forward head posture and 67% of who had a forward head posture, were correctly classified by the CVA. The cross validation showed that 79.5% of the cases were correctly classified (85.7%, 87.5%, and 55.6% at the individual level respectively).

Table 22. Classification results for CVA discriminant analysis.

	Actual group	Predicted Group Membership			Number of cases
		Aligned	SFHP	FHP	
Original	Aligned	12 (85.7%)	2 (14.3%)	0 (0%)	14
	SFHP	0 (0%)	15 (93.8%)	1 (6.3%)	16
	FHP	0 (0%)	3 (33.3%)	6 (66.7%)	9
Cross-validated	Aligned	12 (85.7%)	2 (14.3%)	0 (0%)	14
	SFHP	1 (6.3%)	14 (87.5%)	1 (6.3%)	16
	FHP	0 (0%)	4 (44.4%)	5 (55.6%)	9

*84.6% of original grouped cases correctly classified
**79.5% of cross-validated grouped cases correctly classified
SFHP=slight forward head posture
FHP= forward head posture

Table 23. Classification results for CIA discriminant analysis.

	Actual group	Predicted Group Membership			Number of cases
		Aligned	SFHP	FHP	
Original	Aligned	12 (85.7%)	2 (14.3%)	0 (0%)	14
	SFHP	2 (12.5%)	14 (87.5%)	0 (0%)	16
	FHP	0 (0%)	9 (100%)	0 (0%)	9
Cross-validated	Aligned	12 (85.7%)	2 (14.3%)	0 (0%)	14
	SFHP	2 (12.5%)	14 (87.5%)	0 (0%)	16
	FHP	0 (0%)	9 (100%)	0 (0%)	9

*66.7% of original grouped cases correctly classified
**66.7% of cross-validated grouped cases correctly classified
SFHP=slight forward head posture
FHP= forward head posture

In Table 23, CIA generally classified 67% of the sample correctly into the observation group. At the individual level, 86% of the patients who had aligned posture and 88% who had slightly forward head posture were correctly classified by the CIA. The classification did not change when the cross validation was analyzed. Because CIA was not able to discriminate FHP and SFHP, none of the subjects were included in the FHP classification (0%).

Table 24. Classification Results for ACIA discriminant analysis.

	Actual group	Predicted Group Membership			Number of cases
		Aligned	SFHP	FHP	
Original	Aligned	11 (78.6%)	3 (21.4%)	0 (0%)	14
	SFHP	3 (18.8%)	13 (81.3%)	0 (0%)	16
	FHP	3 (33.3%)	6 (66.7%)	0 (0%)	9
Cross-validated	Aligned	11 (78.6%)	3 (21.4%)	0 (0%)	14
	SFHP	3 (18.8%)	13 (81.3%)	0 (0%)	16
	FHP	3 (33.3%)	6 (66.7%)	0 (0%)	9

*61.5% of original grouped cases correctly classified
**61.5% of cross-validated grouped cases correctly classified
SFHP=slight forward head posture
FHP= forward head posture

In Table 24, ACIA generally classified 62% of the sample correctly into the observation group. At the individual level, 79% of the patients who had aligned posture and 81% who had slightly forward head posture were correctly classified by the ACIA. Similarly to CIA, the classification did not change when the cross validation was analyzed. Because ACIA was not able to discriminate

FHP and SFHP, none of the subjects were included in the FHP classification (0%).

From the results shown in the classification tables (Tables 22 to 24), CVA was the best predictor of observation assessment and could discriminate among the 3 groups of posture. CIA and ACIA were able to discriminate 2 groups of posture classification: aligned from SFHP and FHP but not between SFHP and FHP.

- Cut-off points

To be able to determine the cut-off points, the values obtained from the cross-validation was used to further proceed with the sensitivity analysis. Based on the number of subjects predicted for each group on the cross-validated tables and based on the original angle values for those included in each group for each angle (please see Appendix J for reference), the following cut-off points were established for each angle (Table 25):

Table 25. Cut-off points calculated from cross validation analysis

	Aligned	SFHP	FHP
CVA	53.7 - 61.5	47.9 - 53.2	42.9 - 47.3
CIA	78.7 - 87.4	65.4 - 76.7	
ACIA	83.3 - 92.2	67.5 - 82.5	

SFHP=slight forward head posture;
FHP= forward head posture

Because CIA and ACIA could not discriminate the 3 postural classification groups, cut-off points for SFHP and FHP were clustered together as one classification.

Sensitivity, Specificity, and Predictive Values

The cut-off points obtained from the cross-validation were used to further proceed with the screening tests (photogrammetry sensitivity/specificity and predictive values) because that is the "true boundary" that distinguishes subjects with or without FHP. The angle values measured on photographs for CVA, CIA and ACIA (i.e. the angles that were able to discriminate posture according to the discriminant analysis) were compared with the visual assessment of posture (no angle measurements) using radiographs. The assessment using radiographs resulted in 13 subjects having aligned posture and 26 subjects having forward head posture (FHP). The results are showed next in Table 26.

According to the data presented in Table 26, better sensitivity was found for CVA and CIA (92%) compared to ACIA (73%). Therefore, 92% of the subjects with FHP determined by the assessment using radiographs were classified as having FHP by CVA and CIA measured on the photographs (24/24+2). A higher level of specificity was found for CIA which showed that 92% of the subjects with aligned posture determined by the assessment using radiographs were classified as having aligned posture measured on the photographs (12/1+12). Better predicted values were also found for CIA and CVA compared to ACIA. Ninety-six percent (96%) of those tested as having FHP by CIA measured on the photographs actually presented FHP determined by the radiographs (24/24+1), and 86% of those tested as having aligned posture by CIA actually presented a aligned posture determined by the radiographs (12/2+12). Therefore, CIA had a higher probability of correctly determining testing subjects with FHP and subjects with aligned posture compared to CVA and ACIA according to the predicted values.

Table 26. Sensitivity, specificity and predicted values for photogrammetry.

	CVA	CIA	ACIA
True Positive	24	24	19
True Negative	10	12	10
False Positive	3	1	3
False Negative	2	2	7
Sensitivity	92%	92%	73%
Specificity	77%	92%	77%
+ Predicted Value	88%	96%	86%
- Predicted Value	83%	86%	59%

CVA=craniovertebral angle; CIA = cervical inclination angle; ACIA = adapted cervical inclination angle; FHP = forward head posture.

Additional Reliability Analysis

- Precision of the Surface Markers Position on the Cervical Spine

The ability of Rater 1 to place the surface markers on the skin over spinous process of C2, C4, C6, and C7 was tested using percentage agreement. The same analysis was performed in Part 1 of this study including 22 subjects. This analysis was performed in this part but including all 39 subjects included in this study (22 from Part 1 plus the additional 17 subjects). The method used for the additional 17 subjects were the same for the 22 subjects included in Part 1 (Chapter 5).

From the 39 subjects, 39 radiographs were analyzed which represents 156 surface markers placements (39 x 4 placements in each subject). From these 156, 19 were misplaced (12.2%). Of the12.2% error 1.3% occurred attempting to find C2; 2.6% on C4; 3.2% on C6; and 5.2% on C7. The total percentage of agreement was 87.8%.

- Inter-rater Reliability

In addition to Part 1 of this study in which reliability analysis was performed, a postural visual assessment of the 39 healthy female subjects who participated in Part 2 was performed by 2 raters and their assessment were compared to test their inter-rater reliability. The visual assessment of posture was performed using photographs and radiographs.

- Radiographs

Two postural positions (i.e. aligned head posture and forward head posture) were used to classify the posture of the subjects in the radiographs. The value of the kappa agreement of the visual assessment of posture between raters using radiographs was 0.83 ($p < .0.001$), 95% CI (0.65-1.01). The agreement between raters was excellent and significant. (73)

- Photographs

Three postural positions (i.e. aligned head posture, slight forward head posture, and forward head posture) were used to classify the posture of the subjects in the photographs (classified clinically using anatomical landmarks as a reference). The value of the kappa agreement of the visual assessment of posture between raters was 0.37 ($p < .0.001$), 95% CI (0.13-0.61). Therefore, a poor to fair agreement was found between raters for the assessment of posture using photographs. (73)

In addition to the inter-rater reliability of the visual assessment of posture, the agreement between the visual postural assessments from the same subject using photographs and radiographs were also calculated using kappa agreement for each rater. Rater 1 presented with higher reliability (Kappa = 0.83 ($p < .0.001$), 95% CI (0.65, 1.01)) compared with Rater 2 (Kappa = 0.26 ($p < 0.001$), 95% CI (-0.04, 0.57)). Therefore, better agreement between the visual postural evaluation using photographs and radiographs was found for Rater 1 than for Rater 2 with Rater 1 being able to reliably classify the same posture using both methods.

DISCUSSION

Each analysis performed in this part of the study will be discussed separately: Concurrent validity; Spearman correlation; discriminant validity; and sensitivity, specificity and predicted values. Two additional reliability tests were performed and they are also discussed in this part of the study (i.e. precision of the marker placement and inter-rater reliability of the visual assessment of posture using photographs and radiographs).

Concurrent Validity

The observation of the surface spine curvature to assess posture in clinical practice is based on the assumption that the surface curvature reflects the curvature of the vertebral column. (66) However, studies in the literature that investigated cervical posture in the standing sagittal view have showed poor to moderate correlations ($r = 0.11 - 0.55$) between surface and vertebral curvatures. In the present study, the surface and vertebral angles were correlated according to the aspect of posture they measured (i.e. head in relation to the cervical spine, inclination of the cervical spine, and lordosis of the cervical spine). The three aspects of posture described and tested in this study were based on the alterations of the craniocervical region when craniocervical posture changed. Forward head posture involves a modification of the position of the head in relation to the vertical reference line (2) and a modification on the position of the cervical spine. (4) When the head is forward in relation to the vertical line, a forward inclination of the cervical spine with a decrease of cervical lordosis occurs. (4)

The angle that better correlated to the radiographic measurement was craniovertebral angle (CVA) which measures the position of the head in relation to the cervical spine ($r=0.84$; $r^2=0.71$). For the angles that measure inclination of the cervical spine, cervical inclination angle (CIA) was better correlated ($r = 0.74$; $r^2 = 0.55$) when compared to adapted cervical inclination angle (ACIA) ($r = 0.63$; $r^2 = 0.39$). Similarly, for the angles that measure lordosis of the cervical spine, CA was better correlated ($r = 0.68$; $r^2 = 0.46$) when compared to ACA ($r = 0.58$; $r^2 = 0.33$). Therefore, the adapted angles (ACIA and ACA) were not better correlated to the radiographic angles when compared to CIA and CA. Therefore, they do not better represent the inclination and lordosis of the cervical spine as previously hypothesized.

The CIA correlation was improved when T1 or T2 in 24 healthy subjects was used as a reference instead of C7 (from $r = 0.55$ to 0.71 and 0.82 respectively) as described by Refshauge et al. (66) The use of T1 and T2 was tested in their study because the greatest difference between vertebral body and surface curve was found to be near the cervicothoracic junction. Therefore, their hypothesis stated that vertebral body and surface measures of cervical inclination were better correlated using vertebrae below C7. Their hypothesis was confirmed with the better correlation being found for T1 and T2 references. However, in the present study, the use of a reference above C7 (i.e. C6) was not better correlated with the vertebral body measurements as hypothesized in this study. The angles using C7 as a reference showed better correlation to the angles on the radiographs than the angles using C6 as a reference. One possible explanation for the lower correlation is the amount of soft tissue covering C6 spinous process. Because the spinous process of C6 is smaller than C7 spinous process, a greater amount of soft tissue was observed between the spine and the surface of C6 spinous process compared to C7 spinous process. The amount of soft tissue could influence the correlations between the angles using C6 as a reference measured on the radiographs and on the skin surface.

The angles measured on the radiographs included the angles using the body of the vertebrae and the spinous processes of the vertebrae. In general, surface angles were better correlated with the angles using spinous processes ($r = 0.68$ to 0.84) than with the angles using cervical bodies ($r = 0.15$ to 0.66), and angles using cervical bodies were better correlated with the angles using the spinous processes ($r = 0.71$ to 0.90) than with the surface angles. These findings were in agreement with Refshauge et al. (66) These authors measured cervical inclination and cervical lordosis in 21 healthy subjects and a high correlation was found between spinous process and vertebral body measures for the lordosis angle ($r=0.85$) and a moderate to good correlation of vertebral body and all surface angles with spinous process measurements (r = 0.63 to 0.80). In general, the angles using spinous processes were better correlated with both the vertebral body and surface angles compared to the correlation between surface and vertebral body angles in their study.

A high correlation between spinous process and surface angles and a low correlation between spinous process and body vertebrae angles would suggest that the differences between the vertebral and surface alignment were the result of variation of the size and shape of the posterior elements of the vertebral column. On the other hand, a low correlation between spinous process and surface angles, and a high correlation between spinous process and body vertebrae angles would indicate that the differences were the result of variation in depth of the soft tissues. (66) Because, in general, the correlation of spinous process angles showed a higher correlation for surface and body vertebrae angles compared to the correlation between surface and vertebral body measurements, the differences observed could possibly be the result of a combination of both variation of size and shape of the posterior elements of the vertebral column and soft tissues. When the spinous process was compared with surface measures or the vertebral body, the factors influencing the correlation were minimized.

Caution needs to be taken when interpreting results if simultaneous radiographs and photographs are not recorded in studies that assess the correlation between surface and vertebral measurements. (135) According to Engsberg et al, (135) when the data was collected simultaneously, strong correlations were found between the coronal vertical alignment (CVA) calculated as the distance between the body of S2 and a vertical line from C7 body in a coronal plane, and the sagittal vertical alignment (SVA) calculated as the distance between the body of S2 and a vertical line from the C7 body in a sagittal plane calculated from radiographs and surface markers representing those landmarks (r = 0.89 and 0.95). These authors concluded that the surface marker variables had the potential to calculate the radiographic variables and therefore can be useful for clinical settings. However, no correlation between the variables was found when they were taken at two different points in time in their previous work despite the same instructions given to the subjects on how to stand. In the present study, a remote cable connected to the camera was used in order to simultaneously take the picture with the radiographs.

As previously discussed, CVA was compared to cervical vertebra tangent/horizontal angle (CVT/hor.) and odontoid process tangent/horizontal angle (OPT/hor.) that measured the inclination of the cervical spine in the Johnson study. (67) In the present study, CVA was compared to the radiographic angles NSL (nasion-sella line)/OPT and NSL/CVT that measure the same aspect of posture (position of the head in relation to the cervical spine). However, little to fair relationship was found (r = -0.21 and –0.34 for NSL/OPT and NSL/CVT angles respectively). Therefore, CVA was not better correlated to the radiographic angles measuring the same aspect of posture compared to the low to fair correlation found of CVA with CVT/hor. and OPT/hor. as found in the Johnson study (r = 0.11 to 0.23 and 0.39 respectively). It is possible that, because NSL/OPT and NSL/CVT angles use different reference points to measure the position of the head in relation to the cervical spine compared to CVA, the correlation was affected. Therefore, CVA does not represent the NSL/OPT and NSL/CVT angles measured on radiographs. However, CVA showed good to excellent correlation to Am (auditory meatus)/spC7 (spinous process of C7)/hor angle (r = 84) which is better than the non-significant correlation of CVA with CPL as found in the Vischer study (r = 43). (42) Because of the high correlation found for CVA with Am/spC7/hor angle in the present study, it is possible that a good correlation might also be found using the C7 vertebral body instead of the spinous process as a reference. However, as previously discussed, the combination of both variation of size and shape of the C7 and soft tissues, this correlation might be lower. This angle was not measured and tested in this study. Further studies on the concurrent validation of CVA should consider this angle to investigate if the correlation using C7 vertebral body is different from the correlation using the C7 spinous process.

The cervical inclination angle measured on the photographs (CIA) and the cervical inclination angle measure on the radiographs (CIAr) showed slightly better correlation in the present study (r = 0.63) when compared to the Refshauge's study (66) (r = 0.55). Similarly, the angles that measured lordosis of the cervical spine on the photographs (CA) and on the radiographs (CAr) showed slightly better correlation in the present study (r = 0.66) compared to the Refshauge's study (r = 0.65). A low correlation was found for CIA with OPT/hor and CVT/hor angles even though the angles represent the same aspect of posture (r = 0.15 and 0.33 respectively). As discussed in the previous paragraph, it is possible that, because OPT/hor and CVT/hor angles use different reference points to measure the inclination of the cervical spine compared to CIA, the correlation was affected.

From the regression analysis, it was concluded that CVA measured on the photographs was good for calculating the position of the head in relation to the cervical spine measured by the Am/spC7/hor on the radiographs (71%). The CIA measured on the photographs was moderate for calculating the inclination of the cervical spine measured by the spCIA on the radiographs (55%). Therefore, although a good correlation was found between CIA with the spCIA on the radiographs ($r = 0.74$), the use of CIA to predict the inclination of the cervical spine should be used with caution ($r^2 = 0.55$). Finally, CA measured on the photographs was only fair for calculating the lordosis of the cervical spine measured by the spCA, CAr, and ARA (39% to 46%). ACIA and ACA were not better than CIA and CA for measuring inclination and lordosis of the cervical spine respectively and therefore, their use is not recommended. In addition, because CA was only fair to predict the variations of the angles measured on the radiographs, this angle is also not recommended for predicting lordosis of the cervical spine.

Spearman Correlation

Based on the results from the Spearman correlation (r_s), CVA showed good to excellent correlation with the postural classifications (aligned, SFHP, and

FHP) as shown by a coefficient of -0.88. A moderate to good correlation (r_s = -0.60) was found for CIA between the value of the angles and the postural classifications. (73)

The fact that CVA and CIA correlated with the postural classifications does not mean that the distribution of the angles according to each postural classification are different. The interpretation of this correlation is based on the concept of covariance where a change in the magnitude of the angles is proportional to the change in postural classification. For example, when the values of CVA increased, the classification of posture was closer to be aligned, and when the values of CVA decreased, the classification of posture was closer to be FHP (r_s = -0.88). The values for CA (cervical angle) and ACA (adapted cervical angle) were not proportional to the postural classification change and therefore, a non significant correlation was found ($p>0.05$). The test of the difference in distribution according to each postural classification was tested using discriminant analysis.

According to Refshauge et al., (66) the cervical inclination angle (CIA) was defined as the forward inclination of the cervical spine, and therefore the forward position of the head in relation to the cervicothoracic spine. They also stated that the more acute the angle, the more forward is the position of the head. Their definitions were in agreement with the Spearman correlation found in this study (r_s = -0.60). In relation to the cervical angle (CA), these authors stated that the smaller the value of the CA, the larger the lordosis of the cervical spine would be. Assuming that with the smaller the cervical lordosis, the more likely it is that the head posture is more forward, (33) with a smaller angle, the more likely it is that the position of the head will be more close to be aligned. However, Spearman correlation was not performed in their study to compare to the values found in the present study. Base on the low correlation of CA values with the postural classification in the present study (r_s = -0.14), the values of CA were not proportional to the change in postural classification and therefore does not agree with the definition stated by Refshauge et al. study for this angle.

Discriminant Validity

In this study, the photogrammetry discriminant validity was tested using discriminant analysis (DA). According to the results from the discriminant analysis (DA), CVA best correctly classified the postural classifications (84.6% from the original data and 79.5% from the cross-validated data) (Table 22). CVA was the only angle that could discriminate among the 3 postural classifications. At an individual level, CVA correctly classified 85.7% and 87.5% of those presenting as aligned head posture or slight forward head posture respectively based on the cross validation. However, only 55.6% of the subjects with FHP were correctly classified. Based on the classification results in Table 22, 3 subjects (33.3%) from the original data and 4 subjects (44.4%) from the cross validation out of the 9 subjects classified as having FHP were misclassified according to the prediction. They were classified as having SFHP instead, showing an overlap between SFHP and FHP classifications. Therefore, although

CVA was able to discriminate the 3 postural classifications, more overlap was found between SFHP and FHP.

CIA and ACIA were able to discriminate only 2 postural classifications (aligned head posture and SFHP). All of the subjects classified as having FHP were predicted as having SFHP according to the CIA measurements (Table 23). Because of the overlap between SFHP and FHP angle values, these 2 classifications could not be discriminated. For a practical interpretation of these results, one could conclude that CIA and ACIA were able to discriminate between subjects with or without FHP. However, based on the original data, CIA was better able to predict the postural classifications compared to ACIA. At an individual level, CIA correctly classified 85.7% and 87.5% of those with aligned and FHP respectively, while ACIA correctly classified 78.6% and 81.3% of those aligned and FHP respectively.

For the present study, the ability of the angles to correctly predict and discriminate posture was assessed separately having one statistical model for each angle. The results from pulling all the angles together would not have importance in a clinical situation as the clinician would not use all of the angles to assess the patient's posture but rather use the best angle available. If one measure 2 angles and the conclusions are the same, there is no reason for measuring both angles to assess the patient's posture. Or, if one angle is better than another to measure FHP, the best angle should be used by the clinician. For this reason, the violation of one assumption in DA did not influence the results and the best angle was identified.

For the DA, the angles measured on the photographs were tested in relation to the visual assessment of posture using anatomical landmarks as a reference to test if the angles could predict and discriminate the postures that are commonly classified by the clinicians in clinical settings: aligned head posture, SFHP, and FHP. Because 3 categories were included for the postural classification, a multiple discriminant analysis (MDA) was used. Even though radiographs are the gold standard to evaluate the position of the head and the cervical spine, radiographs were not used in this analysis because clinicians do not normally use radiographs to visually classify a patient as having aligned head posture, SFHP, or FHP but instead, the posture is measured visually by the clinician during the patient's visit at the clinic and/or by photographs taken of the patient (clinical standard). Therefore, because of the clinical importance of the visual assessment of posture to classify the patient's posture, this evaluation was the criteria used.

Because the visual assessment of posture through photographs was used in the MDA to test whether the angles were able to detect postural differences, the visual assessment of posture through radiographs was used to test the sensitivity and specificity to assess whether the angles were able to detect postural differences considering 2 of the postural categories (i.e. aligned head posture and FHP). Therefore, the ability of the angles measured on the photographs to detect postural differences was tested using the visual assessment of posture using both clinical standard and the gold standard (radiographs). However, only the visual assessment of posture was used to assess posture through the radiographs since the angles measured on the radiographs were not tested in relation to the postural classification of posture in this study or in any study in the literature in order to know the angle values that represent each postural classification.

Because only one sample was used in this study, the cross-validation was performed to increase the accuracy of the results and to improve the study's external validity by giving a better estimate of what classification results would be in the population. (124) This procedure was important to give an unbiased estimate (free of error) of the percentage of the correctly classified posture. However, the cross-validation was performed on a total of 39 subjects separated into 3 groups. Unequal number of individuals appeared in each group of the dependent variable (14, 16, and 9 subjects). Although unequal sample sizes are acceptable in discriminant analysis, the small sample size in each group needs to be taken into account. According to Meyers et al., (136) the sample size of the smallest group (9 in this case for the FHP group) needs to exceed the number of predictor variables (3 in this case). As a "rule of thumb", the smallest sample size should be at least 20 for 4 or 5 predictors. While this low sample size may work, it is not encouraged, and generally the recommended sample size should be 20 times the number of predictors. If the number of predictors was 3 in this study, 60 subjects per group would be the recommended size. The power for this part of the study was calculated using the Press's Q statistic to investigate whether the discriminatory power of the classification was statistically better than chance. (124) According to the calculation (see Appendix H for reference), the accuracy of CVA was statistically significant, but because this analysis was affected by sample size, the Binominal test was also calculated. A significant discriminating power was found for CVA ($p<0.0001$), marginally significant power for CIA ($p=0.05$) and a non significant power for ACIA ($p=0.20$) (Appendix H).

The postural assessment of the 39 subjects included in this study was based on the assessment of 1 rater. The postural assessment may be different if the assessment was done by another rater. Therefore, the results of this analysis are based on the sample included and on the assessment performed by 1 rater. More studies using discriminant analysis are needed using different samples and different raters in order to compare with the results from this study. Unfortunately, no other studies were found that investigated whether the angles measured on the photographs were able to predict and discriminate different postures.

Sensitivity, Specificity, and Predictive Values

Sensitivity and specificity were calculated and both need to be high in order to consider the angles as having a good ability to detect differences in craniocervical posture determined by the visual assessment of posture using radiographs. If the sensitivity and specificity of the angles are low, differences in the craniocervical posture are not captured.

The angles measured to assess posture need also to provide a sufficient number of accurate responses to be clinically useful. This feature is assessed by the predicted values. Predictive values are often used in medical research to evaluate the usefulness of a diagnostic test. (73) They are related to sensitivity and specificity. A test that has high sensitivity leads to a high negative predictive value because, in terms of this study, it would identify subjects with FHP (positive cases) easily and therefore it was less likely that someone with a negative test would have FHP. Similarly, a test that had high specificity leading to a high positive predictive value because it would identify subjects with aligned posture (negative cases) easily and therefore it was less likely that someone with a positive test would have aligned posture. (73)

According to the results, sensitivity, specificity, and predicted values were acceptable for CVA and CIA but the negative predicted value was not acceptable for ACIA. Only 59% of those tested as having a negative test (aligned posture) actually presented with aligned posture according to the assessment through radiographs. Therefore, about 40% of these subjects actually presented with FHP according to the assessment using radiographs. If the use of ACIA measured on photographs were used to diagnose these subjects, about 40% of them tested as having aligned posture actually had FHP and they would not receive postural treatment.

For the previous reasons, in terms of measuring the inclination of the cervical spine, CIA better detected postural differences on the subjects compared to ACIA. Of those diagnosed as having FHP or aligned posture by the radiographic assessment, CIA better detected them compared to ACIA (sensitivity and specificity). Of those tested as having FHP or aligned posture by the angles measured on the photographs, CIA better agreed with the radiographic assessment compared to ACIA (predictive values). In terms of measuring the position of the head in relation to the cervical spine, CVA was able to satisfactorily detect the postural differences measured through radiographs (Table 26).

In conclusion, CVA and CIA were useful to test subjects with or without FHP determined by the radiographs according to the cut-off points established. No studies were found that tested the sensitivity/specificity and predictive values to compare with the results presented. Commonly in the literature, craniocervical posture is compared among subjects with or without pain (i.e. neck pain, headache, or TMD) but not necessarily with or without FHP. Subjects with pain do not necessarily present FHP, and subjects with no pain can present FHP. Therefore, more studies investigating posture are needed regardless of the presence of pain.

Visscher et al. (33) studied the relationship between posture and curvature of the cervical spine in healthy subjects using measurements on radiographs. An angle formed by a line representing the reference points for the first 6 cervical vertebrae with the horizontal line was measured and the curvature was classified visually as lordodic, straight, or reversed. A more forward posture of the cervical spine was related to a partially reversed curvature, and a more upright posture was related to a lordodic curvature ($p=0.006$). In the present study, posture was assessed using radiographs in terms of having or not FHP but did not assess the spine curvature specifically. Additional studies should test if photogrammetry can detect the different cervical spine curvatures and relate these curvatures with the presence of forward head posture.

Additional Reliability Analysis

- Precision of the Surface Markers Position on the Cervical Spine

The agreement found for the marker positions in relation to the cervical spinous processes in Part 2 (87.8%) was comparable to what was found for in Part 1 (87.5%). Also, similarly to Part 1, C2 marker placement in relation to the C2 spinous process remained the most precise but C7 increased the percentage of error in Part 2 while C4 decreased. A possible explanation for the difference of precision found for C4 and C7 in relation to Part 1 is the greater variability of subjects added in Part 2 of the study. Two of the possible variations could be related to BMI and age. According to a t-test, there was no significant difference between the subjects in Part 1 and Part 2 in terms of BMI ($t = -0.491$, $p = 0.317$). Therefore, BMI had no influence on the difference of precision found. However, there was a significant subject's difference between Part 1 and Part 2 in terms of age ($t = -3.13$, $p < 0.01$). Age could therefore, influenced the precision results. The degeneration process of the cervical spine with age could influence the palpation of the spinous processes. Even though subjects older than 50 years of age were not included in the study in order to control as much as possible for the degenerative process, degenerative changes might occur in early ages. Another possible explanation could be related to the cervical spine anatomical variability of the subjects added in Part 2, independent of age of the subjects, which could influence the palpation process such as size of spinous processes or vertebral mobility during flexion/extension which was performed for the palpation of C7 for example. However, this was not tested in this study and therefore these are only expeculations and need to be further evaluated.

- Inter-rater Reliability for the Visual Assessment of Posture

Clinicians frequently evaluate posture based on history and visual assessment. However, measures of the reliability of the visual assessment of posture are not sufficiently investigated in the literature.

In the present study, Kappa agreement between raters on the classification of posture assessed visually through anatomical landmarks as a reference using photographs was considered low (k=0.37). This result showed that the visual assessment of posture could be subjective and therefore could result in a poor reliability among clinicians. Even if SFHP and FHP were merged together the kappa agreement remained low (0.38). Considering that discriminant analysis (DA) was tested based on the visual assessment of posture using photographs by Rater 1 only, and that the inter-rater reliability of the visual assessment was shown to be low when using photographs, the DA results may be different if the posture was classified by another rater. Therefore, the results from the DA cannot be generalized to all raters. Nevertheless, Rater 1 was accurate in classifying the subjects posture using photographs when compared to the classification of posture using radiographs from the same subjects (Kappa = 0.83 ($p < .0.001$), 95% CI (0.65, 1.01)).

The low reliability found for the visual assessment of posture using photographs was comparable to the Fedorak et al. study (59) where a low kappa value was found among physical therapists (kappa=0.29). Three categories were used in their study to measure lordosis of the cervical and lumbar spine: normal, increased, or decreased lordosis. Six chiropractors, seven physical therapists, six physiatrists, four rheumatologists, and five orthopedic surgeons assessed 36 subjects. The clinicians had a range of experience from 1 to 42 years of practice with a mean of 11 years, and all groups were equal in terms of years of experience. Poor inter-rater reliability was found (0.16 to 0.29). Intra-rater reliability was also tested in their study and the mean Kappa value for all examiners was fair (0.50). Based on their results, visual assessment of cervical and lumbar lordosis was not reliable; therefore, clinicians need to be aware of the limitations of visual assessment. Because visual assessment does not quantify posture and it is subjective, the use of this method to measure posture can result in unreliable assessment within and between assesors. The lack of inter-rater reliability could cause misunderstandings between clinicians. Even clinicians from the same profession could assess the same patient differently. (59) Therefore, a more reliable measurement such as photogrammetry should be used for the assessment of posture.

The present study did not test the intra-rater reliability of the visual assessment of posture and only 2 raters were used. More studies are necessary to test the intra and inter-rater reliability of the visual assessment of the craniocervical posture.

The visual assessment of posture using radiographs was high (k=0.83) which was different from the visual assessment of posture using photographs. Possible reasons for the difference in Kappa values were that the criteria used to evaluate posture in the radiographs were more objective than when using photographs. Therefore, the use of radiographs to visually assess craniocervical posture was more reliable than the visual assessment of posture using photographs between the 2 raters. Although poor reliability was found, visual assessment of posture using photographs should not be discarded. Visual assessment of posture during the clinical examination could alert the clinicians for possible pathology. Therefore, visual assessment in combination with another method to improve the assessment should be used. (59) The clinician, for example, would assess the patient's posture visually and detect the alteration of posture through this method but he/she should quantify the posture through the use of photogrammetry and compare the results after treatment in order to measure how much improvement was needed.

Rater 1 was more reliable concerning the classification of posture of a subject from both photographs and radiographs assessment (K = 0.83) compared to Rater 2 (K = 0.26). Therefore, for Rater 1, the majority of the subjects were equally classified using both methods. For example, a subject classified as having aligned posture through the assessment using photographs was also classified as having aligned posture through the assessment using radiographs by Rater 1. Therefore, the visual assessment of posture using photographs by Rater 1 was considered accurate in relation to the visual assessment of posture using radiographs. Since the radiographs were coded without showing the subjects name, the assessment was blind for both raters. Possible reasons for the difference found between raters were again, the subjectivity of the assessment, the difference in experience in the area and/or not enough training of rater 2 for the assessments. Rater 2 for this part of the study was a physical therapist with 2 years of experience in research in the area different from Rater 1 (4 years of clinical experience and 7 years of research in the area). These differences could influence the decision made by the raters. Because higher inter-rater reliability was found for the radiographs compared to the photographs, the disagreement of Rater 2 when assessing the same subject using both methods was more likely to be related to her assessment using photographs.

CHAPTER 7. SUMMARY AND CONCLUSIONS

Traditionally, the use of radiographs is the most well-known and applied evaluation method in clinical practice. (131) Radiographic examinations of the cervical spine have been used for assessing patients with neck pain and temporomandibular disorders (TMD), for example. However, over the past few decades, research has been conducted to lower the radiation exposure to patients as much as possible. Digital photogrammetry has been considered an alternative to the quantitative assessment of postural alterations. (131) Because more tests of the photogrammetry to assess craniocervical posture were needed, this study was conducted, so that clinicians potentially would have more confidence in using photogrammetry as part of the diagnostic process and as part of the assessment in helping to determine the effect of postural treatment.

RELIABILITY

This study showed that photogrammetry was reliable within and between 2 raters for assessing craniocervical posture in the sagittal plane (i.e. intra and inter-rater reliability). Rater 1 was precise and able to reliably reattach the markers on the spinous processes on the cervical spine a week later. The posture of the subjects was reproducible a week apart when using measurements on radiographs (intra-subject reliability). Therefore, because the subjects could reproduce their posture, and the rater was able to replicate her own measurements and to reattach the markers on the cervical spine, it appears that, with training, the use of photogrammetry to test the reproducibility of posture is considered a suitable method in future studies. This study demonstrated the reliability of craniocervical posture digital photogrammetry.

Having a reliable method for measuring craniocervical posture in the clinic is essential to detecting changes that result from physical therapy interventions. However, the interpretation of an acceptable level of reliability is context-specific and therefore, readers must determine if the raters, subjects, and instrument used in the study reflect their clinical or research setting so the reliability study is relevant. (125,137) Good reliability of the angle measurements might be found in a study but will not necessarily be found in all clinical and research settings. Based on the raters and the subjects included, and the method used, the use of photogrammetry to measure craniocervical posture was found to be reliable.

Sources of Variability

The 2 main sources of variability (error) tested in this study were: from the rater's measurements (intra and inter-rater reliability), and from the subjects (intra-subject reliability). The other source of variability, specifically from this study, was from the placement of the markers on the cervical spine (ability to replace the markers on the cervical spine a week later and the precision of placing the markers on the spinous processes). Another source of variability occurred from the instrument used. In this case, the angle measurements using the Alcimage software which was related to testing the surface markers replacement since different days were used to test them. Therefore, this study tested as much as possible the sources of variability presented.

One source of variability not tested in the present study is related to the raters' measurements. Only 1 rater was used to test the precision and the ability to reattach the markers on the cervical spine. This was done to avoid more radiation exposure to the subjects. If another rater had been included, 2 more radiographs would have been needed to test whether this rater was able to reattach the markers a week later. Perhaps, in studies involving patients who need more than one radiograph taken of their spine, clinical researchers could take advantage the radiographs being taken for another reason and test the agreement of marker placement on the spinous processes. With this approach, the relative risk for patients who receive x-rays would be minimized by a potential medical benefit of the test, and further information on palpation accuracy could be determined.

A period of a week between measurements was established in this study to test the reproducibility of the posture of the subjects and the ability of the rater to replace the markers on the cervical spine. Longer periods between measurements should also be considered and tested to study whether the variability of posture and the variability of the rater to replace the markers changed over longer periods.

The variability of the sample used in a study could also have influenced the reliability results. The sample of a reliability study needs to be heterogeneous in order to be reliable. If the between-subject variability is large, the reliability will be high. On the other hand, if the variability between subjects is low, the reliability will be low. (125) In the present study, even though only healthy subjects were included, the reliability coefficients were good showing that the variability between them was high. This happened because posture was not the same for all subjects included and therefore presented with a variability of angle values.

VALIDITY

In this study, the craniovertebral angle (CVA) measured on the photographs appeared to be valid in determining the position of the head in relation to the cervical spine when measured on the radiographs (Concurrent Validity) and the angle was able to predict and discriminate subjects with aligned posture, slight forward head posture (SFHP), and forward head posture (FHP) assessed by one rater (Discriminant Validity). The cervical inclination angle (CIA) appears to be valid in discriminating subjects with aligned and FHP but cautions are needed when using this angle to predict the cervical spine inclination because moderate coefficients of determination were found in the regression analysis. Therefore, if this angle is used to predict the inclination of the cervical spine, one needs to be aware that only about half of the variability of the cervical spine will be detected by this angle. CVA and CIA were responsive in detecting aligned posture and FHP assessed visually using radiographs. The angles that measured cervical lordosis, the cervical angle (CA) and the adapted cervical angle

(ACA) were not able to discriminate posture and predict the lordosis of the cervical spine. The results from studies that used these angles to measure posture are questionable because if these angles cannot infer changes in posture or changes in the lordosis of the cervical spine, a non-valid method to measure posture is being used.

The validity analysis tested in this study accounted for clinical errors from finding the spinous processes on the cervical spine to place the markers (12.2%). This makes the results from the study more applicable to the clinical settings because possible errors may exist in the clinical practice when attempting to find the spinous processes during palpation. If only the data with a perfect marker precision was included, the results would be applicable to clinicians who are assumed to have perfect precision of finding the spinous process and attaching the markers on the cervical spine. Because this is not a rule among clinicians and it cannot be assumed, the results would be less realistic and therefore not as relevant to the clinical practice as testing a clinical measure accounting for these possible errors.

Internal and External Validity

When doing a validity study, the subjects included should ideally represent the population that the clinicians will evaluate in clinical practice. Representative means for the present study were presented for a sample of female subjects who had no history of pain in the craniocervical region. However, even though the subjects were healthy, a variety of craniocervical postures were seen (aligned, slight forward head posture, and forward head posture). The results from this study are also based on the experience of 2 raters. For the discriminant validity, the visual assessment of posture was based in only 1 rater. Therefore, cautions are needed when using the results from this analysis prospectively. These results are only applicable to the sample and based in one specific evaluator used in this study. If the results of this study are used in other studies that do not specifically test the validation of the same angle measurements but are used for measuring postural treatment effect for example, the authors need to acknowledge that the generalizability of the measurements tested is limited to a specific sample and methodology.

This study supports the validation of the craniovertebral and cervical inclination angles measured using photogrammetry. However, the results are applied only to the sample used in this study. Validation is an ongoing process and other samples need to be evaluated using the angles tested. "Validation is almost never a complete process, nor is ever accomplished with only one study" as stated by Portney and Watkins (p. 108). (73) Therefore, the use of photogrammetry to assess craniocervical posture must be applied in varied settings with different populations to determine their useful measurement properties.

RESEARCH AND CLINICAL IMPLICATIONS

This was the first study in which several measurement property tests of the surface angles were analyzed. Reliability and the ability of the measurements to detect differences are prerequisites for validity and these tests were lacking in previous studies. Therefore, this study contributes to the improvement of the assessment of craniocervical posture using a non-invasive and quantitative approach.

According to Karanicolas et al., (125) the validation of a clinical method should always mimic, as close as possible, the clinical practice environment. It is important to know if the method is really practical to be used in clinical settings. This study focused in a pragmatic approach concerning the method used to assess posture. The pictures were taken in a clinic where no special equipment was used. The use of a high technology digital camera is not necessary and a simple tripod can be used to stabilize it. The surface markers used in the present study were made of metal so they could be visible on the radiographs. However, in the clinical setting, the markers can be made of styrofoam, for example, and they could be attached to the skin with a regular double side tape as used in this study. However, in order to determine if photogrammetry was really useful, the subjects information related to the presence of forward head posture or not was hidden as much as possible during the angle measurements so as not to influence the raters. In a clinical situation, this procedure would not be used.

Considering that visual assessment of the craniocervical posture is still a common approach among clinicians, the use of photogrammetry to assess craniocervical posture in clinical settings will improve the ability of the clinician to detect and quantify posture alterations. The advantages of using visual assessment to classify head posture include the fact that it is an easy and fast method. However, a patient, for example, may be classified as having FHP after treatment by the visual assessment of posture even though improvement has occurred. The improvement could be detected by photogrammetry so that the clinician can be assured that the treatment strategy was correct even though further treatment might be required. Therefore, visual assessment is less sensitive and more subjective for capturing postural changes. Using photogrammetry, posture can be quantified so small differences are detectable if the angles measured are reliable. The disadvantages of this method over visual assessment is that it is more time consuming because it includes placing the markers on the head and/or cervical spine and drawing the angles. However, it is useful and still viable in clinical settings. In cases where the clinician does not have a computer or specific software where the pictures can be measured, the clinician could still use protractors to measure the angles. However, further studies should test whether the use of protractors is also reliable within and between raters.

From a clinical perspective, the ability of craniocervical posture photogrammetry to predict the cervical spine position is a step toward reducing the number of radiographs required for the patients. (135) Photogrammetry is less expensive to use than the radiographic method, and there would be no risk of radiation exposure for the patients.

In the present study, the assessment of the craniocervical posture was related to 3 constructs of posture (position of the head in relation to the cervical spine, and the inclination and the lordosis of the cervical spine). Based on the results of this study, the clinician should be able to assess the craniocervical posture of the patients and the effectiveness of a treatment in modifying craniocervical posture in a clinical setting using a non-invasive approach (photogrammetry). In addition, the clinician could use subjects determined by this method to investigate whether there is a possible relationship between craniocervical posture alteration (i.e. forward head posture) and presence of pain. This relationship could be more specifically assessed looking at alterations in the position of the head in relation to the cervical spine using the CVA (craniovertebral angle) or looking at the inclination of the cervical spine using CIA (cervical inclination angle). Alterations in the lordosis of the cervical spine using this non-invasive method cannot be used to assess the relationship between craniocervical posture and the presence of pain because the angles that measure lordosis of the cervical spine were shown not to be valid.

Another important issue concerning the validation of a method is its feasibility (time and expense is practical). (125) Based on what was discussed previously, the use of photogrammetry to assess craniocervial posture was considered a feasible method to use in the clinical practice. It appears that, with training, the use of photogrammetry in a clinical setting could be a good method to measure craniocervical posture in a sagittal view.

FUTURE CONSIDERATIONS

Based on the results of this study and on its limitations, future studies are needed to substantiate the validation of photogrammetry for measuring craniocervical posture.

Sample size calculation for the validity analysis (Part 2) was based on the concurrent validity (correlation), therefore when the subjects were classified according to posture, a small sample was included in each category. Even though a small sample size was included in each postural classification, the discriminatory power calculated in discriminant analysis was significant for CVA and CIA and therefore, we can conclude with confidence that the difference found was valid for the sample used (i.e. absence of Type I error). In other words, sufficient power was found for these angles in detecting craniocervical postural differences. However, for future studies, the validity of the measurements should be assessed in a bigger sample.

Only healthy female subjects were included in this study. Therefore, to better generalize the validation of the photogrammetry, male subjects and subjects with pain such as neck pain, headache, and temporomandibular disorders patients should be included. Nevertheless, future studies may use the craniocervical posture evaluation results from the group of healthy subjects used in the present study to compare to the results from same evaluation performed in a group of pain subjects.

Only 2 raters were used in this study to measure the angles and posture. The inclusion of more raters with different levels of experience is encouraged in future research so the results can be generalized to a varying level of expertise such as that seen in the clinical practice. (125)

Finally, the test of acceptability of the photogrammetry (i.e. whether clinicians will actually use it in practice) (125) is necessary. It is believed that, with the need of better postural assessment in practice and consequently a better treatment outcome, clinicians will gradually introduce the use of photogrammetry in their clinical routine.

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APPENDICES

A. APPROVAL FROM THE RADIATION SAFETY COMMITTEE

Capital Health RADIATION SAFETY COMMITTEE

2A2.41 WMC, 8440- 112 St.
Edmonton, AB T6G 2B7

24 January 2007

Ms. Inae Gadotti
PhD Student
3-50 Corbett Hall
Faculty of Rehabilitation Medicine

Email: igadotti@ualberta.ca

Dear Ms. Gadotti:

Thank you for your letter of 01 December 2006 re: craniocervical posture assessment and temporomandibular disorders. Thank you for your submission of your revised proposal. This has been reviewed by the Radiation Safety Committee and has been approved.

If you have any other questions or concerns, please contact me directly.

With kind regards,

Yours sincerely,

Robert G. W. Lambert, MB, BCh, FRCR, FRCPC
Chairman, Radiation Safety Committee
Academic Chair
Department of Radiology & Diagnostic Imaging
University of Alberta

RL/jh

B. APPROVAL FROM THE HEALTH RESEARCH ETHICS BOARD

Health Research Ethics Board

213 Heritage Medical Research Centre
University of Alberta, Edmonton, Alberta T6G 2S2
p.780.492.9724 (Biomedical Panel)
p.780.492.0302 (Health Panel)
p.780.492.0459
p.780.492.0839
f.780.492.7808

ETHICS APPROVAL FORM

Date: **August 24, 2007**

Name(s) of Principal Investigator(s): **Dr. David Magee**

Department: **Physical Therapy, Faculty of Rehabilitation Medicine**

Title: **Craniocervical posture assessment and temporomandibular disorders**

The Health Research Ethics Board (Biomedical Panel) has reviewed the protocol involved in this project which has been found to be acceptable within the limitations of human experimentation. The REB has also reviewed and approved the subject information material and consent form.

Specific Comments:

The Research Ethics Board assessed all matters required by section 50(1)(a) of the Health Information Act. Subject consent for access to identifiable health information is required for the research described in the ethics application, and appropriate procedures for such consent have been approved by the REB Panel.

J. S. Bamforth, M.D.
Associate Chairman, Health Research Ethics Board
Biomedical Panel

OCT - 1 2007
Date of Approval Release

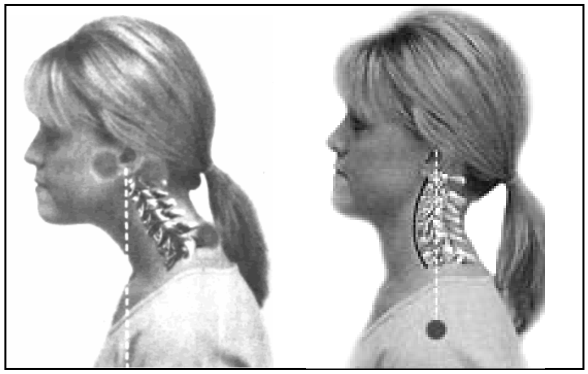
This approval is valid for one year

Issue #7010

UNIVERSITY OF ALBERTA — Capital Health Edmonton and area — CARITAS HEALTH GROUP

C. RECRUITMENT POSTER

VOLUNTEERS NEEDED FOR THE PROJECT:
"HEAD AND NECK POSTURE ASSESSMENT"



Volunteers:

- Female subjects between 20 and 50 years of age;
- No history of neck trauma, surgery, bone pathology, arthritic or other inflammatory disorders;
- No frequent pain in the head and neck region (including pain in the temporomandibular region).

Purpose of the study:

- To test measurements in photographs using surface markers to assess head and neck posture in a lateral view compared with measurements in radiographs.

Benefits of the study:

- You will receive a physical evaluation of your head-neck region and posture;
- You will receive a report of the findings.
- You will be given a small honorarium to cover incidental expenses such as parking.

If you want to volunteer for this project or more information, please contact:

Inae C. Gadotti, PhD Student, University of Alberta, by email (igadotti@ualberta.ca) or phone (780) 492-4824

Head and neck posture assessment
Inae Gadotti phone: 492-4824
email: igadotti@ualberta.ca

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D. INFORMATION LETTER TO SUBJECTS - PART 1

Project Title: “Measurement Properties of the Sagittal Craniocervical Posture Assessment using Photogrammetry”

Researchers

- Dr. David Magee, Professor.
- Inae Gadotti, PhD student.

Background/Purpose

The use of x-ray is the most common way of measuring head and neck posture. However, using a method that does not involve x-rays is valuable for clinical practice. If surface measurements using a photograph are shown to be effective in measuring head and neck posture, it would be less expensive than using x-ray method. Also, it would be no risk of radiation exposure for the patients. Therefore, the purposes of this study are to evaluate if the surface measurements using a photograph to assess head and neck posture in a lateral view are:

- Able to predict alterations in the neck posture;
- Able to differentiate between different postures (aligned posture and forward head posture);
- Able to determine if consistent measurements can be achieved.

It is believed that this study will improve the evaluation of head and neck posture.

Procedure

Three sessions will be needed to evaluate you. The first session is an evaluation of your head and neck. The evaluation includes a questionnaire, a visual assessment of your posture, and an evaluation of pain and movement. You will be asked to wear a strapless top. In the second session, surface markers (little stickers) will be placed on your neck with an adhesive to be used as reference points. One x-ray and 1 photograph of your head and neck will be taken at the Glen Sather clinic. Your usual posture will be evaluated in standing. The position of your feet will be also marked on a piece of paper. In the third session, an additional x-ray and photograph will be taken of your usual posture. The piece of paper used to mark the position of the feet will be used in this session. Each session will take 30 minutes. The second and the third sessions will be 1 week apart and will be performed at the same time of the day.

Benefits

You will receive a complete evaluation of your head and neck posture if you so desire.

Risks

Two x-rays will be taken that will expose you to radiation. These x-rays are not required for a medical reason. There is no direct benefit to you from having the x-rays taken. However, the radiation exposure for the 2 x-rays is considered low. By allowing us to take an x-ray of your head and neck, you will help us to determine if a clinical test can be used that is as good as an x-ray. Thus, future x-rays may not be necessary. The x-rays will be taken under recommended radiation protection guidelines. The radiation exposure will be as low as possible. The University of Alberta Radiation Safety Committee has approved the research. A copy of the approval is available for you to see, if you wish.

Confidentiality
All information will be held confidential, except when professional codes of ethics or the law requires reporting. The information you provide will be kept for at least seven years after the study is completed. The information will be kept in a secure area (i.e. locked filing cabinet). Your name or any other identifying information will not be released. Your name will also never be used in any presentations or publications of the study results. The information gathered for this study may be looked at again in the future to help us answer other study questions. If so, the ethics board will first review the study to ensure the information is used ethically.

Voluntary Participation
Your participation in this research is voluntary. You have the right not to participate. You can quit at any time without giving any reason.

Contact Information
If you have any concerns about the study, you can also contact Dr. Paul Hagler, Associate Dean of Graduate Studies and Research in the Faculty of Rehabilitation Medicine, University of Alberta at (780) 492 9674. If you have any questions regarding the study you can contact Ms. Inae Gadotti at (780) 492 4824 or Dr. David Magee at (780) 492 5765.

E. INFORMATION LETTER TO SUBJECTS - PART B

Title: "Measurement Properties of the Sagittal Craniocervical Posture Assessment using Photogrammetry"

Researchers

- Dr. David Magee, professor
- Inae Gadotti, PhD student.

Background/Purpose
The use of x-ray is the most common way of measuring head and neck posture. However, using a method that does not involve x-rays is valuable for clinical practice. If surface measurements using a photograph are shown to be effective in measuring head and neck posture, it would be less expensive than using x-ray method. Also, it would be no risk of radiation exposure for the patients. Therefore, the purposes of this study are to evaluate if the surface measurements using a photograph to assess head and neck posture in a lateral view are:

- Able to predict alterations in the neck posture;
- Able to differentiate between different postures (aligned posture and forward head posture);
- Able to determine if consistent measurements can be achieved.

It is believed that this study will improve the evaluation of head and neck posture.

Procedure
Two sessions will be needed to evaluate you. The first session is an evaluation of your head and neck. The evaluation includes a questionnaire, a visual assessment of your posture, and an evaluation of pain and movement. You will be asked to wear a strapless top. In the second session, surface markers (little stickers) will be placed on your neck with an adhesive to be used as reference points. One x-ray and 1 photograph of your head and neck will be taken at the Glen Sather clinic. Your usual posture will be evaluated in standing. Each session will take 30 minutes.

Benefits
You will receive a complete evaluation of your head and neck posture if you so desire.

Risks
One x-ray will be taken that will expose you to radiation. This x-ray is not required for a medical reason. There is no direct benefit to you from having the x-ray taken. However, the radiation exposure for the x-ray is considered low. By allowing us to take an x-ray of your head and neck, you will help us to determine

if a clinical test can be used that is as good as an x-ray. Thus, future x-rays may not be necessary. The x-ray will be taken under recommended radiation protection guidelines. The radiation exposure will be as low as possible. The University of Alberta Radiation Safety Committee has approved the research. A copy of the approval is available for you to see, if you wish.

Confidentiality

All information will be held confidential, except when professional codes of ethics or the law requires reporting. The information you provide will be kept for at least seven years after the study is completed. The information will be kept in a secure area (i.e. locked filing cabinet). Your name or any other identifying information will not be released. Your name will also never be used in any presentations or publications of the study results. The information gathered for this study may be looked at again in the future to help us answer other study questions. If so, the ethics board will first review the study to ensure the information is used ethically.

Voluntary Participation

Your participation in this research is voluntary. You have the right not to participate. You can quit at any time without giving any reason.

Contact Information

If you have any concerns about the study, you can also contact Dr. Paul Hagler, Associate Dean of Graduate Studies and Research in the Faculty of Rehabilitation Medicine, University of Alberta at (780) 492 9674. If you have any questions regarding the study you can contact Ms Inae Gadotti at (780) 492 4824 or Dr. David Magee at (780) 492 5765.

F. SUBJECT CONSENT FORM

Part 1 (to be completed by the Principal Investigator):

Title of Project: Craniocervical posture assessment and temporomandibular disorders

Principal Investigator(s): Dr. David Magee — Phone Number(s): (780) 492-5765
Co-Investigator(s): Inae Caroline Gadotti — Contact Names: David Magee and Inae Gadotti
Phone Number(s): (780) 492-2718

Part 2 (to be completed by the research subject):	Yes	No
Do you understand that you have been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study? (i.e. do you understand that x-ray will be taken from your head and neck?)	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to withdraw from the study at any time, without having to give a reason and without affecting your future medical care?	☐	☐
Has the issue of confidentiality been explained to you?	☐	☐
Do you understand who will have access to your records, including personally identifiable health information?	☐	☐
Do you want the investigator(s) to inform your family doctor that you are participating in this research study? If so, give his/her name ___________________	☐	☐

Who explained this study to you? ____

I agree to take part in this study: YES ☐ NO ☐

Signature of Research Subject ____

(Printed Name) ____

Date:______________________________

Signature of Witness ____

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.
Signature of Investigator or Designee ________________________________ Date __________

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH SUBJECT

G. APPROVAL FROM THE GLEN SATHER CLINIC

GLEN SATHER
SPORTS MEDICINE CLINIC

E-05 Van Vliet Centre Edmonton, Alberta T6G 2H9 Tel:(780)492-4752 Fax:(780)492-1637

8/15/2007

Ethics Board
University of Alberta
Edmonton, Alberta

Re: Project: Craniocervical Posture Assessment and Temporomandibular Disorders

Investigators: Dr. David Magee
Inae Caoline Gadotti, PhD student

As per a request, I am just writing to indicate my support for the above project, particularly for the xrays, as documented in the Project Proposal, to be taken at our facility in the Glen Sather Sports Medicine Clinic at the University of Alberta, by Jan Dubeta.

If you have any other questions, please do not hesitate to contact me.

Sincerely,

Connie Lebrun

Constance M. Lebrun
Director, Glen Sather Sports Medicine Clinic
University of Alberta
E-05 Van Vliet Centre
Edmonton, Alberta T6G 2H9
Ph: 780 492-4752
FAX: 780 492-1637
Office: 780 492-1033
email: clebrun@sports.ualberta.ca

H. SAMPLE SIZE AND POWER CALCULATIONS

Sample size estimation for reliability analysis (alpha = 0.05 and power = 0.80)

Repetitions	For ICC_0 ICC_1	0.6 Sample size	0.7 Sample size	0.8 Sample size	0.9 Sample size
2	0.7	205			
	0.75	80	555		
	0.8	39	117		
	0.85	21	42	250	
	0.9	12	18	45	
	0.95	6	6	13	49
3	0.7	133			
	0.75	53	374		
	0.8	26	80		
	0.85	14	29	176	
	0.9	8	13	33	
	0.95	4	6	9	36
4	0.7	110			
	0.75	44	314		
	0.8	22	68		
	0.85	12	25	152	
	0.9	7	11	28	
	0.95	4	5	8	32
5	0.7	98			
	0.75	40	284		
	0.8	20	61		
	0.85	11	23	139	
	0.9	6	10	26	
	0.95	4	5	8	30

As per Walter sample size and optimal designs for reliability studies

Stat Med. 17 (1) 101-110, 1998 (113)

Sample size estimation for validity analysis based on correlation coefficient (r) using alpha of 0.05.

	R								
Power	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
0.70	470	117	52	28	18	12	8	6	4
0.80	617	153	68	37	22	15	10	7	5
0.90	854	211	92	50	31	20	13	9	6

Adapted from Table 3.4.1 in Cohen, J. Statistical Power Analysis for the Behavioral Sciences, ed 2. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988. (88)

Power calculation for discriminant analysis.*

To answer the question: Is the discriminatory power of the classification statistically better than chance (50%) assignment **Press's Q statistic was used, The formula is given by:**

$$\text{Press's Q statistic} = \frac{[N - (nK)]^2}{N(K-1)}$$

where N = total sample size
n = number of observations correctly classified
K = number of groups

For a 5% level of significance and 2 degrees of freedom, the critical χ^2 value is 5.991.

For CVA:

$$\text{Press's Q statistic} = \frac{[39 - (34 \times 3)]^2}{39(3-1)} = 50.885$$

Since the calculated Press's Q statistic > 5.991, the accuracy of the CVA classification was better than chance.

For CIA:

$$\text{Press's Q statistic} = \frac{[39 - (26\text{x}3)]^2}{39\,(3 - 1)} = 19.500$$

Since the calculated Press's Q statistic > 5.991, the accuracy of the CIA classification was better than chance.

For ACIA:

$$\text{Press's Q statistic} = \frac{[39 - (24\text{x}3)]^2}{39\,(3 - 1)} = 13.962$$

Since the calculated Press's Q statistic > 5.991, the accuracy of the ACIA classification was better than chance.

Test of significance of Press's Q statistic showed that CVA, CIA and ACIA all had discriminatory power. However, Press's Q is undesirably affected by sample size, a binomial test with p=0.50 on the accuracy was obtained.

For CVA:

Binomial Test

		Category	N	Observed Prop.	Test Prop.	Asymp. Sig. (2-tailed)
correct	Group 1	1.00	33	0.85	0.50	0.000[a]
	Group 2	0.00	6	0.15		
	Total		39	1.00		

a. Based on Z Approximation.

For CIA:

Binomial Test

		Category	N	Observed Prop.	Test Prop.	Asymp. Sig. (2-tailed)
correct	Group 1	1.00	26	0.67	0.50	0.053[a]
	Group 2	0.00	13	0.33		
	Total		39	1.00		

[a.] Based on Z Approximation.

For ACIA:

Binomial Test

		Category	N	Observed Prop.	Test Prop.	Asymp. Sig. (2-tailed)
correct	Group 1	1.00	24	0.62	0.50	0.200[a]
	Group 2	0.00	15	0.38		
	Total		39	1.00		

[a.] Based on Z Approximation.

Results of the binomial tests showed that CVA was significant; CIA was marginally significant and ACIA was not significant. This implies that among the three angle measurements, CVA had the best discriminatory power compared to CIA and ACIA.

*Chan,Y.H. Biostatistics 303. Discriminant Analysis. *Singapore Med J.* 46 (2), 2005. (124)

I. EVALUATION FOR THE SELECTION OF THE SUBJECTS

Name: Code: Date:

Age: Date of birth:___/___/______ Gender:

Height (m): Weight (kg):

Body mass index (weight/height^2): ____/____ = ______

1) Medical history

Head and neck region	**Yes**	**No**	**Sometimes**	**Frequency (per month)**
History of surgery			NA	NA
History of trauma			NA	NA
History/present other pathology (arthritis, inflammation)			NA	NA
Present pain*				
Present headache**				

*Subjects will be excluded from the study if they present with constant pain; or pain that has an effect on regular activities.

**Subjects will be excluded from the study if the frequency of headache is more than 2 episodes per month or 1 episode of more than 3 days of duration (120).

2) Visual assessment of the head and neck posture*

- Present forward head posture (according to Kendall, 1970)?

  Yes______ No______ Slightly_____

*This item alone does not influence the final decision of including the subjects in the study.

3) Physical assessment

Cervical region Palpation	**Pain**	**No Pain**
Trapezius		
Splenius		
Esternocleido		

Masticatory region palpation	**Pain**	**No Pain**
Temporalis		
Masseter		
Supra-hyoids		

Cervical	**Range of motion***	**Pain**	**No Pain**
Flexion			
Extension			
Side flexion right			
Side flexion left			
Rotation right			
Rotation left			

* The ROM was measured using a goniometer. ROM criteria used: Normal flexion = 30º to 70º; extension = 45º to 111º; side flexion = 20 º to 65º; and rotation = 50 º to 85º (Youdas et al., 1992).

FINAL DECISION:

Include____

Exclude____

J. CALCULATION OF ANGLES CLASSIFICATIONS IN DISCRIMINANT ANALYSIS

A discriminant score is calculated for each subject based on the unstandardized canonical discriminant function coefficients

Discriminant function coefficients for CVA

Canonical Discriminant Function Coefficients

	Function
	1
cva	0.440
(Constant)	-22.642

Unstandardized coefficients

Discriminant function coeffients for CIA

Canonical Discriminant Function Coefficients

	Function
	1
cia	0.259
(Constant)	-19.977

Unstandardized coefficients

Discriminant function coeffients for ACIA

Canonical Discriminant Function Coefficients

	Function
	1
aciamean	0.242
(Constant)	-19.727

Unstandardized coefficients

It is given by the equation:

Discriminant score (for CVA) = -22.642 + (0.440xCVA)

Discriminant score (for CIA) = -19.977 + (0.259xCIA)

Discriminant score (for ACIA) = -19.727 + (0.440xACIA)

Based on the discriminant score, a maximum likelihood method was used to classify group membership. A subject is assigned to group k if its probability of membership is greater in group k than any other groups (see next tables).

Casewise Statistics to classify group membership (CVA).

Casewise Statistics – CVA

				Highest Group				Second Highest Group			Discriminant Scores	Angle measures
				P(D>d | G=g)								
	Case Number	Actual Group	Predicted Group	p	df	P(G=g | D=d)	Squared Mahalanobis Distance to Centroid	Group	P(G=g | D=d)	Squared Mahalanobis Distance to Centroid	Function 1	
Original	2	1	1	0,024	1	1,000	5,064	2	0,000	26,088	4,397	61,46
	8	1	1	0,238	1	0,634	1,395	2	0,358	2,809	0,965	53,66
	10	1	1	0,211	1	0,999	1,567	2	0,001	16,884	3,398	59,19
	12	1	1	0,269	1	0,999	1,224	2	0,001	15,712	3,253	58,86
	15	1	1	0,350	1	0,779	0,874	2	0,217	3,696	1,212	54,22
	16	1	1	0,872	1	0,970	0,026	2	0,030	7,273	1,986	55,98
	27	1	1	0,528	1	0,997	0,399	2	0,003	12,171	2,778	57,78
	31	1	1	0,995	1	0,981	0,000	2	0,019	8,127	2,140	56,33
	32	1	1	0,385	1	0,810	0,755	2	0,187	3,954	1,278	54,37
	37	1	1	0,963	1	0,983	0,002	2	0,017	8,431	2,193	56,45
	40	1	1	0,304	1	0,999	1,055	2	0,001	15,090	3,174	58,68
	43	1	1	0,848	1	0,989	0,037	2	0,011	9,295	2,338	56,78
	1	2	2	0,231	1	0,669	1,432	1	0,302	2,758	0,486	52,57
	3	2	2	0,705	1	0,850	0,143	3	0,113	3,037	-0,333	50,71
	4	2	2	0,641	1	0,852	0,217	3	0,100	3,351	-0,245	50,91
	6	2	2	0,335	1	0,775	0,928	1	0,179	3,587	0,253	52,04
	13	2	2	0,847	1	0,836	0,037	3	0,142	2,427	-0,517	50,29
	17	2	2	0,604	1	0,688	0,269	3	0,310	0,714	-1,230	48,67
	21	2	2	0,616	1	0,852	0,252	3	0,095	3,481	-,209	50,99

22	2	2	0,550	1	0,848	0,358	3	0,083	3,852	-0,113	51,21
23	2	2	0,398	1	0,587	0,713	3	0,412	0,270	-1,556	47,93
25	2	2	0,434	1	0,607	0,613	3	0,392	0,338	-1,494	48,07
30	2	2	0,735	1	0,737	0,115	3	0,259	1,052	-1,050	49,08
34	2	2	0,142	1	0,497	2,159	1	0,488	1,927	0,758	53,19
39	2	2	0,761	1	0,745	0,092	3	0,250	1,125	-1,014	49,16
41	2	2	0,398	1	0,587	0,713	3	0,412	0,270	-1,556	47,93
42	2	2	0,816	1	0,762	0,054	3	0,232	1,279	-0,944	49,32
18	3	3	0,878	1	0,637	0,024	2	0,362	2,304	-2,229	46,4
19	3	3	0,808	1	0,506	0,059	2	0,494	1,259	-1,833	47,3
20	3	3	0,885	1	0,635	0,021	2	0,365	2,277	-2,220	46,42
33	3	3	0,795	1	0,500	0,068	2	0,500	1,219	-1,815	47,34
36	3	3	0,358	1	0,833	0,845	2	0,167	5,213	-2,994	44,66
38	3	3	0,094	1	0,933	2,808	2	0,067	9,241	-3,751	42,94
7	3	2**	0,989	1	0,806	0,000	3	0,182	1,825	-0,724	
9	1	2**	0,262	1	0,708	1,259	1	0,258	3,012	0,411	
26	3	2**	0,297	1	0,521	1,087	3	0,479	0,103	-1,754	
28	3	2**	0,518	1	0,650	0,418	3	0,348	0,515	-1,358	
29	1	2**	0,215	1	0,644	1,539	1	0,329	2,614	0,530	
44	2	3**	0,592	1	0,748	0,288	2	0,252	3,612	-2,611	

Casewise Statistics to classify group membership (CIA).

Casewise Statistics - CIA

				Highest Group				Second Highest Group			Discriminant Scores	Angle measures
				P(D>d | G=g)								
	Case Number	Actual Group	Predicted Group	p	df	P(G=g | D=d)	Squared Mahalanobis Distance to Centroid	Group	P(G=g | D=d)	Squared Mahalanobis Distance to Centroid	Function 1	
Original	8	1	1	0,446	1	0,431	0,582	2	0,357	1,228	0,425	78,74
	10	1	1	0,619	1	0,887	0,248	2	0,069	5,611	1,686	83,61
	12	1	1	0,947	1	0,779	0,004	2	0,137	3,753	1,255	81,94
	15	1	1	0,197	1	0,971	1,663	2	0,017	9,988	2,478	86,66
	16	1	1	0,683	1	0,594	0,166	2	0,253	2,141	0,780	80,11
	27	1	1	0,365	1	0,944	0,821	2	0,034	7,711	2,094	85,18
	29	1	1	0,936	1	0,784	0,007	2	0,134	3,809	1,269	82
	31	1	1	0,877	1	0,701	0,024	2	0,186	2,944	1,033	81,09
	32	1	1	0,747	1	0,850	0,104	2	0,092	4,813	1,511	82,93
	37	1	1	0,257	1	0,962	1,286	2	0,023	9,030	2,322	86,06
	40	1	1	0,141	1	0,979	2,163	2	0,012	11,168	2,659	87,36
	43	1	1	0,714	1	0,613	0,134	2	0,241	2,264	0,822	80,27
	1	2	2	0,192	1	0,649	1,701	3	0,342	1,829	-1,987	69,43
	3	2	2	0,697	1	0,530	0,151	3	0,303	0,116	-0,294	75,97
	4	2	2	0,018	1	0,665	5,564	3	0,334	5,794	-3,042	65,36
	6	2	2	0,874	1	0,565	0,025	3	0,320	0,012	-0,524	75,08
	13	2	2	0,566	1	0,494	0,330	3	0,286	0,277	-0,108	76,68
	17	2	2	0,919	1	0,572	0,010	3	0,323	0,003	-0,581	74,86
	21	2	2	0,623	1	0,511	0,242	3	0,294	0,196	-0,191	76,36
	23	2	2	0,962	1	0,588	0,002	3	0,330	0,009	-0,730	74,28

	25	2	2	0,980	1	0,581	0,001	3	0,327	0,001	-0,658	74,56
	30	2	2	0,662	1	0,521	0,191	3	0,299	0,151	-0,246	76,15
	34	2	2	0,881	1	0,566	0,022	3	0,320	0,010	-0,533	75,04
	41	2	2	0,078	1	0,657	3,112	3	0,339	3,285	-2,447	67,66
	42	2	2	0,747	1	0,541	0,104	3	0,309	0,076	-0,360	75,71
	44	2	2	0,461	1	0,633	0,543	3	0,343	0,616	-1,419	71,62
	22	2	1**	0,886	1	0,705	0,021	2	0,183	2,984	1,045	
	39	2	1**	0,970	1	0,744	0,001	2	0,158	3,363	1,151	
	2	1	2**	0,782	1	0,548	0,076	3	0,312	0,052	-0,406	
	7	3	2**	0,752	1	0,611	0,100	3	0,338	0,132	-0,998	
	9	1	2**	0,541	1	0,627	0,373	3	0,342	0,435	-1,294	
	18	3	2**	0,359	1	0,639	0,841	3	0,343	0,931	-1,600	
	19	3	2**	0,902	1	0,569	0,015	3	0,322	0,006	-0,559	
	20	3	2**	0,895	1	0,596	0,017	3	0,333	0,032	-0,814	
	26	3	2**	0,600	1	0,505	0,274	3	0,291	0,226	-0,159	
	28	3	2**	0,596	1	0,503	0,281	3	0,290	0,232	-0,152	
	33	3	2**	0,948	1	0,590	0,004	3	0,331	0,013	-0,748	
	36	3	2**	0,756	1	0,543	0,096	3	0,310	0,069	-0,373	
	38	3	2**	0,707	1	0,532	0,142	3	0,304	0,108	-0,307	

Casewise Statistics to classify group membership (ACIA).

Casewise Statistics - ACIA

				Highest Group				Second Highest Group			Discriminant Scores	Angle measures
				P(D>d | G=g)			Squared Mahalanobis Distance to Centroid			Squared Mahalanobis Distance to Centroid		
	Case Number	Actual Group	Predicted Group	p	df	P(G=g | D=d)		Group	P(G=g | D=d)		Function 1	
Original	10	1	1	0,732	1	0,781	0,117	2	0,124	4,073	1,379	87,28
	12	1	1	0,944	1	0,647	0,005	2	0,205	2,575	0,965	85,57
	15	1	1	0,203	1	0,941	1,622	2	0,031	8,697	2,310	91,13
	16	1	1	0,531	1	0,429	0,393	2	0,344	1,099	0,409	83,27
	27	1	1	0,561	1	0,840	0,339	2	0,089	5,096	1,618	88,27
	29	1	1	0,986	1	0,667	0,000	2	0,193	2,748	1,018	85,79
	31	1	1	0,685	1	0,798	0,164	2	0,114	4,330	1,442	87,54
	32	1	1	0,712	1	0,788	0,136	2	0,119	4,181	1,405	87,39
	37	1	1	0,293	1	0,917	1,105	2	0,044	7,434	2,087	90,21
	40	1	1	0,125	1	0,960	2,348	2	0,021	10,290	2,568	92,2
	43	1	1	0,891	1	0,719	0,019	2	0,161	3,285	1,173	86,43
	1	2	2	0,103	1	0,695	2,652	3	0,295	3,214	-2,268	72,2
	3	2	2	0,972	1	0,560	0,001	3	0,312	0,017	-0,604	79,08
	4	2	2	0,006	1	0,738	7,618	3	0,260	8,552	-3,399	67,52
	6	2	2	0,595	1	0,470	0,282	3	0,284	0,135	-0,108	81,13
	13	2	2	0,521	1	0,445	0,412	1	0,281	1,068	0,003	81,59
	17	2	2	0,607	1	0,473	0,264	3	0,286	0,122	-0,125	81,06
	21	2	2	0,393	1	0,394	0,731	1	0,355	0,673	0,216	82,47
	23	2	2	0,626	1	0,622	0,237	3	0,319	0,424	-1,126	76,92
	30	2	2	0,601	1	0,471	0,274	3	0,285	0,129	-0,116	81,1

	34	2	2	0,947	1	0,574	0,004	3	0,315	0,053	-0,706	78,66
	41	2	2	0,157	1	0,685	2,004	3	0,301	2,496	-2,055	73,08
	42	2	2	0,619	1	0,477	0,247	3	0,287	0,111	-0,142	
												80,99
	44	2	2	0,703	1	0,612	0,145	3	0,319	0,297	-1,020	77,36
	22	2	1**	0,521	1	0,423	0,412	2	0,348	1,069	0,395	
	25	2	1**	0,477	1	0,396	0,506	2	0,366	0,929	0,324	
	26	3	1**	0,486	1	0,401	0,486	2	0,362	0,957	0,339	
	39	2	1**	0,594	1	0,466	0,284	2	0,320	1,306	0,503	
	2	1	2**	0,829	1	0,593	0,047	3	0,318	0,145	-0,856	
	7	3	2**	0,872	1	0,587	0,026	3	0,317	0,106	-0,800	
	8	1	2**	0,494	1	0,435	0,467	1	0,294	0,984	0,044	
	9	1	2**	0,675	1	0,616	0,176	3	0,319	0,341	-1,059	
	18	3	2**	0,385	1	0,653	0,755	3	0,314	1,068	-1,508	
	19	3	2**	0,836	1	0,592	0,043	3	0,318	0,137	-0,846	
	20	3	2**	0,530	1	0,448	0,394	1	0,276	1,098	-0,012	
	28	3	2**	0,654	1	0,487	0,201	3	0,291	0,081	-0,191	
	33	3	2**	0,564	1	0,460	0,333	3	0,280	0,170	-0,062	
	36	3	2**	0,750	1	0,513	0,101	3	0,300	0,024	-0,321	
	38	3	2**	0,814	1	0,596	0,056	3	0,318	0,160	-0,875	

Table 1. Repeated measurements on the same photographs by Rater 1.

CVA								CIA							
P1M1	**P1M2**	**Mean**	**SD**	**P2M1**	**P2M2**	**MEAN**	**SD**	**P1M1**	**P1M2**	**MEAN**	**SD**	**P2M1**	**P2M2**	**MEAN**	**SD**
53.69	53.47	53.58	0.16	52.28	52.52	52.40	0.17	74.05	73.85	73.95	0.14	72.32	71.89	72.11	0.30
48.65	48.85	48.75	0.14	49.97	49.67	49.82	0.21	73.47	73.44	73.46	0.02	73.19	73.3	73.25	0.08
52.05	52.03	52.04	0.01	53.21	53.72	53.47	0.36	75.21	74.94	75.08	0.19	73.77	74.09	73.93	0.23
50.64	50.6	50.62	0.03	53.57	53.74	53.66	0.12	82.75	83.05	82.90	0.21	78.99	78.49	78.74	0.35
50.76	50.65	50.71	0.08	46.74	46.53	46.64	0.15	76.03	75.9	75.97	0.09	75.55	75.37	75.46	0.13
51.28	51.22	51.25	0.04	52.6	52.54	52.57	0.04	66.69	66.47	66.58	0.16	69.18	69.68	69.43	0.35
42.97	42.88	42.93	0.06	47.54	47.05	47.30	0.35	66.01	67.3	66.66	0.91	75.28	74.6	74.94	0.48
59.15	59.22	59.19	0.05	59.68	59.86	59.77	0.13	83.63	83.58	83.61	0.04	82.15	82.11	82.13	0.03
48.5	48.57	48.54	0.05	46.49	46.3	46.40	0.13	67.32	66.46	66.89	0.61	70.38	71.47	70.93	0.77
47.94	47.13	47.54	0.57	47.58	47.41	47.50	0.12	71.65	72.45	72.05	0.57	72.05	72.05	72.05	0.00
61.41	61.51	61.46	0.07	60.78	60.71	60.75	0.05	75.3	75.76	75.53	0.33	79.95	79.25	79.60	0.49
55.66	55.57	55.62	0.06	58.96	58.76	58.86	0.14	80.85	80.27	80.56	0.41	81.83	82.05	81.94	0.16
47.62	47.73	47.68	0.08	48.09	47.76	47.93	0.23	71.74	71.48	71.61	0.18	74.77	73.79	74.28	0.69
50.6	49.98	50.29	0.44	49.97	50.19	50.08	0.16	77.15	76.21	76.68	0.66	76.05	77.01	76.53	0.68
48.66	48.67	48.67	0.01	49.19	48.77	48.98	0.30	74.94	74.77	74.86	0.12	74.77	74.56	74.67	0.15
54.26	54.18	54.22	0.06	56.22	56.52	56.37	0.21	86.46	86.86	86.66	0.28	86.13	86.15	86.14	0.01
50.94	51.03	50.99	0.06	49.22	49.29	49.26	0.05	76.4	76.32	76.36	0.06	76.41	76.04	76.23	0.26
55.41	55.53	55.47	0.08	54.95	54.92	54.94	0.02	83.8	83.35	83.58	0.32	85.88	84.88	85.38	0.71
46.42	46.42	46.42	0.00	46.94	46.93	46.94	0.01	73.51	74.4	73.96	0.63	78.13	78.2	78.17	0.05
50.18	50.19	50.19	0.01	51.3	50.51	50.91	0.56	66.35	66.76	66.56	0.29	65.64	65.08	65.36	0.40
52	51.32	51.66	0.48	51.21	51.21	51.21	0.00	79.72	79.38	79.55	0.24	81.15	81.11	81.13	0.03
55.8	56.16	55.98	0.25	55.6	55.78	55.69	0.13	79.89	80.33	80.11	0.31	79.27	78.85	79.06	0.30
Mean of SD			0.13				0.17				0.31				0.30

CA								ACIA							
P1M1	**P1M2**	**MEAN**	**SD**	**P2M1**	**P2M2**	**MEAN**	**SD**	**P1M 1**	**P1M 2**	**MEAN**	**SD**	**P2M 1**	**P2M 2**	**MEAN**	**SD**
214.96	215.6	215.28	0.45	218.15	216.44	217.30	1.21	80.69	80.61	80.65	0.06	77.61	76.78	77.20	0.59
217.99	216.34	217.17	1.17	216.04	215.71	215.88	0.23	81.71	81.25	81.48	0.33	77.78	78.76	78.27	0.69
207.98	207.3	207.64	0.48	207.95	208.83	208.39	0.62	81.23	81.03	81.13	0.14	78.39	78.87	78.63	0.34
201.88	200.07	200.98	1.28	204.52	204.54	204.53	0.01	86.92	86.94	86.93	0.01	81.95	81.57	81.76	0.27
204.41	204.59	204.50	0.13	204.32	204.91	204.62	0.42	78.99	79.16	79.08	0.12	78.75	78.58	78.67	0.12
211.84	211.37	211.61	0.33	208.08	210.85	209.47	1.96	70.91	70.14	70.53	0.54	71.25	73.14	72.20	1.34
198.07	201.86	199.97	2.68	198.5	198.2	198.35	0.21	69.08	69.93	69.51	0.60	78.21	77.94	78.08	0.19
199.69	199.2	199.45	0.35	201.8	201.47	201.64	0.23	87.44	87.12	87.28	0.23	85.47	85.73	85.60	0.18
202.85	203.88	203.37	0.73	211.41	212.23	211.82	0.58	71.17	70.39	70.78	0.55	74.71	75.96	75.34	0.88
214.04	214.8	214.42	0.54	215.23	213.07	214.15	1.53	74.24	74.96	74.60	0.51	76.5	76.23	76.37	0.19
204.98	205.43	205.21	0.32	200.06	200.02	200.04	0.03	78.01	78.06	78.04	0.04	83.08	82.5	82.79	0.41
202.95	201.68	202.32	0.90	197.13	197.75	197.44	0.44	84.01	83.31	83.66	0.49	85.29	85.85	85.57	0.40
194.01	195.73	194.87	1.22	197.53	197.68	197.61	0.11	73.65	73.65	73.65	0.00	76.71	77.12	76.92	0.29
215.11	214.82	214.97	0.21	203.08	205.85	204.47	1.96	82.04	81.13	81.59	0.64	81.62	82.38	82.00	0.54
215.51	216.64	216.08	0.80	210.46	210	210.23	0.33	81.43	80.69	81.06	0.52	79.82	79.7	79.76	0.08
201.57	202.78	202.18	0.86	199.98	200.31	200.15	0.23	91.15	91.11	91.13	0.03	89.65	90	89.83	0.25
203.99	202.92	203.46	0.76	208.15	208.71	208.43	0.40	82.57	82.36	82.47	0.15	81.92	81.43	81.68	0.35
202.41	201.47	201.94	0.66	201.39	201.13	201.26	0.18	86.97	86.4	86.69	0.40	88.79	88.21	88.50	0.41
216.27	217	216.64	0.52	210	210.62	210.31	0.44	81.49	81.56	81.53	0.05	81.31	85.34	83.33	2.85
207.36	205.96	206.66	0.99	205.07	205.1	205.09	0.02	68.55	68.83	68.69	0.20	67.97	67.07	67.52	0.64
194.49	196.59	195.54	1.48	191.53	191.57	191.55	0.03	81.82	81.97	81.90	0.11	83.07	83.35	83.21	0.20
196.55	196.39	196.47	0.11	191.49	191.94	191.72	0.32	83.31	83.22	83.27	0.06	81.21	81.52	81.37	0.22
Mean of SD			0.77				0.52				0.26				0.52

ACA							
P1M1	**P1M2**	**MEAN**	**SD**	**P2M1**	**P2M2**	**MEAN**	**SD**
209.23	209.32	209.28	0.06	215.41	213	214.21	1.70
209.56	208.71	209.14	0.60	212.19	211.33	211.76	0.61
199.92	199.28	199.60	0.45	204.29	204.58	204.44	0.21
197.78	197.13	197.46	0.46	202.16	202.82	202.49	0.47
203.06	202.48	202.77	0.41	200.5	201.84	201.17	0.95
207.67	209.12	208.40	1.03	206.54	209.11	207.83	1.82
195.53	199.58	197.56	2.86	194.33	194.97	194.65	0.45
195.08	195.26	195.17	0.13	197.63	197.18	197.41	0.32
199.21	198.28	198.75	0.66	208.85	207.59	208.22	0.89
214.94	216.04	215.49	0.78	213	212.96	212.98	0.03
203.57	204.95	204.26	0.98	197.34	197.35	197.35	0.01
200.06	199.71	199.89	0.25	193.15	193.83	193.49	0.48
192.18	193.16	192.67	0.69	194.97	195.12	195.05	0.11
212.19	213.22	212.71	0.73	199.7	200.19	199.95	0.35
208.46	209.95	209.21	1.05	205.61	205.87	205.74	0.18
195.96	196.81	196.39	0.60	195.11	194.95	195.03	0.11
195.31	193.93	194.62	0.98	201.86	202.41	202.14	0.39
198.3	196.88	197.59	1.00	197.84	198.21	198.03	0.26
208.96	210.46	209.71	1.06	201.29	201.52	201.41	0.16
207.76	206.29	207.03	1.04	206.3	205.22	205.76	0.76
192.98	193	192.99	0.01	189.11	191.31	190.21	1.56
192.99	192.99	192.99	0.00	189.37	188.43	188.90	0.66
Mean of SD			0.72				0.57

*CVA: craniovertebral angle; CIA: cervical inclination angle; CA: cervical angle; ACIA: adapted cervical inclination angle; ACA: adapted cervical angle; P1: picture 1; P2: picture 2; M1: measurement 1; M2: measurement 2; SD: standard deviation.

Table 2. Repeated measurements on the photographs taken a week apart by Rater 1.

CVA				CIA				CA			
P1	**P2**	**Mean**	**SD**	**P1**	**P2**	**Mean**	**SD**	**P1**	**P2**	**Mean**	**SD**
53.58	52.40	52.99	0.83	73.95	72.11	73.03	1.30	215.28	217.30	216.29	1.43
48.75	49.82	49.29	0.76	73.46	73.25	73.36	0.15	217.17	215.88	216.53	0.91
52.04	53.47	52.76	1.01	75.08	73.93	74.51	0.81	207.64	208.39	208.02	0.53
50.62	53.66	52.14	2.15	82.90	78.74	80.82	2.94	200.98	204.53	202.76	2.51
50.71	46.64	48.68	2.88	75.97	75.46	75.72	0.36	204.50	204.62	204.56	0.08
51.25	52.57	51.91	0.93	66.58	69.43	68.01	2.02	211.61	209.47	210.54	1.51
42.93	47.30	45.12	3.09	66.66	74.94	70.80	5.85	199.97	198.35	199.16	1.15
59.19	59.77	59.48	0.41	83.61	82.13	82.87	1.05	199.45	201.64	200.55	1.55
48.54	46.40	47.47	1.51	66.89	70.93	68.91	2.86	203.37	211.82	207.60	5.98
47.54	47.50	47.52	0.03	72.05	72.05	72.05	0.00	214.42	214.15	214.29	0.19
61.46	60.75	61.11	0.50	75.53	79.60	77.57	2.88	205.21	200.04	202.63	3.66
55.62	58.86	57.24	2.29	80.56	81.94	81.25	0.98	202.32	197.44	199.88	3.45
47.68	47.93	47.81	0.18	71.61	74.28	72.95	1.89	194.87	197.61	196.24	1.94
50.29	50.08	50.19	0.15	76.68	76.53	76.61	0.11	214.97	204.47	209.72	7.42
48.67	48.98	48.83	0.22	74.86	74.67	74.77	0.13	216.08	210.23	213.16	4.14
54.22	56.37	55.30	1.52	86.66	86.14	86.40	0.37	202.18	200.15	201.17	1.44
50.99	49.26	50.13	1.22	76.36	76.23	76.30	0.09	203.46	208.43	205.95	3.51
55.47	54.94	55.21	0.37	83.58	85.38	84.48	1.27	201.94	201.26	201.60	0.48
46.42	46.94	46.68	0.37	73.96	78.17	76.07	2.98	216.64	210.31	213.48	4.48
50.19	50.91	50.55	0.51	66.56	65.36	65.96	0.85	206.66	205.09	205.88	1.11
51.66	51.21	51.44	0.32	79.55	81.13	80.34	1.12	195.54	191.55	193.55	2.82
55.98	55.69	55.84	0.21	80.11	79.06	79.59	0.74	196.47	191.72	194.10	3.36
Mean of SD			0.98				1.40				2.44

ACIA				ACA			
P1	**P2**	**Mean**	**SD**	**P1**	**P2**	**Mean**	**SD**
80.65	77.20	78.93	2.44	209.28	214.21	211.75	3.49
81.48	78.27	79.88	2.27	209.14	211.76	210.45	1.85
81.13	78.63	79.88	1.77	199.60	204.44	202.02	3.42
86.93	81.76	84.35	3.66	197.46	202.49	199.98	3.56
79.08	78.67	78.88	0.29	202.77	201.17	201.97	1.13
70.53	72.20	71.37	1.18	208.40	207.83	208.12	0.40
69.51	78.08	73.80	6.06	197.56	194.65	196.11	2.06
87.28	85.60	86.44	1.19	195.17	197.41	196.29	1.58
70.78	75.34	73.06	3.22	198.75	208.22	203.49	6.70
74.60	76.37	75.49	1.25	215.49	212.98	214.24	1.77
78.04	82.79	80.42	3.36	204.26	197.35	200.81	4.89
83.66	85.57	84.62	1.35	199.89	193.49	196.69	4.53
73.65	76.92	75.29	2.31	192.67	195.05	193.86	1.68
81.59	82.00	81.80	0.29	212.71	199.95	206.33	9.02
81.06	79.76	80.41	0.92	209.21	205.74	207.48	2.45
91.13	89.83	90.48	0.92	196.39	195.03	195.71	0.96
82.47	81.68	82.08	0.56	194.62	202.14	198.38	5.32
86.69	88.50	87.60	1.28	197.59	198.03	197.81	0.31
81.53	83.33	82.43	1.27	209.71	201.41	205.56	5.87
68.69	67.52	68.11	0.83	207.03	205.76	206.40	0.90
81.90	83.21	82.56	0.93	192.99	190.21	191.60	1.97
83.27	81.37	82.32	1.34	192.99	188.90	190.95	2.89
Mean of SD			1.76				3.03

*CVA: craniovertebral angle; CIA: cervical inclination angle; CA: cervical angle; ACIA: adapted cervical inclination angle; ACA: adapted cervical angle; P1: picture 1; P2: picture 2; SD: standard deviation.

Table 3. Repeated measurements on the same radiographs by Rater 1.

NSL/OPT				NSL/CVT				OPT/h.				CVT/h.			
M1	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**
94.13	93.93	94.03	0.14	97.36	97.09	97.23	0.19	95.33	95.15	95.24	0.13	91.12	90.91	91.02	0.15
104.69	105.08	104.89	0.28	109.22	109.65	109.44	0.30	86.01	86.33	86.17	0.23	82.02	82.72	82.37	0.49
86.46	86.49	86.48	0.02	94.78	93.87	94.33	0.64	94.02	94.61	94.32	0.42	84.94	85.63	85.29	0.49
108.07	109.43	108.75	0.96	111.77	111.58	111.68	0.13	81.85	82.04	81.95	0.13	79.65	79.77	79.71	0.08
99.8	99.06	99.43	0.52	105.35	105.43	105.39	0.06	89.16	89.69	89.43	0.37	82.11	81.75	81.93	0.25
101.55	101.48	101.52	0.05	105.89	106.66	106.28	0.54	92.4	93.02	92.71	0.44	89.62	89.22	89.42	0.28
112.53	111.22	111.88	0.93	113.5	113.74	113.62	0.17	75.38	76.69	76.04	0.93	72.88	72.75	72.82	0.09
92.32	93.11	92.72	0.56	97.08	96.79	96.94	0.21	99.97	99.26	99.62	0.50	93.07	93.21	93.14	0.10
93.79	93.61	93.70	0.13	100.83	100.72	100.78	0.08	89.48	89.5	89.49	0.01	79.66	79.71	79.69	0.04
97.16	96.93	97.05	0.16	106.55	107.34	106.95	0.56	93.44	93.87	93.66	0.30	83.03	82.98	83.01	0.04
95.19	96.82	96.01	1.15	100.42	100.84	100.63	0.30	89.48	87.95	88.72	1.08	85.92	85.29	85.61	0.45
92.92	92.92	92.92	0.00	93.44	93.46	93.45	0.01	92.84	92.73	92.79	0.08	88.72	89.15	88.94	0.30
106.15	106.19	106.17	0.03	113.6	112.78	113.19	0.58	83.82	83.4	83.61	0.30	76.73	76.73	76.73	0.00
98.74	98.33	98.54	0.29	99.85	100.52	100.19	0.47	89.61	90.13	89.87	0.37	86.87	87.09	86.98	0.16
84.3	85.01	84.66	0.50	92.19	92.06	92.13	0.09	94.09	94.09	94.09	0.00	89.06	89.28	89.17	0.16
88.72	89.49	89.11	0.54	90.59	91.48	91.04	0.63	94.72	93.74	94.23	0.69	91.51	90.74	91.13	0.54
94.68	94.36	94.52	0.23	97.59	97.77	97.68	0.13	91.86	91.83	91.85	0.02	88.45	88.44	88.45	0.01
93.16	93.38	93.27	0.16	100.75	101.23	100.99	0.34	91.62	91.02	91.32	0.42	85.8	85.58	85.69	0.16
94.54	94.21	94.38	0.23	100.96	101.59	101.28	0.45	94.87	95.16	95.02	0.21	88.84	88.17	88.51	0.47
99.78	100.01	99.90	0.16	112.11	110.54	111.33	1.11	103.99	103.63	103.81	0.25	89.51	90.24	89.88	0.52
105.02	104.12	104.57	0.64	108.3	108.37	108.34	0.05	84.14	84.99	84.57	0.60	80.25	80.17	80.21	0.06
109.89	109.7	109.80	0.13	111.17	111.48	111.33	0.22	77.83	77.41	77.62	0.30	77.31	76.04	76.68	0.90
Mean of SD			0.36				0.33				0.35				0.26

CIAr				CAr				ARA				ACIAr			
M1	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**
84.7	85.72	85.21	0.72	186.01	187.68	186.85	1.18	19.07	21.03	20.05	1.39	89.6	90	89.80	0.28
78.54	78.54	78.54	0.00	188.88	190.72	189.80	1.30	16.68	18.3	17.49	1.15	79.02	78.82	78.92	0.14
79.63	79.77	79.70	0.10	191.66	191.19	191.43	0.33	21.6	21.64	21.62	0.03	80.68	81.04	80.86	0.25
80.43	80.78	80.61	0.25	182.65	184.14	183.40	1.05	3.74	3.75	3.745	0.01	80.75	81.24	81.00	0.35
78.22	78.51	78.37	0.21	183.4	183.61	183.51	0.15	12.84	10.07	11.455	1.96	79.29	79.58	79.44	0.21
81.63	81.73	81.68	0.07	190.19	190.36	190.28	0.12	15.63	14.13	14.88	1.06	85.25	85.46	85.36	0.15
77.06	77.03	77.05	0.02	181.12	181.21	181.17	0.06	-5.56	-5.35	-5.455	0.15	75.08	74.83	74.96	0.18
88.79	88.92	88.86	0.09	184.87	185.21	185.04	0.24	12.97	13.73	13.35	0.54	91.64	91.28	91.46	0.25
71.62	71.88	71.75	0.18	185.35	186.17	185.76	0.58	7.21	8.8	8.005	1.12	73.98	74.24	74.11	0.18
84.05	83.89	83.97	0.11	183.51	183.63	183.57	0.08	7.14	8.9	8.02	1.24	81.97	82.36	82.17	0.28
83.17	83.85	83.51	0.48	185.98	186.55	186.27	0.40	5.61	5.72	5.665	0.08	83.98	84.02	84.00	0.03
86.6	87.23	86.92	0.45	186.42	186.76	186.59	0.24	16.56	13.92	15.24	1.87	86.95	87.17	87.06	0.16
78.69	78.4	78.55	0.21	180.72	181	180.86	0.20	3.89	3.9	3.895	0.01	77.14	77.01	77.08	0.09
79.56	79.88	79.72	0.23	191.12	190.48	190.80	0.45	13.41	14.52	13.965	0.78	81.28	81.51	81.40	0.16
80.17	79.98	80.08	0.13	193.99	193.3	193.65	0.49	21.33	23.45	22.39	1.50	83.99	84.81	84.40	0.58
89.46	89.64	89.55	0.13	183.36	183.66	183.51	0.21	5.91	5.01	5.46	0.64	91.14	91.13	91.14	0.01
80.95	80.81	80.88	0.10	191.33	191.4	191.37	0.05	28.65	28.15	28.4	0.35	86.3	86.5	86.40	0.14
83.29	83.45	83.37	0.11	181.34	182.29	181.82	0.67	9	7.92	8.46	0.76	82.85	83.81	83.33	0.68
80.62	80.3	80.46	0.23	196.06	195.71	195.89	0.25	29.08	30.27	29.675	0.84	83.55	83.57	83.56	0.01
77.65	77.83	77.74	0.13	201.54	201.44	201.49	0.07	29.13	30.37	29.75	0.88	79.25	78.91	79.08	0.24
79.57	79.54	79.56	0.02	180.98	181.12	181.05	0.10	-2.21	-3.13	-2.67	0.65	79.8	80.03	79.92	0.16
80.1	80.1	80.10	0.00	176.3	176.59	176.45	0.21	-16.42	-18.46	-17.44	1.44	79.51	79.34	79.43	0.12
Mean of SD			0.18				0.38				0.84				0.21

ACAr				AmspC7/h.				spCIA				spCA			
M1	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**
184.54	186.39	185.47	1.31	62.32	61.45	61.89	0.62	69.81	70.86	70.34	0.74	211.76	213.71	212.74	1.38
187.24	188.55	187.90	0.93	62.55	62.27	62.41	0.20	67.13	67.93	67.53	0.57	218.71	217.61	218.16	0.78
187.3	186.29	186.80	0.71	68.41	68.26	68.34	0.11	77.25	77.52	77.39	0.19	221.57	224.73	223.15	2.23
180.77	184.37	182.57	2.55	60.27	60.22	60.25	0.04	72.51	72.43	72.47	0.06	207.96	206.09	207.03	1.32
180.14	180.78	180.46	0.45	65.63	65.20	65.42	0.30	75.92	75.44	75.68	0.34	213.78	209.67	211.73	2.91
182.65	182.55	182.60	0.07	61.70	61.39	61.55	0.22	74.95	74.76	74.86	0.13	217.56	217.26	217.41	0.21
181.46	182.4	181.93	0.66	66.85	66.64	66.75	0.15	73.58	74.18	73.88	0.42	215.42	216.07	215.75	0.46
182.03	182.04	182.04	0.01	67.27	67.13	67.20	0.10	73.82	75.55	74.69	1.22	216.42	216.49	216.46	0.05
193.52	193.73	193.63	0.15	58.71	58.51	58.61	0.14	66.60	67.26	66.93	0.47	213.81	215.66	214.74	1.31
187.82	187.1	187.46	0.51	61.62	61.64	61.63	0.01	65.73	65.28	65.51	0.32	204.87	208.53	206.70	2.59
180.49	179.41	179.95	0.76	.	.			.	.			.	.		
182.86	184.32	183.59	1.03	57.89	58.02	57.96	0.09	64.76	64.32	64.54	0.31	222.11	223.04	222.58	0.66
177.81	177.74	177.78	0.05	69.54	69.68	69.61	0.10	77.09	77.55	77.32	0.33	206.59	205.99	206.29	0.42
187.38	187	187.19	0.27	53.47	53.11	53.29	0.25	63.87	63.36	63.62	0.36	195.05	195.37	195.21	0.23
187.25	187.31	187.28	0.04	66.88	66.12	66.50	0.54	78.41	78.40	78.41	0.01	199.72	203.19	201.46	2.45
181.73	181.62	181.68	0.08	70.39	70.14	70.27	0.18	80.19	80.40	80.30	0.15	218.36	218.51	218.44	0.11
190.27	189.28	189.78	0.70	64.52	64.29	64.41	0.16	68.65	68.76	68.71	0.08	212.91	213.18	213.05	0.19
180.84	181.29	181.07	0.32	64.07	64.17	64.12	0.07	72.27	72.51	72.39	0.17	211.76	209.56	210.66	1.56
192.47	191.26	191.87	0.86	67.40	67.25	67.33	0.11	78.31	79.64	78.98	0.94	220.83	219.53	220.18	0.92
199.29	198.81	199.05	0.34	63.73	63.29	63.51	0.31	74.30	73.30	73.80	0.71	210.27	212.79	211.53	1.78
177.09	178.44	177.77	0.95	67.06	66.89	66.98	0.12	78.83	78.66	78.75	0.12	213.10	212.32	212.71	0.55
177.28	177.29	177.29	0.01	65.59	65.31	65.45	0.20	71.80	71.80	71.80	0.00	204.39	205.88	205.14	1.05
Mean of SD			0.58				0.19				0.36				1.10

spACIA				spACA			
M1	**M2**	**Mean**	**SD**	**M1**	**M2**	**Mean**	**SD**
75.08	76.62	75.85	1.09	208.47	208.54	208.51	0.05
77.50	77.76	77.63	0.18	208.60	206.28	207.44	1.64
82.84	83.69	83.27	0.60	216.10	221.81	218.96	4.04
79.25	78.38	78.82	0.62	198.67	198.05	198.36	0.44
80.22	79.46	79.84	0.54	211.31	207.35	209.33	2.80
87.20	87.16	87.18	0.03	202.10	201.42	201.76	0.48
83.56	84.38	83.97	0.58	204.23	203.90	204.07	0.23
79.19	80.92	80.06	1.22	212.45	212.56	212.51	0.08
77.26	77.68	77.47	0.30	200.59	203.09	201.84	1.77
69.16	70.14	69.65	0.69	202.93	205.82	204.38	2.04
.	.			.	.		
69.12	68.76	68.94	0.25	224.73	224.54	224.64	0.13
80.16	80.72	80.44	0.40	206.51	205.62	206.07	0.63
63.63	63.36	63.50	0.19	198.35	198.44	198.40	0.06
82.04	82.82	82.43	0.55	196.66	199.50	198.08	2.01
92.43	92.92	92.68	0.35	201.09	200.37	200.73	0.51
78.08	77.89	77.99	0.13	202.03	201.84	201.94	0.13
78.53	78.59	78.56	0.04	206.44	204.48	205.46	1.39
92.33	93.18	92.76	0.60	199.50	197.94	198.72	1.10
79.35	78.88	79.12	0.33	206.15	208.07	207.11	1.36
86.58	87.47	87.03	0.63	204.43	200.74	202.59	2.61
74.73	75.54	75.14	0.57	202.58	202.16	202.37	0.30
Mean of SD			0.47				1.13

*NSL= nasion-sella line; OPT= odontoid process tangent; CVT= cervical vertebra tangent; CIA= cervical inclination angle; ACIA= adapted cervical inclination angle; ARA= absolute rotation angle; CA= cervical angle; ACA= adapted cervical angle; r=measured in radiographs; Am=auditory meatus; h= horizontal; sp=spinous process; M1: measurement 1; M2: measurement 2; SD: standard deviation.

Table 4. Repeated measurements on the radiographs taken a week apart by Rater 1.

NSL/OPT				NSL/CVT				OPT/h.				CVT/h.			
R1	**R2**	**Mean**	**SD**	**R1**	**R2**	**Mean**	**SD**	**R1**	**R2**	**Mean**	**SD**	**R1**	**R2**	**Mean**	**SD**
92.94	94.03	93.49	0.77	97.23	99.50	98.37	1.61	95.48	95.24	95.36	0.17	91.02	89.67	90.35	0.95
104.21	104.89	104.55	0.48	109.44	108.41	108.93	0.73	87.49	86.17	86.83	0.93	82.37	82.94	82.66	0.40
86.76	86.48	86.62	0.20	94.33	94.52	94.43	0.13	92.95	94.32	93.64	0.97	85.29	86.27	85.78	0.69
109.96	108.75	109.36	0.86	111.68	110.81	111.25	0.62	81.47	81.95	81.71	0.34	79.71	79.83	79.77	0.08
96.88	99.43	98.16	1.80	105.39	107.25	106.32	1.32	90.45	89.43	89.94	0.72	81.93	81.87	81.90	0.04
97.97	101.52	99.75	2.51	106.28	109.03	107.66	1.94	97.45	92.71	95.08	3.35	89.42	85.13	87.28	3.03
111.58	111.88	111.73	0.21	113.62	113.79	113.71	0.12	74.89	76.04	75.47	0.81	72.82	74.18	73.50	0.96
89.70	92.72	91.21	2.14	96.94	99.23	98.09	1.62	100.49	99.62	100.06	0.62	93.14	93.36	93.25	0.16
90.71	93.70	92.21	2.11	100.78	104.74	102.76	2.80	89.76	89.49	89.63	0.19	79.69	78.50	79.10	0.84
99.57	97.05	98.31	1.78	106.95	104.06	105.51	2.04	90.24	93.66	91.95	2.42	83.01	86.73	84.87	2.63
95.67	96.01	95.84	0.24	100.63	100.53	100.58	0.07	90.45	88.72	89.59	1.22	85.61	84.11	84.86	1.06
90.43	92.92	91.68	1.76	93.45	95.85	94.65	1.70	92.04	92.79	92.42	0.53	88.94	90.00	89.47	0.75
106.60	106.17	106.39	0.30	113.19	112.30	112.75	0.63	83.14	83.61	83.38	0.33	76.73	77.55	77.14	0.58
92.76	98.54	95.65	4.09	100.19	104.62	102.41	3.13	94.33	89.87	92.10	3.15	86.98	83.92	85.45	2.16
84.86	84.66	84.76	0.14	92.13	92.01	92.07	0.08	96.11	94.09	95.10	1.43	89.17	86.78	87.98	1.69
86.43	89.11	87.77	1.90	91.04	91.61	91.33	0.40	95.72	94.23	94.98	1.05	91.13	90.38	90.76	0.53
94.94	94.52	94.73	0.30	97.68	98.01	97.85	0.23	90.91	91.85	91.38	0.66	88.45	87.98	88.22	0.33
93.56	93.27	93.42	0.21	100.99	100.59	100.79	0.28	93.10	91.32	92.21	1.26	85.69	83.95	84.82	1.23
96.34	94.38	95.36	1.39	101.28	99.95	100.62	0.94	93.18	95.02	94.10	1.30	88.51	89.68	89.10	0.83
98.82	99.90	99.36	0.76	111.33	112.93	112.13	1.13	102.41	103.81	103.11	0.99	89.88	90.84	90.36	0.68
103.42	104.57	104.00	0.81	108.34	109.64	108.99	0.92	85.20	84.57	84.89	0.45	80.21	79.38	79.80	0.59
109.41	109.80	109.61	0.28	111.33	111.33	111.33	0.00	79.07	77.62	78.35	1.03	76.68	76.26	76.47	0.30
Mean of SD			1.14				1.02				1.09				0.93

CIAr				CAr				ARA				ACIAr			
R1	**R2**	**Mean**	**SD**	**R1**	**R2**	**Mean**	**SD**	**R1**	**R2**	**Mean**	**SD**	**R1**	**R2**	**Mean**	**SD**
87.83	85.21	86.52	1.85	186.85	187.79	187.32	0.66	17.85	20.05	18.95	1.56	89.80	87.30	88.55	1.77
77.21	78.54	77.88	0.94	189.80	189.94	189.87	0.10	19.205	17.49	18.35	1.21	78.92	80.15	79.54	0.87
78.25	79.70	78.98	1.03	191.43	189.29	190.36	1.51	23.74	21.62	22.68	1.50	80.86	81.86	81.36	0.71
79.91	80.61	80.26	0.49	183.40	183.43	183.42	0.02	4.035	3.745	3.89	0.21	81.00	81.70	81.35	0.49
78.48	78.37	78.43	0.08	183.51	182.92	183.22	0.42	12.52	11.455	11.99	0.75	79.44	79.66	79.55	0.16
82.63	81.68	82.16	0.67	190.28	185.14	187.71	3.63	20.23	14.88	17.56	3.78	85.36	81.71	83.54	2.58
74.63	77.05	75.84	1.71	181.17	181.73	181.45	0.40	-4.49	-5.455	-4.97	0.68	74.96	77.08	76.02	1.50
89.46	88.86	89.16	0.42	185.04	185.60	185.32	0.40	13.94	13.35	13.65	0.42	91.46	91.13	91.30	0.23
74.67	71.75	73.21	2.06	185.76	190.16	187.96	3.11	7.57	8.005	7.79	0.31	74.11	71.28	72.70	2.00
82.57	83.97	83.27	0.99	183.57	188.08	185.83	3.19	4.345	8.02	6.18	2.60	82.17	84.69	83.43	1.78
82.76	83.51	83.14	0.53	186.27	181.22	183.75	3.57	10.645	5.665	8.16	3.52	84.00	84.20	84.10	0.14
84.93	86.92	85.93	1.41	186.59	185.94	186.27	0.46	16.54	15.24	15.89	0.92	87.06	88.95	88.01	1.34
76.80	78.55	77.68	1.24	180.86	177.97	179.42	2.04	4.62	3.895	4.26	0.51	77.08	78.59	77.84	1.07
79.35	79.72	79.54	0.26	190.80	187.06	188.93	2.64	21.4	13.965	17.68	5.26	81.40	80.59	81.00	0.57
80.73	80.08	80.41	0.46	193.65	190.31	191.98	2.36	23.545	22.39	22.97	0.82	84.40	82.59	83.50	1.28
90.09	89.55	89.82	0.38	183.51	183.56	183.54	0.04	7.47	5.46	6.47	1.42	91.14	90.57	90.86	0.40
83.16	80.88	82.02	1.61	191.37	194.15	192.76	1.97	24.415	28.4	26.41	2.82	86.40	84.29	85.35	1.49
84.03	83.37	83.70	0.47	181.82	180.22	181.02	1.13	7.935	8.46	8.20	0.37	83.33	83.00	83.17	0.23
79.96	80.46	80.21	0.35	195.89	195.59	195.74	0.21	32.065	29.675	30.87	1.69	83.56	83.76	83.66	0.14
76.26	77.74	77.00	1.05	201.49	200.10	200.80	0.98	29.715	29.75	29.73	0.02	79.08	80.78	79.93	1.20
79.68	79.56	79.62	0.08	181.05	177.91	179.48	2.22	-1.385	-2.67	-2.03	0.91	79.92	79.39	79.66	0.37
80.51	80.10	80.31	0.29	176.45	175.21	175.83	0.88	-13.92	-17.44	-15.68	2.49	79.43	78.53	78.98	0.64
Mean of SD			0.84				1.45				1.53				0.95

ACAr			
R1	**R2**	**Mean**	**SD**
184.23	185.47	184.85	0.88
188.57	187.90	188.24	0.47
188.44	186.80	187.62	1.16
181.94	182.57	182.26	0.45
182.37	180.46	181.42	1.35
186.97	182.60	184.79	3.09
180.82	181.93	181.38	0.78
182.04	182.04	182.04	0.00
187.82	193.63	190.73	4.11
184.81	187.46	186.14	1.87
184.57	179.95	182.26	3.27
183.84	183.59	183.72	0.18
179.88	177.78	178.83	1.48
188.78	187.19	187.99	1.12
189.17	187.28	188.23	1.34
181.83	181.68	181.76	0.11
187.12	189.78	188.45	1.88
183.38	181.07	182.23	1.63
191.51	191.87	191.69	0.25
199.92	199.05	199.49	0.62
180.72	177.77	179.25	2.09
178.33	177.29	177.81	0.74
Mean of SD			1.31

*NSL= nasion-sella line; OPT= odontoid process tangent; CVT= cervical vertebra tangent; CIA= cervical inclination angle; ACIA= adapted cervical inclination angle; ARA= absolute rotation angle; CA= cervical angle; ACA= adapted cervical angle; r=measured in radiographs; h= horizontal; R1: radiograph 1; R2: radiograph 2; SD: standard deviation.

Table 5. Angle measurements on the photographs by 2 raters.

CVA								CIA							
P1-1	**P1-2**	**Mean**	**SD**	**P2-1**	**P2-2**	**MEAN**	**SD**	**P1-1**	**P1-2**	**MEAN**	**SD**	**P2-1**	**P2-2**	**MEAN**	**SD**
53.58	53.24	53.41	0.24	52.4	51.98	52.19	0.30	73.95	75.93	74.94	1.40	72.11	73.86	72.99	1.24
48.75	47.58	48.17	0.83	49.82	49.38	49.60	0.31	73.46	74.86	74.16	0.99	73.25	75.82	74.54	1.82
52.04	52.04	52.04	0.00	53.47	53.57	53.52	0.07	75.08	75.72	75.40	0.45	73.93	74.15	74.04	0.16
50.62	49.61	50.12	0.71	53.66	53.12	53.39	0.38	82.9	84.1	83.50	0.85	78.74	79.53	79.14	0.56
50.71	49.43	50.07	0.91	46.64	45.86	46.25	0.55	75.97	75.28	75.63	0.49	75.46	75.57	75.52	0.08
51.25	50.68	50.97	0.40	52.57	51.9	52.24	0.47	66.58	67.72	67.15	0.81	69.43	72.47	70.95	2.15
42.93	42.26	42.60	0.47	47.3	46.69	47.00	0.43	66.66	66.52	66.59	0.10	74.94	73.73	74.34	0.86
59.19	58.19	58.69	0.71	59.77	59.4	59.59	0.26	83.61	85.4	84.51	1.27	82.13	80.4	81.27	1.22
48.54	48.46	48.50	0.06	46.4	45.84	46.12	0.40	66.89	68.94	67.92	1.45	70.93	72.12	71.53	0.84
47.54	46.71	47.13	0.59	47.5	47.05	47.28	0.32	72.05	74.94	73.50	2.04	72.05	74.82	73.44	1.96
61.46	60.97	61.22	0.35	60.75	60.31	60.53	0.31	75.53	77.36	76.45	1.29	79.6	81.38	80.49	1.26
55.62	55.13	55.38	0.35	58.86	58.63	58.75	0.16	80.56	82.24	81.40	1.19	81.94	83.87	82.91	1.36
47.68	46.93	47.31	0.53	47.93	47.02	47.48	0.64	71.61	71.7	71.66	0.06	74.28	74.21	74.25	0.05
50.29	49.7	50.00	0.42	50.08	49.19	49.64	0.63	76.68	77.56	77.12	0.62	76.53	77.93	77.23	0.99
48.67	47.99	48.33	0.48	48.98	48.08	48.53	0.64	74.86	75.4	75.13	0.38	74.67	74.48	74.58	0.13
54.22	53.18	53.70	0.74	56.37	56.27	56.32	0.07	86.66	87.28	86.97	0.44	86.14	88.05	87.10	1.35
50.99	50.54	50.77	0.32	49.26	48.4	48.83	0.61	76.36	76.58	76.47	0.16	76.22	77.33	76.78	0.78
55.47	54.89	55.18	0.41	54.94	54.55	54.75	0.28	83.58	83.9	83.74	0.23	85.38	86.37	85.88	0.70
46.42	46.03	46.23	0.28	46.94	46.01	46.48	0.66	73.96	75.31	74.64	0.95	78.17	79.34	78.76	0.83
50.19	49.8	50.00	0.28	50.91	50.44	50.68	0.33	66.56	67.47	67.02	0.64	65.36	65.99	65.68	0.45
51.66	50.81	51.24	0.60	51.21	50.38	50.80	0.59	79.55	79.41	79.48	0.10	81.13	81.19	81.16	0.04
55.98	55.57	55.78	0.29	55.69	54.86	55.28	0.59	80.11	80.5	80.31	0.28	79.06	79.62	79.34	0.40
Mean of SD			0.45				0.41				0.74				0.87

CA								ACIA							
P1-1	**P1-2**	**Mean**	**SD**	**P2-1**	**P2-2**	**MEAN**	**SD**	**P1-1**	**P1-2**	**MEAN**	**SD**	**P2-1**	**P2-2**	**MEAN**	**SD**
215.28	217.85	216.57	1.82	217.3	219.98	218.64	1.90	80.65	82.79	81.72	1.51	77.2	79.8	78.50	1.84
217.17	220.23	218.70	2.16	215.88	222.04	218.96	4.36	81.48	83.92	82.70	1.73	78.27	81.05	79.66	1.97
207.64	210.71	209.18	2.17	208.39	212.12	210.26	2.64	81.13	81.73	81.43	0.42	78.63	79.08	78.86	0.32
200.98	200.47	200.73	0.36	204.53	204.71	204.62	0.13	86.93	88	87.47	0.76	81.76	81.94	81.85	0.13
204.5	203.13	203.82	0.97	204.62	205.71	205.17	0.77	79.08	77.6	78.34	1.05	78.67	78.19	78.43	0.34
211.61	215.73	213.67	2.91	209.47	217.06	213.27	5.37	70.53	72.23	71.38	1.20	72.2	76.74	74.47	3.21
199.97	203.87	201.92	2.76	198.35	193.93	196.14	3.13	69.51	70.26	69.89	0.53	78.08	76.45	77.27	1.15
199.45	205.62	202.54	4.36	201.64	199.31	200.48	1.65	87.28	90.15	88.72	2.03	85.6	84.09	84.85	1.07
203.37	205.3	204.34	1.36	211.82	212.38	212.10	0.40	70.78	73.42	72.10	1.87	75.34	76.51	75.93	0.83
214.42	220.93	217.68	4.60	214.15	223.89	219.02	6.89	74.6	78.13	76.37	2.50	76.37	79.59	77.98	2.28
205.21	210.86	208.04	4.00	200.04	201.59	200.82	1.10	78.04	80.56	79.30	1.78	82.79	84.47	83.63	1.19
202.32	205.65	203.99	2.35	197.44	199.47	198.46	1.44	83.66	85.69	84.68	1.44	85.57	86.83	86.20	0.89
194.87	195.56	195.22	0.49	197.61	195.9	196.76	1.21	73.65	74.3	73.98	0.46	76.92	77.38	77.15	0.33
214.97	219.47	217.22	3.18	204.47	208.7	206.59	2.99	81.59	83.06	82.33	1.04	82	83.36	82.68	0.96
216.08	215.8	215.94	0.20	210.23	208.23	209.23	1.41	81.06	82.15	81.61	0.77	79.76	79.52	79.64	0.17
202.18	201.97	202.08	0.15	200.15	200.04	200.10	0.08	91.13	92.47	91.80	0.95	89.83	91.59	90.71	1.24
203.46	204.42	203.94	0.68	208.43	208.99	208.71	0.40	82.47	81.67	82.07	0.57	81.68	83.34	82.51	1.17
201.94	201.93	201.94	0.01	201.26	203.7	202.48	1.73	86.69	86.53	86.61	0.11	88.5	89.55	89.03	0.74
216.64	219.6	218.12	2.09	210.31	209.77	210.04	0.38	81.53	83.4	82.47	1.32	83.33	86.39	84.86	2.16
206.66	209.61	208.14	2.09	205.09	200.69	202.89	3.11	68.69	70.5	69.60	1.28	67.52	68.99	68.26	1.04
195.54	198.21	196.88	1.89	191.55	191.08	191.32	0.33	81.9	81.94	81.92	0.03	83.21	83.38	83.30	0.12
196.47	197.34	196.91	0.62	191.72	195.35	193.54	2.57	83.27	83.6	83.44	0.23	81.37	82.28	81.83	0.64
Mean of SD			1.87				2.00				1.07				1.08

ACA							
P1-1	**P1-2**	**MEAN**	**SD**	**P2-1**	**P2-2**	**MEAN**	**SD**
209.28	212.85	211.07	2.52	214.21	216.96	215.59	1.94
209.14	211.58	210.36	1.73	211.76	218.01	214.89	4.42
199.6	202.79	201.20	2.26	204.44	208.45	206.45	2.84
197.46	198.54	198.00	0.76	202.49	203.79	203.14	0.92
202.77	201.78	202.28	0.70	201.17	203.93	202.55	1.95
208.4	213.98	211.19	3.95	207.83	215.58	211.71	5.48
197.56	199.31	198.44	1.24	194.65	189.53	192.09	3.62
195.17	200.84	198.01	4.01	197.41	194.6	196.01	1.99
198.75	200.86	199.81	1.49	208.22	208.88	208.55	0.47
215.49	223.04	219.27	5.34	212.98	222.1	217.54	6.45
204.26	209.68	206.97	3.83	197.35	198.28	197.82	0.66
199.89	203.06	201.48	2.24	193.49	197.43	195.46	2.79
192.67	193.68	193.18	0.71	195.05	192.37	193.71	1.90
212.71	216.15	214.43	2.43	199.95	204.48	202.22	3.20
209.21	207.76	208.49	1.03	205.74	202.89	204.32	2.02
196.39	195.67	196.03	0.51	195.03	195.69	195.36	0.47
194.62	197.63	196.13	2.13	202.14	202.6	202.37	0.33
197.59	200.11	198.85	1.78	198.03	199.91	198.97	1.33
209.71	208.81	209.26	0.64	201.41	198.39	199.90	2.14
207.03	210.52	208.78	2.47	205.76	199.44	202.60	4.47
192.99	196.19	194.59	2.26	190.21	188.28	189.25	1.36
192.99	193.36	193.18	0.26	188.9	190.78	189.84	1.33
Mean of SD			2.01				2.37

*CVA: craniovertebral angle; CIA: cervical inclination angle; CA: cervical angle; ACIA: adapted cervical inclination angle; ACA: adapted cervical angle; P1: picture 1; P2: picture 2; 1: Rater 1; 2: Rater 2; SD: standard deviation.

Table 6. Angle measurements on the radiographs by 2 raters.

NSL/OPT				NSL/CVT				OPT/h.				CVT/h.			
Rater 1	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**
100.95	102.18	101.57	0.87	104.62	106.48	105.55	1.32	88.88	89.43	89.16	0.39	85.19	85.73	85.46	0.38
97.29	97.28	97.29	0.01	107.49	108.16	107.83	0.47	100.69	101.3	101.00	0.43	90.64	91.28	90.96	0.45
107.03	106.66	106.85	0.26	109.92	113.63	111.78	2.62	94.84	94.84	94.84	0.00	91.8	93.03	92.42	0.87
111.98	111.86	111.92	0.08	113.55	114.09	113.82	0.38	79.4	80.66	80.03	0.89	77.95	79.92	78.94	1.39
91.69	97.8	94.75	4.32	98.76	103.12	100.94	3.08	100.31	99.17	99.74	0.81	93.79	93.45	93.62	0.24
99.38	100.34	99.86	0.68	102.46	100.73	101.60	1.22	93.63	93.22	93.43	0.29	90.6	91.24	90.92	0.45
97.01	97.44	97.23	0.30	99.07	103.9	101.49	3.42	95.53	96.73	96.13	0.85	93.48	93.73	93.61	0.18
86.43	84.63	85.53	1.27	94.89	94.87	94.88	0.01	101.96	104.47	103.22	1.77	93.54	93.22	93.38	0.23
94.89	92.94	93.92	1.38	107.33	106.17	106.75	0.82	96.51	97.1	96.81	0.42	84.23	84.58	84.41	0.25
87.58	87.35	87.47	0.16	97.55	96.86	97.21	0.49	97.77	98.57	98.17	0.57	87.72	88.17	87.95	0.32
88.25	91.2	89.73	2.09	96.9	97.16	97.03	0.18	92.85	92.39	92.62	0.33	84.04	85.52	84.78	1.05
86.71	87.58	87.15	0.62	96.22	96.36	96.29	0.10	103.56	106.29	104.93	1.93	94.32	94.89	94.61	0.40
108.97	110.31	109.64	0.95	115.13	117.14	116.14	1.42	76.03	77.73	76.88	1.20	69.98	69.61	69.80	0.26
90.75	91.23	90.99	0.34	99.38	95.18	97.28	2.97	97.22	97.61	97.42	0.28	88.69	88.65	88.67	0.03
80.01	82.34	81.18	1.65	91.32	90.86	91.09	0.33	111.47	111.01	111.24	0.33	100.21	99.19	99.70	0.72
79.66	78.26	78.96	0.99	92.82	91.9	92.36	0.65	106.73	107.19	106.96	0.33	93.7	94.47	94.09	0.54
96.81	96.78	96.80	0.02	104.32	104.45	104.39	0.09	96.47	97.78	97.13	0.93	88.83	88.39	88.61	0.31
94.97	97.07	96.02	1.48	99.3	99.42	99.36	0.08	93.63	94.65	94.14	0.72	89.48	88.58	89.03	0.64
96.13	95.49	95.81	0.45	103.36	103.74	103.55	0.27	95.71	95.27	95.49	0.31	88.69	88.53	88.61	0.11
92.92	94.11	93.52	0.84	95.85	93.33	94.59	1.78	92.79	94.6	93.70	1.28	90	91.51	90.76	1.07
101.52	102.32	101.92	0.57	109.03	107.69	108.36	0.95	92.71	91.23	91.97	1.05	85.13	83.9	84.52	0.87
Mean of SD			0.92				1.08				0.72				0.51

CIAr				CAr				ARA				ACIAr			
Rater 1	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**
82.55	82.73	82.64	0.13	185.85	185.47	185.66	0.27	17.31	25.32	21.32	5.66	84.88	84.78	84.83	0.07
78.59	78.66	78.63	0.05	197.06	197.49	197.28	0.30	24.56	26.55	25.56	1.41	82.38	82.04	82.21	0.24
85.69	85.78	85.74	0.06	193.04	192.48	192.76	0.40	24.22	30.52	27.37	4.45	89.05	89.63	89.34	0.41
77.96	77.14	77.55	0.58	185.16	183.84	184.50	0.93	6.43	11.59	9.01	3.65	78.8	77.84	78.32	0.68
86.95	86.46	86.71	0.35	191.77	191.19	191.48	0.41	19.68	20.07	19.88	0.28	88.77	88.54	88.66	0.16
84.3	83.91	84.11	0.28	194.1	193.82	193.96	0.20	25.82	22.72	24.27	2.19	87.31	86.61	86.96	0.49
85.81	85.58	85.70	0.16	198.97	198.4	198.69	0.40	27.34	30.38	28.86	2.15	90	89.29	89.65	0.50
85.68	85.77	85.73	0.06	193.92	193.38	193.65	0.38	23.16	25.22	24.19	1.46	87.81	87.75	87.78	0.04
75.61	75.73	75.67	0.08	191.09	190.76	190.93	0.23	24.39	25.35	24.87	0.68	76.82	76.82	76.82	0.00
79.28	79.21	79.25	0.05	192.44	191.47	191.96	0.69	20.3	23.06	21.68	1.95	80.89	80.46	80.68	0.30
74.93	74.9	74.92	0.02	194.06	194.56	194.31	0.35	12.34	16.87	14.61	3.20	75.94	75.86	75.90	0.06
85.13	84.98	85.06	0.11	193.99	192.97	193.48	0.72	27.08	31.28	29.18	2.97	87.84	87.33	87.59	0.36
70.47	70.53	70.50	0.04	178.93	178.74	178.84	0.13	-2.61	6.25	1.82	6.26	69.58	69.44	69.51	0.10
87.41	87.32	87.37	0.06	182.42	182.54	182.48	0.08	17.8	19.46	18.63	1.17	88.46	88.8	88.63	0.24
89.83	89.74	89.79	0.06	193.8	194.55	194.18	0.53	29.12	30.32	29.72	0.85	92.02	92.52	92.27	0.35
82.11	82.12	82.12	0.01	198.6	198.35	198.48	0.18	31	31.92	31.46	0.65	84.69	84.46	84.58	0.16
80.93	80.32	80.63	0.43	190.93	191.85	191.39	0.65	22.97	24.65	23.81	1.19	83.12	82.79	82.96	0.23
87.98	88.14	88.06	0.11	186.94	186.87	186.91	0.05	20.84	15.38	18.11	3.86	90.74	90.37	90.56	0.26
82.16	81.78	81.97	0.27	190.18	189.69	189.94	0.35	19.04	21.26	20.15	1.57	83.93	83.54	83.74	0.28
86.92	86.91	86.92	0.01	185.94	185.86	185.90	0.06	15.24	19.72	17.48	3.17	88.95	88.77	88.86	0.13
81.68	79.99	80.84	1.20	185.14	186.46	185.80	0.93	14.88	19.25	17.07	3.09	81.71	81.46	81.59	0.18
Mean of SD			0.20				0.39				2.47				0.25

ACAr				AmspC7/h.				spCIA				spCA			
Rater 1	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**
182.26	182.15	182.21	0.08	61.89	62	61.95	0.08	70.34	69.46	69.90	0.62	212.74	214.18	213.46	1.02
191.8	193.45	192.63	1.17	62.41	62.6	62.51	0.13	67.53	67.45	67.49	0.06	218.16	224.62	221.39	4.57
188.62	186.97	187.80	1.17	68.34	68.88	68.61	0.38	77.39	77.12	77.26	0.19	223.15	222.87	223.01	0.20
184.62	183.45	184.04	0.83	60.25	60.34	60.30	0.06	72.47	70.24	71.36	1.58	207.03	204.98	206.01	1.45
190.88	189.62	190.25	0.89	65.42	66.02	65.72	0.42	75.68	75.49	75.59	0.13	211.73	215.26	213.50	2.50
190.73	191.21	190.97	0.34	61.55	61.65	61.60	0.07	74.86	72.02	73.44	2.01	217.41	225.32	221.37	5.59
193.95	194.84	194.40	0.63	66.75	66.73	66.74	0.01	73.88	71.3	72.59	1.82	215.75	230.95	223.35	10.75
192.42	192.02	192.22	0.28	67.2	67.32	67.26	0.08	74.69	74.54	74.62	0.11	216.46	220.83	218.65	3.09
190.88	190.03	190.46	0.60	58.61	58.71	58.66	0.07	66.93	64.32	65.63	1.85	214.74	214.24	214.49	0.35
192.26	191.36	191.81	0.64	61.63	62.21	61.92	0.41	68.04	65.23	66.64	1.99	216.78	212.84	214.81	2.79
195.17	195.44	195.31	0.19	57.96	58.14	58.05	0.13	64.54	63.57	64.06	0.69	222.58	219.77	221.18	1.99
191.41	191.23	191.32	0.13	69.61	70.78	70.20	0.83	77.32	76.37	76.85	0.67	206.29	208.51	207.40	1.57
180.71	179.84	180.28	0.62	53.29	53.35	53.32	0.04	63.62	63.4	63.51	0.16	195.21	196.91	196.06	1.20
179.94	179.79	179.87	0.11	66.5	66.52	66.51	0.01	78.41	78	78.21	0.29	201.46	206.52	203.99	3.58
191.53	191.85	191.69	0.23	70.27	70.46	70.37	0.13	80.3	77.18	78.74	2.21	218.44	220.04	219.24	1.13
196.98	196.94	196.96	0.03	64.41	64.41	64.41	0.00	68.71	68.18	68.45	0.37	213.05	222.54	217.80	6.71
188.09	189.06	188.58	0.69	64.12	64.69	64.41	0.40	72.39	72.18	72.29	0.15	210.66	211.37	211.02	0.50
182.84	182.52	182.68	0.23	67.33	69.09	68.21	1.24	78.98	77.95	78.47	0.73	220.18	214.59	217.39	3.95
188.18	188.09	188.14	0.06	63.51	64.58	64.05	0.76	73.8	73.75	73.78	0.04	211.53	215.99	213.76	3.15
183.59	183.22	183.41	0.26	66.98	67.38	67.18	0.28	78.75	79.19	78.97	0.31	212.71	212.88	212.80	0.12
182.6	184.53	183.57	1.36	65.45	65.8	65.63	0.25	71.8	69.72	70.76	1.47	205.14	202	203.57	2.22
Mean of SD			0.50				0.28				0.83				2.78

spACIA				spACA			
Rater 1	**Rater 2**	**Mean**	**SD**	**Rater 1**	**Rater 2**	**Mean**	**SD**
75.85	75.12	75.49	0.52	208.51	208.89	208.7	0.27
77.63	76.29	76.96	0.95	207.44	216.11	211.775	6.13
83.27	82.53	82.90	0.52	218.96	220.92	219.94	1.39
78.82	76.77	77.80	1.45	198.36	197.68	198.02	0.48
79.84	81.77	80.81	1.36	209.33	207.64	208.485	1.20
87.18	87.44	87.31	0.18	201.76	211.15	206.455	6.64
83.97	83.31	83.64	0.47	204.07	216.67	210.37	8.91
80.06	80.19	80.13	0.09	212.51	217.57	215.04	3.58
77.47	74.98	76.23	1.76	201.84	202.6	202.22	0.54
73.53	69.74	71.64	2.68	214.17	210.62	212.395	2.51
68.94	68.24	68.59	0.49	224.64	221.98	223.31	1.88
80.44	79.86	80.15	0.41	206.07	211.14	208.605	3.59
63.5	62.68	63.09	0.58	198.4	200.16	199.28	1.24
82.43	82.32	82.38	0.08	198.08	204.75	201.415	4.72
92.68	89.73	91.21	2.09	200.73	207.55	204.14	4.82
77.99	78.31	78.15	0.23	201.94	212.71	207.325	7.62
78.56	77.55	78.06	0.71	205.46	208.24	206.85	1.97
92.76	91.8	92.28	0.68	198.72	195.76	197.24	2.09
79.12	77.37	78.25	1.24	207.11	213.8	210.455	4.73
87.03	86.98	87.01	0.04	202.59	204.68	203.635	1.48
75.14	75.56	75.35	0.30	202.37	194.62	198.495	5.48
Mean of SD			0.80				3.39

*NSL= nasion-sella line; OPT= odontoid process tangent; CVT= cervical vertebra tangent; CIA= cervical inclination angle; ACIA= adapted cervical inclination angle; ARA= absolute rotation angle; CA= cervical angle; ACA= adapted cervical angle; r=measured in radiographs; Am=auditory meatus; h= horizontal; sp=spinous process; SD: standard deviation.