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The manuscript, as accepted by the publisher, is reproduced here as it appears in the first author's Ph.D. thesis, entitled *Développement et validation d'un outil clinique pour l'analyse quantitative de la posture auprès de personnes atteintes d'une scoliose idiopathique*. The thesis citation is as follows:

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Chapitre3 Développement de l’outil quantitatif clinique d’évaluation de la posture

Ce chapitre présente la méthodologie et les résultats concernant le processus de développement de l’outil clinique. La première phase consiste en une recension de la littérature présentée sous forme d’un article. Cet article a permis, à travers la recension des différentes méthodes cliniques d’évaluation de la posture, d’identifier plusieurs IP permettant de mesurer la posture sous toutes ses dimensions (alignement des différents segments corporels dans les plans frontal et sagittal). La deuxième phase du développement de l’outil concerne la sélection d’IP qui ont servi à la construction de l’outil clinique.

3.1 Article 1 : Clinical methods for quantifying posture: a literature review

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Contribution des auteurs:

Carole Fortin: recension de la littérature, analyse et interprétation des données, rédaction de l’article : 90%.

Debbie Feldman : rédaction de l’article.

Farida Cheriet : correction de l’article et approbation de la version finale.

Hubert Labelle : correction de l’article et approbation de la version finale.

Clinical methods for quantifying posture: a literature review

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ABSTRACT

Purpose: Clinicians commonly assess posture in persons with musculoskeletal disorders and tend to do so subjectively. Evidence-based practice requires the use of valid, reliable and sensitive tools to monitor treatment effectiveness. The purpose of this article was to determine which methods were used to assess posture in a clinical setting and to identify psychometric properties of posture indices measured from these methods or tools.

Methods: We conducted a comprehensive literature review. Pertinent databases were used to search for articles on quantitative clinical assessment of posture. Searching keywords were related to posture and assessment, scoliosis, back pain, reliability, validity and different body segments.

Results: We identified sixty-five (65) articles with angle and distance posture indices that corresponded to our search criteria. Several studies showed good intra and inter-rater reliability for measurements taken directly on the persons (e.g. goniometer, inclinometer, flexible curve, tape measurement) or from photographs but validity of these measurements was not always demonstrated.

Conclusion: Taking measurements of all body angles directly on the person is a lengthy process and may affect the reliability of the measurements. Measurement of body angles from photographs may be the most accurate and rapid way to assess global posture quantitatively in a clinical setting.

Keywords: Posture and assessment, posture and scoliosis, posture and reliability, posture and low back pain.

INTRODUCTION

Musculoskeletal and neurologic pathologies as well as cardio-vascular-respiratory dysfunction are often associated with posture impairments [1-5]. Posture is defined as the alignment or orientation of body segments while maintaining an upright position [6]. The resulting body alignment depends on the effect of gravity, muscle tension and integrity of bony structures [6, 7]. Posture relates to physical and psychosocial wellbeing [8,9,10,11]. Improving posture or postural alignment is one of the aims of rehabilitation programs [12]. Physiotherapists and physicians commonly assess posture and current practice is based on subjective impressions that are not quantified using a reliable and valid measurement scheme [2, 13-17].

There are different methods based on visual observations to assess posture. Some report presence or absence of posture impairment [13,15,16,18] while others use the plumb line to determine normal or abnormal posture types [2]. There are also ordinal rating scales to evaluate posture asymmetries [14, 19-24]. Fedorak et al.[18] reported a moderate intra-rater (Kappa = 0.50) and poor inter-rater (Kappa < 0.40) reliability on a three-category qualitative rating scale (normal, increased, decreased) of cervical and lumbar lordosis among 36 adults with and without back pain. Bryan et al. [13] also found a poor level of validity for visual observation of lumbar lordosis using measurement on radiographs as their gold standard. Reliability of different ordinal rating scales to assess some aspects of lying, sitting and standing posture was examined among normal persons and persons with stroke, cerebral palsy or idiopathic scoliosis [14, 19-24]. Results of these studies demonstrate a poor to good level of intra and inter-rater reliability and only the Foot Posture Index showed good level of validity with measurements done concurrently with a 3D posture analysis system [22]. Nevertheless, according to Tyson [11], none of the measurement tools, which are based on visual observation scales (direct or from photographs) met the criteria to assess the effectiveness of physiotherapy intervention in patients with stroke.

Several authors have pointed out the importance of quantifying posture indices to monitor treatment effectiveness on body segment posture, for either physiotherapy, brace or surgical treatment [25-27]. Effectiveness of physiotherapy in persons with idiopathic scoliosis has been criticized [28, 29] and this may be due to the lack of adequate clinical measurement tools to monitor objective change in body posture. Actually, radiological images are used to assess or to monitor change over time in persons presenting with musculoskeletal disorders. These images are mostly used to verify the bony structures or spinal alignment. Radiographs are invasive and thus cannot be used for repeated measures of body segment posture. Several 3D posture analysis systems such as Optotrak, Vicon, Motion Analysis and surface topography systems are used to quantitatively assess posture [1,4,26,27]. However, these systems are not easily accessible for most clinicians since they are expensive, require specialized trained technicians and the data processing is complex. Thus reliable, valid and accessible clinical measures are essential if physiotherapists are to properly assess treatment effectiveness in improving posture.

The objectives of this paper are to report, from the medical literature, various clinical methods for quantifying body segment posture and to identify the psychometric properties of posture indices measured by these methods.

METHODS

We embarked on a comprehensive literature search in order to retrieve methods of posture assessment that have been used previously. Once identified, we extracted posture indices, as defined by an angle or distance representing the alignment or the position in the sagittal or frontal plane of body segments, evaluated by these methods and reported their psychometric properties.

Search strategy

The following databases (CINAHL, EMBASE and Medline) were used to search for articles on posture from 1980 to 2009. Searching keywords were: posture assessment, posture alignment, postural alignment, posture and outcome measure, posture and responsiveness, posture and reproducibility, posture and reliability, posture and sensitivity, posture and validity, posture and scoliosis, posture and backache, posture and low back pain. We also combined each body segment with posture as keywords such as head posture, neck posture, cervical posture, thoracic posture, trunk posture, lumbar posture, shoulder posture, arm posture, upper limb posture and lower limb posture. In addition, we searched for related articles from references cited in the articles identified from the original search.

We limited our search to English and French papers dating from 1980 to October 2009 and those reporting postural indices from clinical measurements. We excluded the following: 1) papers on clinical qualitative assessment of posture (including those with an ordinal scale); 2) papers on X-ray measurement or trunk movement only; 3) articles concerning postural sway or balance only; 4) papers reporting laboratory methods such as surface topography systems, computerized motion analysis systems and video methods utilising digitalisation as these were not tools that are readily available in a clinical setting.

Data collection and analysis

For the selection of the papers, each of the three databases was examined and duplicate records of the same paper were removed. Titles were first examined and irrelevant papers were removed at this stage. Following that, the abstracts were read to determine if the paper concerned study on psychometric properties of a clinical posture tool. Finally, the full text of relevant papers were retrieved and read and were kept if the study met the inclusion criteria. For the reliability, interpretation of the coefficients is as follows: values above 0.75 are considered as good reliability, those between 0.50 and

0.75 as moderate and those under 0.5 as poor [30]. The validity evidence for posture assessment methods is interpreted using the same threshold values as above.

RESULTS

We identified sixty-five (65) articles representing five principal methods used to assess body segment posture (photographs, goniometers, inclinometers, tape measurement and flexible rule) with posture indices (represented by angles or distances) that responded to our search criteria (Table 1). They documented posture measurement reliability and validity mostly in normal persons and a few in those with orthopaedic problems such as osteoporosis or pain. Quantitative clinical measurement of posture can be categorized into indirect methods by mean of angles or distances calculation obtained from photographs and direct methods by mean of different tools measuring posture indices directly on persons. In each section, data are reported for the reliability and the validity. The reliability of posture indices is reported using mainly intra-class coefficient correlation (ICCs) but the type of ICC is not always mentioned. Some authors have also reported the standard error of measurement (SEM) which is the error in terms of the unit of measurement. For the validity, Pearson product-moment correlation coefficients (r) were used in most studies whereas Spearman correlation coefficients (r_s) were used in one study [31].

Body angle or distance calculation from photographs

We found sixteen (16) articles reporting psychometric properties of angle and distance measurements based on photographs taken in the standing or sitting positions (Table 1 – A). All of these studies were done among healthy children, adolescents or adults. Several posture indices were assessed and represent the different body segments (head and neck, shoulder and scapula, thoracic and lumbar regions, pelvis and lower limbs). However, except for Raine's study [32], no study offers an evaluation of posture including all body segments. The angle or distance measurements were obtained by printing a metric grid on an overhead transparency and then aligning this grid with vertical gridlines by using the plumb lines visible on the photographs [21] or by developing software programs and using digitizing process to obtain x and y coordinates of previously placed reflective markers on anatomical landmarks [32-39]. The intra-rater and inter-rater reliability was good for the majority of the posture indices (>0.75) (Table 1 – A). However, some authors have reported poor to moderate levels of intra and inter-rater reliability (ICCs: < 0.75) for posture indices such as sagittal head angle [32, 35, 40], shoulder protraction and scapula angle [33], frontal pelvis angle [33, 35], angles in cervical, thoracic and lumbar frontal and sagittal curves [41, 42] and for some distance measurements in frontal or sagittal plane [37, 43]. When using the ICC (2,1) type to generalize the results to the universe of occasions and raters, one can observe lower reliability coefficients [35, 40]. Dunk et al.[42] have questioned the validity of body angle calculation from photographs as a reliable tool to assess posture in a clinical setting. Their study on 14 healthy persons demonstrated that the six spinal angles taken from photographs in sagittal and frontal planes (cervical, thoracic and lumbar) had poor to moderate repeatability. In Dunk et al.'s study [42], angle measurements were calculated as deviations from the vertical reference line whereas relative measurements between body segments were used in other cited studies. In a subsequent study based on relative measurements between body segments, Dunk et al.[41] found a better level of reliability for the same spinal angles among 20 healthy adults.

The SEM or differences between measurements in degree or mm are reported in five papers. The SEM varied from 0.7º to 10º and from 1 to 23 mm [33, 35, 36, 39, 40]. Higher values were found in inter-rater design for scapula distance in standing position and for posture indices in slump sitting [36].

Only few authors have reported the concurrent validity of posture indices measured from photographs and it was with X-rays [31, 39, 44, 45] (Table 1). Johnson [44] did not find significant correlation between the craniovertebral angle and three of the cervical angles taken on radiographs in the standing position. The other posture indices taken from photographs concurrently assessed with X-rays are the shoulder frontal plane tilt (shoulder balance) in the standing position [31] and the sagittal head angle, the cervical angle, the shoulder protraction/retraction angle, the thoracic angle and the arm angle in different sitting positions [39]. Except for the shoulder protraction/retraction angle in normal sitting (r=0.48), these indices had moderate to good level of correlation with X-rays (r: ranged from 0.66 to 0.97 and r_s from 0.60 to 0.76).

Direct body measurements by goniometry and inclinometers

Different types of goniometers used to quantify aspects of posture include the universal goniometer, electrogoniometer and inclinometer. We found 23 papers reporting psychometric properties of these methods. These instruments have been used to measure posture of the head (sagittal plane), pelvis and of cervical, thoracic and lumbar spine in sagittal and frontal planes in different groups of persons as well as measurements of lower limb alignment [46-50]. These methods were usually used to assess one or two posture indices in the studies. Peterson et al. [51] used the Sahrmann technique to document shoulder protraction. This method consists of measuring the shoulder flexion angle between the person's upper arm and midline of the trunk (person against the wall) with a standard manual goniometer. Other types of goniometer such as modified gravity goniometer and parallelogram goniometer were also used for measuring lumbar spine and pelvic positions in the sagittal plane [52]. The intra and inter-rater reliability of these different types of goniometer was similar and was moderate to good (ICCs > 0.50) for most posture indices measured with these tools (Table 1 – B).

At the lower limb level, the reliability of goniometers was only assessed for genu recurvatum [49], rear foot angle (or tibiocalcaneal angle) [47, 48, 53] and arch angle indices [48]. Intra-rater reliability was good and inter-rater reliability was moderate to good (ICCs: 0.50 to 0.95) for these indices. The SEM or difference between sessions is reported in eight studies and is < 4º.

The validity of measurements taken with goniometers and inclinometers has been concurrently assessed with radiographs only for shoulder protraction, lumbar lordosis, sagittal pelvic tilt and frontal lower limb alignment [51-57] (Table 1 – B). The shoulder index measured by the Sarhmann technique was compared with measurement of horizontal distance between the C7 spinous process and the anterior tip of the left acromion on a standing left lateral cervical spine radiograph. It has moderate correlation (r:-0.65) in persons without forward shoulder protraction (FSP) but weak correlation in persons with FSP and when both groups were analyzed together (r: -0.21 and -0.33 respectively) meaning that this index is not valid to assess shoulder protraction. The validity of the different types of goniometers and inclinometers was also weak (r: -0.13 to 0.60) for measurements of lumbar lordosis and sagittal pelvic tilt indices [52, 54, 55]. For lower limb alignment assessment, correlation between goniometer measurements of Q angle and rearfoot alignment (tibiocalcaneus angle) and radiographs were weak to moderate (r=0.32 and 0.74 respectively) [53, 56]. The frontal knee alignment measured with an inclinometer has good correlation with measurement of mechanical axis of the leg on radiographs (r=0.83) [57].

Direct body measurements by other methods

Other direct methods such as measuring the distance between bony landmarks with specific devices or tape measurement have been used to assess the resting position of the head, forward shoulder posture and pelvic positions in the sagittal plane, of the scapula position in the frontal plane, and lower limb alignment in frontal and sagittal planes [51, 58-60] (Table 1 – C).

Sagittal head posture was assessed by measuring the distance from the wall or from the plumb line and showed good intra and inter-rater reliability (ICCs > 0.80) [58, 61]. In Hickey et al.'s study [61], the distance measurement technique showed higher level of reliability than the cervical range of motion device (CROM) for measuring sagittal resting head posture ($ICCs_{2,1}$ from 0.68 to 0.78). Garrett et al, [62], report higher intra and inter-rater level of reliability but they used less conservative ICCs ($ICCs_{1,1}$: 0.93 and 0.83, respectively). Peterson et al. [51] have developed specific devices to assess forward shoulder posture. These are: the Baylor square which is used to measure the distance from the C7 spinous process to the anterior tip of the acromion process and the modified double square which measures the distance from the wall to the anterior tip of the person's left acromion process. The same authors measured the scapula position by using a cloth tape. The intra-rater reliability for these three techniques was good (ICCs: 0.89 to 0.91). Levis and Valentine [63] have also assessed scapula position reliability and they report moderate to good level of reliability with both healthy persons and persons with shoulder symptoms (ICCs > 0.61).

One study reported reliability of trunk list [64]. These authors compared three methods for measuring trunk list from T12 to S1 among 7 to 27 adult persons with trunk list: a plumb line (N=27); a shadow projected from a vertical wire onto the skin of the back (N=12) and a more sophisticated system called 3Space Isotrak (N=7). The first two methods were measured with a tape measure and did not significantly differ from each other and the third one was obtained from a computer and differed significantly from the other two techniques. There were no significant differences for repeated measures by each observer or between two observers for trunk list measurements using the plumb line.

Gajdosik et al.[59] and Alviso et al. [65] measured the distance between the anterior or posterior iliac spines (previously marked) to the floor to assess standing pelvic tilt (SPT), anterior pelvic tilt angle (APT) and posterior pelvic tilt angle (PPT) in the sagittal plane with a tape measurement or a meter sticks mounted on a wooden base. Intra-rater [59] and inter-rater [65] reliability was good (r and ICCs > 0.75).

Several authors also used distance measurement to determine the reliability of the sagittal alignment of lower limb [58] and the magnitude of knee valgus/varus [48, 56] and foot pronation in standing (navicular height, navicular drop - distance of the marked navicular to the ground in milimeters) [49]. The knee valgus was determined by the distance measured from the plumb line to the medial malleolus and knee varus from the plumb line to the medial joint line of the knee [48]. The navicular drop was obtained by calculating the difference between one measure taken in sitting with the subtalar joint in the neutral position and the other taken in standing. Intra and inter-rater reliability were good for these indices (ICCs > 0.90) [48, 49]. Other measurements were also used to characterize the foot and the medial longitudinal arch (navicular height, height of the dorsum of the foot, angle of the first ray, etc.) by Williams and McClay [66]. In their study, the intra-rater reliability was good for all parameters (ICCs > .80) in the 10% and 90% conditions of weight bearing. The inter-rater reliability was better in the 10% weight bearing condition. The SEMs reported were between 2 and 5mm for lower limb indices and from 5 to 10mm for trunk list.

The validity of distance measurements is only reported for shoulder protraction [51], knee varus and valgus [56] and indices of the foot [66-69]. The Baylor square had better correlation with radiographic measurements of the distance between the C7 spinous process and the anterior tip of the left acromion than the modified double square (r = 0.77 vs 0.65). The correlation between distance measurement of knee varus/valgus with a plumb line and a calliper method was moderate to good (r=0.71 and 0.76, respectively). Validity of foot position is also moderate to good with measurement taken on radiographs.

Another device called flexible curve (flexi-rule, flexible ruler or flexi-curve) has also been used to measure the posture of the pelvic and the sagittal spinal curves on normal persons and two studies were in persons with neck and back pain [70, 71]. This tool is designed to adapt to the contour of the back and used to measure cervical and lumbar lordosis or thoracic kyphosis. It has good intra and inter-rater reliability [50, 71-75]. In general, thoracic kyphosis had a better level of reliability (ICCs: 0.89 to 0.97) than cervical and lumbar lordosis (ICCs: 0.60 to 0.97) in healthy persons. According to Hinman [72], this could be attributed to the difficulty in adapting the flexible curve to the smaller concave curvature of the lumbar spine and from some person's clothing. The level of reliability was lower when measurements were taken among persons with neck and back pain (ICCs: 0.23 and 0.18 for cervical lordosis and 0.35 to 0.62 for lumbar lordosis) [70, 71]. The spinal pantograph which draws the shape of the back, was also used to measure kyphosis and lordosis [76]. Willner [76] has investigated the reproducibility of the standing posture on thirty patients with this instrument, three to five times at intervals varying from one day to one month. The accuracy did not differ in thoracic and lumbar curve measurements. Measurement errors of flexible curves are only reported in two studies and are 3.2º for thoracic kyphosis [77] and the mean absolute difference for cervical lordosis was 26.4º [78].

The concurrent validity with radiograph measurements of lumbar lordosis using flexible curve was good [79].

DISCUSSION

The purposes of this article were to report various methods used in a clinical setting for quantifying body segment posture and to identify psychometric properties of posture indices that may be used for clinical assessment of posture to characterize and monitor posture over time.

Several authors have pointed out the need to have quantitative indices of posture [7, 11, 26, 27]. These posture indices may serve as an integral part of a clinical evaluation to facilitate the analysis and diagnosis of the underlying mechanical causes of postural abnormalities. We presently do have sophisticated 3D posture analysis systems such as Optotrak, Vicon, Motion Analysis and surface topography systems to assess posture in a quantitative fashion. However, these systems are not accessible for most clinicians treating persons with musculoskeletal or neurologic disorders.

Several attempts to quantify clinical posture indices among healthy persons such as calculation of body angles from photographs, the use of goniometry, measurements of the distance between two points, flexible curve and of other methods like spinal pantograph, the Baylor square or double square are reported in this paper. Most of the studies showed good intra and inter-rater reliability for measurements taken from photographs or directly on the persons. Nevertheless, the validity of these measurements was not always assessed. Several of the clinical tools were verified using radiographs, although the validity was usually weak. Correlation between internal spinal curve and external posture asymmetry has been questioned by Goldberg et al.[1]. More sophisticated 3D posture analysis systems such as Motion Analysis, Optotrak, Vicon or surface topography systems may be more appropriate to validate these clinical measures. To our knowledge, the only clinical postural tool that has been through a complete validation process with a 3D posture analysis system is the Foot Posture Index (FPI) [22]. This five level scale (Likert) is useful but it does not provide enough sensitivity to measure small changes over time. The objective of the FPI is to help the clinician in the diagnosis of foot pathologies (normal, pronated or supinated foot).

Reproducibility and sensitivity to change are other important characteristics of a measurement tool. Factors affecting reliability of postural measures need to be identified. These may be related to 1) the person's physiological factors such as balance or sway problem during stance; 2) measurement technique (misplacement of the tool) and ability to identify the bony landmarks, 3) the device itself and 4) the number of investigators [44, 80, 81]. According to Mayer et al. [81] the most important factor affecting reliability is the test administrator training followed by the human/device interface error, the magnitude of the movement evaluated, the device error and human performance variability (balance problem, age, gender, motivation). These authors showed that these errors decreased substantially with training.

Standardization of the position and information given to the person are also helpful to improve reliability [60, 81]. According to Zabjek et al.[27], the effect of data collection duration on the measurement of body segments position is another important aspect of the reliability. There was an increased root mean square (RMS) due to postural sway with an increased sample time in persons with idiopathic scoliosis. Thus a short acquisition time is necessary to minimize between segment artefacts caused by body sway. Another factor affecting reliability was the way that posture body angles were calculated. Reliability of posture body angles was higher in studies using biologically relevant measurements (relative measurements between body segments) [21,32,34] than the one of Dunk et al.[42] that used an external vertical line reference for posture angle calculation. The difference in the two measurement techniques may be due to body sway in the sagittal and frontal plane. Possibly, a change in ankle joint angle due to body sway may modify spine position [4, 82].

The most promising technique to assess posture in a global fashion may be the calculation of body angles on photographs in the sagittal (two sides) and frontal planes (anterior and posterior view). Photograph acquisition is fast, easy to do, and is accessible for the majority of physiotherapists working in clinical settings. The clinical measurement would be quick which is important, in particular, for those patients with pain or balance problems.

Current tools or methods presented in this paper to assess posture from photographs do not include posture indices representing all body segments. According to the definition of posture [2, 6, 19], a posture assessment tool should contain posture indices representing all body segments. It must be also useful to characterize a specific pathology. Tyson and Desouza [19] have conducted a study among physiotherapists working with persons with stroke and they established that the following must be included in a posture assessment tool: position of the head and neck (flexion/extension, side flexion); position or alignment of the trunk; position or alignment of the pelvis and hip (anterior/posterior tilt, lateral tilt); position of hips, knees and feet; position and alignment of the scapula and position of the upper limb. To construct a useful global quantitative clinical posture assessment tool, these criteria and other posture indices such as trunk list [64, 83-85], measurement of sagittal spinal curves [20, 45, 52, 72] and head rotation [86] should also be added as these indices are important in patients with idiopathic scoliosis, neck and low back pain or other pathologies such as ankylosis spondylitis. Moreover, to our knowledge, the reliability and validity of posture indices calculated from photographs have not yet been demonstrated for all body segments and on persons with musculoskeletal pathologies or balance disorders.

Taking measurements of all body angles directly on the person is a lengthy process and may be difficult for both the therapist and the patient. Moreover, the person may tend to move during a lengthy evaluation which may affect the reliability of the measurements. Direct measurements can be appropriated for the assessment of one body segment. However, the sensitivity to change is questionable because the errors of measurement reported for goniometers and inclinometers vary from 1.5º to 9.5º according to the type of the device, the person's impairment or the test administrator training [81, 87].

In our literature review, few authors reported SEM and no study was conducted to assess sensitivity of indirect or direct measurements of posture indices to detect changes in time. The SEM is useful for clinicians, more so than the reliability coefficient, since it denotes the smallest detectable difference from one occasion or one rater to the other [88, 89]. Moreover, sample size, design of the reliability studies and position for the acquisition are important factors to take into account. According to Eliasziw et al. [89], to obtain a reliability coefficient of 0.9 with 80% power for a 5% significance level, a minimum of 35 participants is recommended in a two repeated measurement design. Forty-one out of 65 papers analysed in our manuscript reported psychometric properties of posture indices with sample sizes lower than 35 persons.

Results of these studies must thus be interpreted with caution. The same is true for studies using $ICC_{3,1}$ or $ICC_{2,1}$ or when the type of ICC is not clearly mentioned. The type of ICC provides information about the possibility to generalize the results to the "universe" of occasions and/or raters [89,90]. Only $ICC_{2,1}$ can be generalized to the "universe" of occasions and raters [90]. Finally, while natural standing posture seems to be the most chosen position for data acquisition, there was no consensus about standardization of the position for posture assessment in the studied papers. Since standardization contributes to reliability [60, 81], we believe that this should be considered in future studies or in clinical practice.

As already mentioned by Sahrmann [5, 91] and Souchard [92], posture evaluation must be understood in a global fashion and should be specific for each person. Body angle calculations depict a static position of a body segment and can only be used as a reference to monitor change in posture over time. It does not directly indicate the cause of the posture asymmetry. A professional who is trained in evaluation of musculoskeletal system function (such as a physiotherapist) must identify whether muscles, balance impairment or structural deformities are responsible for the observed asymmetries and if these observations are causes or consequences of the pathology (e.g. scoliosis, pain, spasticity) [5, 14,17, 60].

CONCLUSION

A posture assessment tool must contain posture indices that are useful to characterize the specific pathology, easy and fast to measure, reproducible and sensitive to short-term clinically important change, inexpensive and accessible for use in clinical settings. Current posture assessment tools based on measurements taken directly on the person do not meet the necessary criteria to assess posture for all body segments. Measurement of body angles taken from photographs may be the most comprehensive and rapid way to assess posture. Based on our literature review and analysis, posture can be measured quantitatively in a clinical setting – i.e. there exist several reliable and valid tools for specific body segments. However, there is a need to develop a global clinical posture tool that includes all pertinent body segments especially in children and adults with cerebral palsy, hemiplegia, idiopathic scoliosis or back pain who often demonstrate posture compensations in the whole body. This tool will require a rigorous validation process before its utilisation.

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Table 1. Psychometric properties of postural indices based on clinical instruments.

Study Authors (year)	**Type of Subjects (N, age)**	**Clinical tool type (Posture indices)**	**Psychometric properties Reliability (R), Validity (V)**
A) Body angle calculation from photographs			
Akel et al. (2008)	Healthy adolescents (91, 10-18)	1 body angle in posterior view (Shoulder balance)	V: with measures on X-rays : r (Spearman's test): coracoid height difference: .76; clavicular angle: .74; clavicle rib-cage intersection difference: .73; T1-tilt: .28; clavicular tilt angle difference: .60
Braun and Amundson (1989)	Healthy adults (20, 22-45)	2 body angles in sagittal plane (P) (Head and shoulder positions in sitting)	R: intra-session: $ICCs_{2,1}$: .39, .85 Mean difference between measurement (absolute value): 5.1º, 9.4º R: inter-session: $ICCs_{2,1}$: .56, .87 Mean difference between measurement (absolute value): 3.9º, 8.9º
Canhadas Bali et al. (2009)	Healthy children (5, 11 ±1.4)	5 angles on the face (external orbicularis, commissural labiorum, acromioclavicular joint, sternoclavicular joint, ear lobe) 4 angles in anterior view (anterosuperior iliac spines – AS, right and left knee angles – rKA and lKA, forward inclination of fibula – FIF) 7 angles in posterior view	R: intra-rater: ICCs*: Face: >.75 Anterior view: < .40 for AS, <.75 for FIF and .82 to .87 for rKA and lKA Posterior view: .43 to .67 for IS, Pl and PS and .80 to .96 for OC, PL, rFI and lFI Sagittal view: < .40 for KF

Study Authors (year)	**Type of Subjects (N, age)**	**Clinical tool type (Posture indices)**	**Psychometric properties Reliability (R), Validity (V)**
A) Body angle calculation from photographs			
Canhadas Bali et al. (2009)	Healthy children (5, 11 ±1.4)	(inferior angle of scapula – IS, olecranon central region – OC, posterosuperior iliac spines – PS, posteroinferior iliac spines – PI, popliteal lines – PL, right and left foot inclination – rFI and lFI) 6 angles in sagittal view (forward head posture – FHP, cervical lordosis – CL, thoracic kyphosis – TK, lumbar lordosis – LL, knee flexor –KF, tibiotarsal angle – TTA) 2 sagittal plane angles – respiration (Maximum inspiration – SAMI, maximum expiration – SAME)	and > .75 for FHP, CL, TK, LL and TTA. Respiration: > .91 for SAMI and SAME.
Dunk et al. (2005)	Healthy adults (20, 21-24)	6 body angles in lateral and posterior view (Cervical, thoracic and lumbar)	R: inter-trial and inter- session: ICCs$_{2,1}$: Sagittal: .64 to .84 ; Posterior: < .61
Dunk et al (2004)	Healthy adults (14, 21-23)	6 body angles in lateral, anterior and posterior view (Cervical, thoracic and lumbar)	R: inter-trial and inter-session: ICCs$_{2,1}$: < .70
Johnson (1998)	Healthy women (R:10, V:34, 17-31)	2 body angles (Cervical and craniovertebral)	R: intra-rater: ICCs*: .96-.99 R: test-retest: ICC*: .88 V: (with X-ray) : no consistent significant correlation
McEvoy and Grimmer (2005)	Healthy boys/girls (38, 5-12)	5 body angles (Head, neck, trunk, lower limbs)	R: intra-rater: ICCs$_{1,3}$: .93 to .99

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
A) Body angle calculation from photographs			
Normand et al. (2007)	Healthy adults (40, 24.4 ± 1.9)	9 measurements of rotation 9 measurements of translation (Head, thorax and pelvis)	R: Head: intra-rater: $ICC_{2,1}$: 0.67 to 0.77; $ICC_{3,1}$: 0.85 to 0.94 Inter-rater: $ICC_{2,1}$: 0.54 to 0.69; $ICC_{3,1}$:0.89 to 0.95 Thorax: intra-rater: $ICC_{2,1}$: 0.68 to 0.84; $ICC_{3,1}$: 0.91 to 0.93 Inter-rater: $ICC_{2,1}$: 0.54 to 0.72; $ICC_{3,1}$:0.89 to 0.94 Pelvis: intra-rater: $ICC_{2,1}$: 0.64 to 0.88; $ICC_{3,1}$: 0.92 to 0.97 Inter-rater: $ICC_{2,1}$: 0.51 to 0.80; $ICC_{3,1}$:0.88 to 0.96 $SEM_{2,1}$: 0.7º to 2.7º and 2.6 to 5.9 mm.
Perry et al. (2008)	Healthy adolescents (22, 13-17)	12 angles and distances in sagittal view in standing and in relaxed and slump sitting (head flexion, neck flexion, pelvic tilt, craniocervical angle, cervicothoracic angle, trunk angle, lumbar angle, sway angle, head displacement, scapula displacement, scapula elevation, slump distance)	R: intra-rater: ICCs* and SEM Standing: .87 to 1.0; SEM: 0.2 to 3.3º and 1.1 to 2.7mm. Relaxed sitting: .76 to 1.0; SEM: 0.3 to 4.2º and 1.3 to 3.5mm Slump sitting: .98 to 1.0; SEM: 0.3 to 2.4º and 0.8 to 2.7mm

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
A) Body angle calculation from photographs			
Perry et al. (2008)	Healthy adolescents (22, 13-17)		Inter-rater: ICCs* and SEM Standing: .26 to .70; SEM: 2.6 to 8.7º and 9.4 to 22.6mm Relaxed sitting: .24 to .72; SEM:3.2 to 9.7º and 10.0 to 19.0mm Slump sitting: .19 to .54; SEM: 4.7 to 10.3º and 11.2 to 20.0mm
Pownall et al. (2008)	Healthy males (11, 29.6 ±10.4)	6 distances in anterior view in standing (Ankle, knee and elbow widths, right and left acromioclavicular joints, ear right) The same 6 distances in posterior view in standing 8 distances or angles in sagittal view (Forward head, head angle, C7-T4, T4-T8, T8-T12, T12-L5, ankle-fib angle) 8 distances or angles in sagittal sitting (Forward head, head angle, C7-T4, T4-T8, T8-T12, T12-L5, hip-trunk angle, greater trochanter angle)	R: intra-rater: ICCs$_{3,4}$ (95% lower and upper CI) Anterior and posterior view in standing: > .76 (.34 to .98) Sagittal view in standing:.35 to .72 (-.80 to .91) for all distances, and .89 and .92 for head and ankle-fib angles (.70 to .98). Sagittal view in sitting: .50 to .70 for all distances and hip-trunk angle (-.40 to .91), and .92 and .93 for head and greater trochanter angles (.77 to .98).

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
A) Body angle calculation from photographs			
Raine S. (1995)	Healthy adults (23, 18-47)	5 body angles of head and shoulder and 9 body angles of lower limbs *(Coronal Head Tilt (CHT); Coronal Shoulder Tilt (CST); Sagittal Head Tilt (SHT); Sagittal C7-Tragus Angle (SC7-Tragus A); Sagittal Shoulder-C7 Angle (SS-C7A); Pelvic obliquity; Q Angle; Coronal Knee Angle; Pelvic Tilt; Sagittal Thigh Angle, Sagittal Thigh-Leg Angle and Sagittal Leg Angle)	R: Intra-rater : Head and shoulder : ICCs* : .71 to .91 R: Intra-rater: Lower limbs: ICCs*: .85 to .98
Raine and Twomey (1994)	Subjects with Scoliosis (15, mean 17 y.)	Upper and lower thoracic region Upper and lower lumbar region	V: r: .48 to .84 for P vs X-ray (vertebral bodies) V: r: .37 to .75 for P vs X-ray (spinous processes)
Refshauge et al. (1994)	Healthy adults (17, 23-62)	3 cervical angles, (Cervical inclinaison, cervical angle, cervicothoracic angle)	R: Intra-session: $ICCs_{2,1}$: .85 to .98 R :inter-session : $ICCs_{2,1}$: .63 to .98
Van Niekerk et al. (2008)	Healthy adolescents (39, 15-16)	5 body angles in upright, normal and slump sitting (Sagittal head angle, cervical angle, protraction/retraction of the shoulder, arm angle, thoracic angle)	$R^{\dagger}$: intra-rater: $ICCs_{2,1}$ (95% CI): .78 to .99 (.56 to .99); SEM: 3.3 to 11.1º $V^{\dagger}$: with X-rays (LODOX system,): r: .48 to .97 with lower correlation for shoulder and arm angles †: n=13 for each sitting position

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
A) Body angle calculation from photographs			
Watson and MacDonncha (2000)	Healthy boys (30, 15-17)	Quantitative posture scales of six posture indices, (Cervical flexion, head protraction, shoulder level, scoliosis angle, achilles angle andcalcaneus angle)	R: Quantitative: limits of agreement 95% CI's: Inter-rater: in order: 2.06º, 3.64º, 0.50mm, 1.40º, 0.98º and 2.5º
Zonnenberg et al. (1996)	Not mentioned (18, NP)	20 distances in anterior and posterior view (Head, shoulder, pelvis positions from plumb-line (x) and from the groundplate (y))	R: intra-rater: ICCs*: .70 to 1.00; r : > .75, p=0.001 Inter-rater: ICCs*: .66 to 1.00; r: > .73, p=0.001
B) Direct body measurements on subjects by goniometry and inclinometers			
Bierma-Zeinstra et al. (2001)	Adults with low back pain (41, 18-65)	Sacral inclination angle with inclinometer	V: (with X-ray): r = 0.28 (p=0.078) Measurement error: 8.26º
Bullock-Saxton (1993)	Healthy adults (25, 18-28) Pregnant women (34, 15-35) Women with low Back pain (30, 17-34)	Clinometer and electrogoniometer (Thoracic kyphosis, lumbar lordosis and sagittal pelvic tilt)	R: ANOVA: no significant intra-day difference Root mean square error: lordosis: 1.05 to 1.15º kyphosis: 0.94 to 2.09º, pelvic tilt: 0.49 to 0.68º

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
B) Direct body measurements on subjects by goniometry and inclinometers			
Burdett et al. (1986)	Healthy adults (23, 20-40)	Goniometers and tape measurement Two body angles (lumbar curve, pelvic tilt)	R: inter-rater: r :.64 to .93; ICCs*: .60 to .92 V: (with X-rays): r: -.13 to.03; V: ICCs: -.55 to -.62
Cornwall and McPoil (2004)	Healthy adults (82, 18-54)	Goniometer (rearfoot angle)	R: inter-trial: ICCs2,k: .95
Cheung Lau et al. (2009)	Healthy adults (27, 19-53) Adults with neck pain (26, 20-55)	Electronic Head Posture Instrument (EHPI) (Craniovertebral angle or head protraction)	R: intra-rater: Healthy : $ICCs_{1,1}$: (95% CI) 0.87 (0.74-0.94); 0.86 (0.72-0.93) Neck pain : $ICCs_{1,1}$: 0.87 (0.73-0.94); 0.91 (0.83-0.96) Inter-rater : Healthy : $ICCs_{2,1}$: 0.85 (0.71-0.93); 0.88 (0.76-0.95) Neck pain : $ICCs_{2,1}$: 0.86 (0.71-0.94); 0.91 (0.83-0.96) V: with index table: paired t-test: p=1.000; and r=1.000, p=0.000
Eng et al (2003)	Healthy adults (31, 21-58)	Goniometer. One body angle (head in sagittal plane)	R: intra-rater: ICCs*:.91, .94 R: inter-rater: ICC*: .95
Garrett et al. (1993)	Adults with orthopaedic disorders (40, 24-77)	Cervical Range of Motion (CROM) instrument (Forward head)	R: intra-rater: $ICC_{1,1}$: 0.93 Inter-rater: $ICC_{1,1}$: 0.83
Gilliam et al. (1994)	Healthy adults (23, 20-44)	Inclinometer, callipers type (Sagittal pelvic angle)	R : intra-rater : ICCs : 0.93 to 0.96 Inter-rater : ICCs : 0.95 V : (with X-ray): Corrected r : 0.51 and 0.60

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
B) Direct body measurements on subjects by goniometry and inclinometers			
Haight et al. (2005)	Healthy adults (18, 22-41)	Goniometer and visual measurement (Tibiocalcaneal angle)	R: intra-rater: $ICCs_{1,1}$: visual:.88 to .94; Gonio: .80 to .93 R: inter-rater: $ICCs_{2,1}$: visual:.56 to .65; Gonio: .50 to .75
Hinman et al. (2006)	Adults with osteoarthritis (40, >50)	Inclinometer (n=40) (tibia alignment) Goniometer (n=26) (Q angle)	V: with mechanical axis on X-rays: Inclinometer: r: .80 (p<0.001) Goniometer: r: .32 (p=0.12)
Johnson and Gross (1997)	Healthy naval midshipmen (63, 18-30)	2 lower extremity measures with goniometer (rear foot angle - RFA, arch angle- AA)	R: intra-rater: $ICCs_{2,1}$: .88 for RFA and . 90 for AA Intra-rater absolute difference: 1.2º ± 0.9º for RFA and 3.1± 2.1º for AA R: inter-rater: $ICCs_{2,1}$: .86 for RFA and .81 for AA Inter-rater absolute difference: 1.5º ± 1.3º for RFA and 4.6± 3.7º for AA
Lewis and Valentine (2008)	Healthy adults (45, 23-56)	Gravity-dependent inclinometer (Static angular measurements of scapula)	R: Healthy: intra-rater: $ICCs_{2,1}$ (95% CI) for the first trial: .84 to .95 (.72-.99) $ICCs_{2,3}$ for the mean of 3 trials: .92 to .98 (.83-.99) SEM: 0.9° to 1.2°

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
B) Direct body measurements on subjects by goniometry and inclinometers			
Lewis and Valentine (2008)	Adults with shoulder symptoms (45, 19-84)	Gravity-dependent inclinometer (Static angular measurements of scapula)	R: With symptoms: intra-rater: $ICCs_{2,1}$ for the first trial: .92 to .95 (.86-.99) $ICCs_{2,3}$ for the mean of 3 trials: .96 to .98 (.83-.99) SEM: 0.7° to 1.0°
Nilsson and Söderlund (2005)	Adults with whiplash (27, 20-54) Healthy adults (40, 20-52)	Universal goniometer (Sagittal head posture)	R: inter-rater: ICCs*: 0.95 Absolute error: 1.8°
Norton et al. (2002)	Healthy adults (30, 23-31)	Inclinometer (tangent method – TM) and Metrocom (tangent and trigonometric (Tr) methods) (Lumbar lordosis)	R: intra-rater: $ICCs_{3,3}$ Metrocom: .92 and .90 for TM and TrM Inclinometer:$ICCs_{3,1}$: .92 for TM
Piva et al. (2003)	Adults with low back pain (40, 18-65)	Inclinometer mounted on a crest level tester (Pelvic frontal tilt in standing and in sitting)	R: inter-rater: $ICCs_{1,1}$ (95% CI) and SEM: Standing: .80 (.69 to .88) and 0.91º Sitting: .73 (.59 to .83) and 0.86º
Peterson et al. (1997)	Healthy adults (49, 20-48)	Goniometer, (Forward shoulder posture – FSP	R: intra-rater $ICCs_{2,1}$: .89 V: (with X-rays): All subjects: r: -.33 Subjects with FSP: r: -0.21 Subjects without FSP: r: -.65

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
B) Direct body measurements on subjects by goniometry and inclinometers			
Prushansky et al. (2008)	Healthy adults (15 women, 15 men, 23-30)	Digital inclinometer (Sagittal neutral pelvic tilt, maximal anterior pelvic tilt, Maximal posterior pelvic tilt)	R: test-retest: $ICCs_{2,k}$: 0.86 to 0.96 SEMs: 0.9º to 2.1º
Robinson et al. (2001)	Healthy adults (8, 20-40)	Goniometer (Rearfoot alignment)	R: intra-rater: r: .93 for left foot, .95 for right foot, mean difference between test sessions: -0.43º and -0.50º. V: with X-rays: r: .74 for skin marking and .92 using calcaneal 40% line
Shultz et al. (2006)	Healthy adults (16, 25.6±3.2)	Inclinometer (sagittal pelvic angle – SPA) Goniometer (Quadriceps angle – QA, tibiofemoral angle – TFA) Straight edge ruler	R: intra-rater: $ICCs_{2,k}$, SEM: SPA: .64 to .98, SEM: 0.5 to 2.8º QA and TFA: .82 to .98, SEM: 0.7 to 5.9º Inter-rater: $ICCs_{2,1}$, SEM : SPA .48 to .68, SEM: 2.2 to 3.3º QA and TFA: .46 to .79, SEM: 1.7 to 3.7º
Trimble et al. (2002)	Healthy adults (43, 21-33)	Goniometer (Genu recurvatum)	R: intra-rater: ICC*: .94 R: inter-rater: ICC*: .95
Vanwanseele and Parker (2009)	Adults with osteoarthritis (11, 55 ±6.6)	Inclinometer (Frontal knee alignment)	V: with mechanical axis on X-rays: r: .83 ($p < 0.001$) With hip knee angle on 3D gait analysis system: r: .84 ($p < 0.001$)
Walker et al. (1987)	Healthy adults (31, 20-33)	Inclinometer (Sagittal pelvic tilt)	R: Inter-rater : ICCs: .84

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
B) Direct body measurements on subjects by goniometry and inclinometers			
Wilmarth and Hilliard (2002)	Healthy children (27, 9-10)	Goniometer (HPSCI – Head Posture Spinal Curvature Instrument) (Craniovertebral angle – sagittal head posture)	R: intra-rater: ICCs (subjects x day x trial): girls:.90, boys:.92 SEM: girls: 1.04 º, boys: 1.64 º
Youdas et al. (1996)	Healthy adults (10, 23-37)	Inclinometer (Pelvic inclination)	R: Intra-rater: $ICC_{1,1}$ .91
C) Other direct methods			
Alviso et al. (1988)	Healthy adults (12, mean of 24)	Meter sticks mounted on a wood base (Right sagittal pelvic tilt in neutral, active anterior tilt and active posterior tilt)	R: inter-rater: $ICCs_{1,6}$: .93 to .95
Arnold et al. (2000)	Women with osteoporosis (20, 55-75)	5 postural alignments with Carpenter's trisquare (distance from backboard to head, shoulder, hip, knee and ankle)	R: intra-rater: ICCs*: 59 to .99 R: inter-rater: ICCs*: .57 to .99
Gajdosik et al. (1985)	Healthy men (20, 19-34)	Tape measuremnt (Sagittal pelvic tilt in neutral, active anterior tilt and active posterior tilt)	R: intra-rater (test-retest) : r : .88 to .92
Hickey et al. (2000)	Healthy adults (122, 18-65)	CROM (Cervical Range Of Motion) and distance from plumb-line (Sagittal head posture)	R: intra-rater: $ICCs_{2,1}$: CROM: .77, .78; plumb-line: .82, .85 Inter-rater: $ICCs_{2,1}$: CROM: .68, .72; plumb-line: .74, .78

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
C) Other direct methods			
Hinman et al. (2006)	Adults with osteoarthritis (40, >50)	Calliper method (distance between medial femoral condyles or from medial malleolus) (Knee varus and knee valgus) Plumb-line method (distance between medial condyle or medial malleolus to plumb-line with calliper) (Knee varus and knee valgus)	V: with mechanical axis on X-rays: calliper method: r: .76 ($p<0.001$); Plumb-line method: r: .71 ($p<0.001$).
Johnson and Gross (1997)	Healthy naval midshipmen (63, 18-30)	1 lower extremity distance with calliper (genu varus /valgus)	R: intra-rater: $ICCs_{2,1}$: .93 Intra-rater absolute difference: 3.5mm ± 3.1mm R: inter-rater: $ICCs_{2,1}$: .95 Inter-rater absolute difference: 2.3mm ± 3.2mm
Lewis and Valentine (2008)	Healthy adults (45, 23-56) Adults with shoulder symptoms (45, 19-84)	Tape measure (Linear measurements of scapula)	R: Healthy : intra-rater: $ICCs_{2,1}$ (95% CI) for the first trial: .61 to .95 (.38-.98) $ICCs_{2,3}$ for the mean of 3 trials: .76 to .98 (.55-.99); SEM: 2mm to 5mm R: With symptoms: intra-rater: $ICCs_{2,1}$ for the first trial: .61 to .94 (.38-.97) $ICCs_{2,3}$ for the mean of 3 trials: .75 to .97 (.55-.98); SEM: 3mm to 5mm

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
C) Other direct methods			
Menz et al. (2003)	Elderly with foot problem (31, 76-87)	Distance (Navicular height)	R: intra-rater: $ICC_{3,1}$ (95%CI): .64 (.38 to .81)
Menz and Munteanu (2005)	Older people (95, 62-94)	3 measurements (arch index, navicular height, Foot Posture Index)	R: test-retest: $ICCs_{3,1}$: .99, .64, .61 V: (with X-rays): r -.52 to .79
McLean et al. (1996)	Adults patients (27, 22-64)	Plumb line (trunk list from T12 to S1).	R: intra-rater: repeatability coefficient in mm: 5 to 8mm R: inter-rater: 10 mm
Saltzman et al. (1995)	Adults with orthopaedic foot or ankle problem (100, 46±16)	Mitutoyo digital calliper to measure height (Arch height, Talar height, Navicular height)	R: intra-rater: ICCs* (95%CI) : .87 to .91 (.77 to .95) (n=45) Inter-rater: ICCs* (95%CI) : .74 to .79 (.55 to .88) (n=33) V†: with X-rays (Talar height): r (95%CI): .81 to .86 (.73 to .90) †: Values normalized to footprint length
Taylor et al. (1995)	Healthy adults (4, NP)	5 distance measurements with tape measure and body measurers (6 inch and 12 inch dividers) (Scapula to T2 spinous process, scapula to T8 spinous process, acromion to mastoid, acromion to iliac crest, acromion to radial styloid)	R: Intra-rater: Coefficient of variation (CV): < 5% Inter-rater: CV: < 5%
Thomson (1994)	Healthy adults (40, 19-26)	2 foot measurement from footprint (Valgus index –VI, relaxed calcaneal stance position – RCSP)	R: accuracy: ± 2 with 3 trials V: VI vs RCSP: r : .51
Trimble et al. (2002)	Healthy adults (43, 21-33)	Tape measurement (Navicular drop)	R: intra-rater: ICC*: .94 R: inter-rater: ICC*: .95,

Study Authors (year)	Type of Subjects (N, age)	Clinical tool type (Posture indices)	Psychometric properties Reliability (R), Validity (V)
C) Other direct methods			
Williams and McClay (2000)	Healthy adults R (20, 20-31) V (10, 20-34)	7 measurements of foot (Navicular height, height of the dorsom of the foot, angle of the first ray, navicular height divided by foot length, navicular height divided by truncated foot length, dorsom height divided by foot length, dorsom height divided by truncated foot length) A)10% and B) 90% of weight bearing	R:intra-rater: $ICCs_{2,1}$: .80 to.98 (A=B) R: inter-rater: $ICCs_{2,k}$: A) .51 to.92; B) .48 to.77 V: (with X-rays) ICCs: A) .77 to .98; B) .71 to .92
Wilford et al. (1996)	Healthy adults (25, 21-42) Adults wearing multifocal lens (25, 38-52)	Posture gauge (distance) (Sagittal head protraction)	R: intra-rater: ICCs*: .99 for both groups
Harrison et al. (2005)	Healthy adults (30, 30.9±9.2)	Flexible curve (Cervical lordosis: arc angle)	R: intra-rater: $ICCs_{2,1}$ (95% CI): 0.23 (0.14-0.37), inter-rater: $ICCs_{2,1}$: 0.18 (0.11-0.29) mean absolute difference: 26.4°
Harrison et al. (2005)	Adults with neck pain (96, 40.1±17.9)	Flexible curve (Cervical lordosis: arc angle)	V: Lower and upper limits of agreement: 15.1-110.8 With X-rays; r: 0.14
Hart & Rose (1986)	Healthy adults (R: 89; V: 8, NP)	Flexible curve Lumbar lordosis	R: intra-rater: ICC* .97 V : (with X-ray) r: .87

Legend: * ICC type not provided, NP: not provided.