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Validation of a computer analysis to determine 3-D rotations and translations of the rib cage in upright posture from three 2-D digital images

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Abstract Since thoracic cage posture affects lumbar spine coupling and loads on the spinal tissues and extremities, a scientific analysis of upright posture is needed. Common posture analyzers measure human posture as displacements from a plumb line, while the PosturePrint™ claims to measure head, rib cage, and pelvic postures as rotations and translations. In this study, it was decided to evaluate the validity of the PosturePrint™ Internet computer system's analysis of thoracic cage postures. In a university biomechanics laboratory, photographs of a mannequin thoracic cage were obtained in different postures on a stand in front of a digital camera. For each mannequin posture, three photographs were obtained (left lateral, right lateral, and AP). The mannequin thoracic cage was placed in 68 different single and combined postures (requiring 204 photographs) in five degrees of freedom: lateral translation (Tx), lateral flexion (Rz), axial rotation (Ry), flexion–extension (Rx), and anterior–posterior translation (Tz). The PosturePrint™ system requires 13 reflective markers to be placed on the subject (mannequin) during photography and 16 additional "click-on" markers via computer mouse before a set of three photographs is analyzed by the PosturePrint™ computer system over the Internet. Errors were the differences between the positioned mannequin and the calculated positions from the computer system. Average absolute value errors were obtained by comparing the exact inputted posture to the PosturePrint™'s computed values. Mean and standard deviation of computational errors for sagittal displacements of the thoracic cage were $Rx = 0.3 \pm 0.1°$, $Tz = 1.6 \pm 0.7$ mm, and for frontal view displacements were $Ry = 1.2 \pm 1.0°$, $Rz = 0.6 \pm 0.4°$, and $Tx = 1.5 \pm 0.6$ mm. The PosturePrint™ system is sufficiently accurate in measuring thoracic cage postures in five degrees of freedom on a mannequin indicating the need for a further study on human subjects.

Keywords Thoracic spine · Rigid-body motion · Posture · Rotation · Translation

Introduction

Human thoracic cage posture has been of interest since ancient times, especially deformities of the rib cage [20, 25, 35, 36, 45]. In his classic texts, Breig [8–10] showed that human postures can cause adverse mechanical tension on the central nervous system, thus correlating abnormal posture with disease. During the past century, thoracic posture (axial translation) has been associated with the treatment of disc degeneration and prolapse [13, 37, 50].

Besides deformity and disc disease, the presence of a high shoulder (lateral bending posture), axial rotation, or trunk list (lateral translation) is of interest to clinicians. The rotational thoracic cage postures (axial, lateral bending, flexion–extension main motions) have been studied for their affects on the lumbar spine (coupled motions), [12, 15, 24, 40, 43, 46, 48, 51, 52] while the translations (left–right, up–down, forward–backward) of the rib cage have received less attention in the literature [18, 22, 23, 47].

Clinically, it is important to measure abnormalities of upright posture. There are several non-invasive methods used to evaluate upright posture, including observation, plumb lines, posture angles on photographs, and orthograms [6, 14, 26, 44]. However, these methods are not able to measure posture as rotations and translations in six degrees of freedom (Fig. 1) as described by Harrison in the early 1980s [21]. Therefore, any dichotomous findings between the validity of posture as a cause of pain in published studies might be due to lack of uniform classification and measurement for normal and abnormal posture [6, 14, 26, 44].

Recently, a new computerized system, PosturePrint™, was developed that claims to measure head, rib cage, and pelvic postures as rotations and translations in three-dimensions (3-D). If these postural measurements had clinically small errors, future postural studies could account for formerly unrealized posture variables to allow for more robust methodology. It is the purpose of the present study to evaluate the validity of this PosturePrint™ computer system by comparing known positions of a mannequin thoracic cage to PosturePrint™ computed values. It was hypothesized that the PosturePrint™ would be sufficiently accurate for postural analysis in the clinical setting, i.e., less than 5° error in all rotations and less than 5 mm error in all translations.

Materials and methods

At the University of Quebec at Three Rivers biomechanics laboratory, 204 photographs (68 sets of three) of a mannequin thoracic cage were obtained in different postures on a stand in front of a digital camera. The object was positioned 61 cm (2 ft.) from a calibrated wall grid, while the camera was at 84 cm (33 in.) in height and 3.4 m (11 ft.) from the wall grid (Fig. 2). The camera was a Kodak, DC3400 with a 2.0 megapixel resolution.

Service for the PosturePrint™ Internet-based computer system is provided by Biotonix (Montreal, Quebec, Canada, http://www.biotonix.com). It requires three digital photographs (left lateral, AP, right lateral) of a standing subject as input data. For a full body evaluation, this computer postural analysis requires 13 reflective markers to be placed on the subject and an additional 16 "click-on" markers on the digital images with the computer mouse. However, there are only a total of nine thoracic cage markers needed to determine thoracic cage rotations and translations.

Using a Cartesian coordinate system suggested in 1974 [39], the PosturePrint™ computer program uses the coordinates of the markers to calculate rotations (in degrees) and translations (in mm) of the head, rib cage, and pelvis in 3-D space. While the PosturePrint™ system returns an analysis of the head, rib cage, and pelvis, only the thoracic cage analysis was of interest in this study.

These 68 different positions of a mannequin thoracic cage were single, double and triple combination postures of lateral flexion (Rz), axial rotation (Ry), flexion–extension (Rx), lateral translation (Tx), and anterior–posterior translation (Tz). Since vertical translation (Ty) is difficult to discern without an X-ray, the system does not attempt to measure that degree of freedom. Figure 1 illustrates these rotational and translational postures as 12 simple motions in 6 degrees of freedom in 3-D.

There were 18 (out of 68) positions of the mannequin rib cage evaluated for single postures of Ry (3, 5, 8, 10, 15, 20, 25, and 30°), Tz (−20, −10, 10, 20, and 30 mm), and Rx (−10, −5, 0, 5, and 10°) determined in the lateral view. There were 20 positions evaluated for the double combination positions of Tz (using −20, −10, +10, +20, and +30 mm) and Rx (using −10, −5, +5, and +10°). For AP view postures, there were 10 positions of the mannequin thoracic cage evaluated for the single postures of Tx (5 lateral translations of −20, −10, +10, +20, and +30 mm) and Rz (5 lateral bendings of −10, −5, +5, and +10°) and 20 double combinations of these same numerical postures of Tx and Rz.

It is a unique feature of the PosturePrint™ system that axial rotation (Ry) is determined in the lateral view by any separation projection of two reflective markers, which are 15 cm (6 in.) apart on a plastic strip placed at the inferior of the scapulae.

The PosturePrint™ computed values were compared to the known positions (true values) of the mannequin thoracic cage and the differences were evaluated as an error analyses.

Results

The postures of Rx, Ry, and Tz are determined from lateral view markers. Mean and standard deviation of computational errors for 18 single sagittal displacements were $Ry = 1.2 \pm 1.0°$, $Rx = 0.3 \pm 0.1°$ and $Tz = 1.5 \pm 0.6$ mm. The mean and standard deviation of computational errors for the 20 double sagittal displacements of Tz and Rx were $Tz = 1.6 \pm 0.8$ mm and $Rx = 0.3 \pm 0.2°$.

The average error comparing the 10 single postures of Rz and Tx of the mannequin (true values) to the computed values were Rz = 0.5 ± 0.3°, and Tx = 1.2 ± 0.5 mm. The average error comparing the 20 double combination positions of Rz and Tx, with computed values, were Rz = 0.7° ± 0.5°, and Tx = 1.6 ± 0.6 mm.

Table 1 provides the mean errors for comparing all the positions in this study ($N = 68$) with PosturePrint™ computed values.

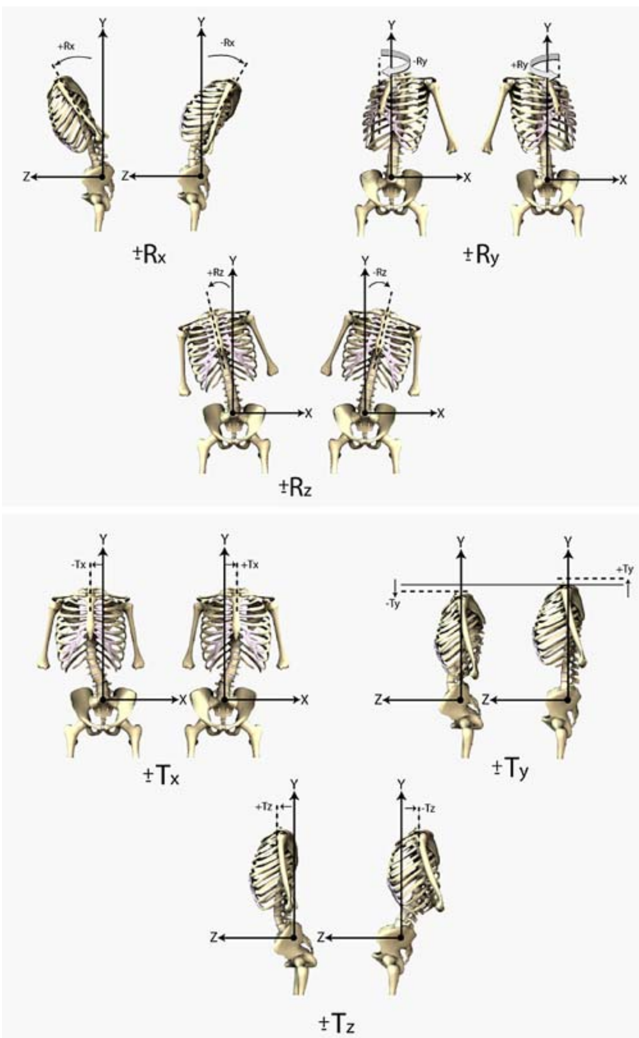

Fig. 1 The 12 simple postures of the thoracic cage in 6 degrees of freedom in three-dimensions (3-D). If considered as a rigid body, the thoracic cage can rotate around (Rx, Ry, Rz in **a**) and translate along (Tx, Ty, Tz in **b**) all three axes in a 3-D coordinate system. If the positive *y*-axis, *z*-axis, and *x*-axis are chosen vertically, anteriorly, and to the left, respectively, then all possible rotations and translations are as illustrated here

Discussion

Our purpose was to evaluate the validity of the PosturePrint™ computer program for postural analysis by comparing computed results from three digital photographs to true positions of a mannequin thoracic cage. It was hypothesized that the PosturePrint™ computer system would be accurate enough for clinical use. Since the average errors between the true position of a mannequin rib cage and the calculated values were less than 1.3° for all rotations and less than 1.7 mm for all translations, the PosturePrint™ computer system is sufficiently accurate for evaluations of ribcage postures.

Since postural analysis with the PosturePrint™ is a computerized method, the limitations are the errors due to approximation, which are small in this case and not clinically relevant. Therefore, any errors due to palpation and placement of the reflective markers by the clinician will be the major errors. Because the mannequin data from computer program approximation indicates small errors and good validity, the next research step would be a clinical reliability–repeatability study.

Since 1970s, segmental spinal movements have been categorized and studied as rotations (Rx, Ry, Rz) and translation (Tx, Ty, Tz) [39]. Very few have described posture as head, rib cage, and pelvic rotations and translations [21]. From extensive literature reviews, we could not locate any postural measurements of the thoracic cage that returned values for rotations and translations. Historically, it seems that the postural analysis, as used clinically, is restricted to lateral flexion (Rz), with a minimal evaluation of flexion–extension (Rx) and sagittal balance [27].

In the minimum, determining thoracic cage posture as rotations and translations would be important for (1) biomechanical studies of main motion and coupled motion, (2) studies concerning stress and strain on spinal tissues, (3) studies on the spinal muscles with EMG, and (4) associated thoracic cage posture with deformity and scoliosis.

It has been observed that scoliotic subjects have straightened thoracic curvatures and anterior weight bearing of the thoracic cage (anterior translation = Tz) [3]. Additionally, these subjects often have a low shoulder (thoracic lateral flexion = Rz) and thoracic side shift (lateral translation = Tx) [3, 7]. Thus, there are some abnormal postures of the thoracic cage, as rotations and translations, which are often associated with scoliotic deformity. However, these rotations and translations of the whole thoracic cage may be present in subjects without scoliosis.

When these postures are the neutral resting posture of the subject, equilibrium equations in the AP view can be used to show that the postures of ± Tx, ± Ry, and ± Rz will result in abnormal asymmetrical loads on the spinal tissues and the

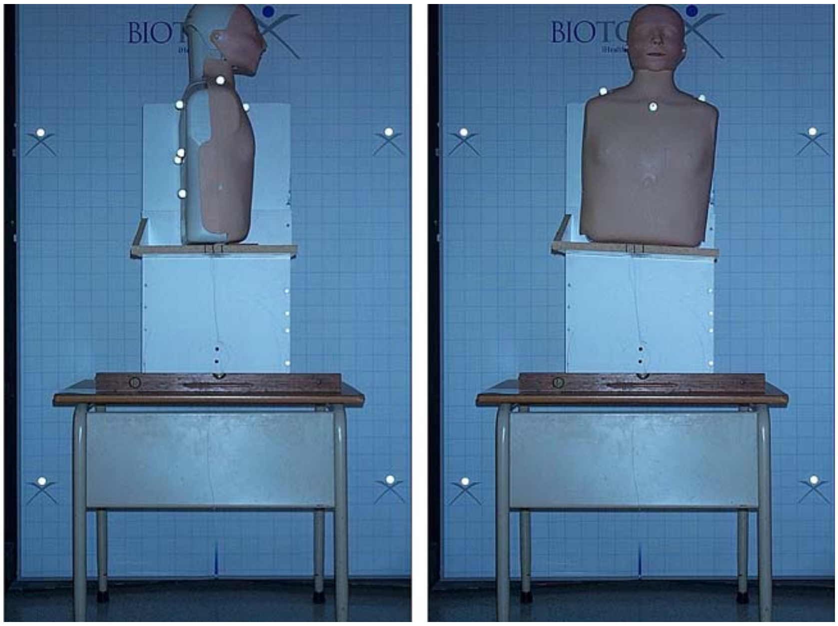

Fig. 2 For the data collection procedure in this study, a mannequin thoracic cage was positioned in front of a calibrated wall grid. Three digital photographs are the data for the PosturePrint™ computer system, [left lateral (shown with some axial rotation in **a**), AP (shown with some right lateral flexion in **b**), right lateral (not shown)]. A 15-mm strip, with reflective markers at each end, is placed at the inferior of the scapulae, symmetrically about the median-sagittal plane. This eliminates the need for a vertical camera to determine axial rotation (Ry), as any projected distance between these strip markers is used to approximate axial rotation. Reflective markers are placed on the T2 spinous process and the T12 spinous process to evaluate for flexion–extension as rotation about the x-axis (Rx). A line through both acromioclavicular joints is compared to the floor as an evaluation of any lateral flexion (Rz) in the AP view (**b**). Two additional click-on computer mouse points are located at the lateral margins of the 8th ribs

lower extremities. These postures are also associated with asymmetrical muscle efforts and abnormal disc loads. Numerous EMG studies over the past four decades support this idea [2, 4, 5, 11, 17, 28, 29, 30, 31, 34, 38].

Additional studies have reported disc response and/or loads for the lumbar spine associated with lateral postures, such as flexion–extension (Rx), [1, 16, 19] forward–backward translation (Tz), [32, 33] and vertical translation (Ty) [13, 50].

Besides the abnormal loads on the spinal tissues and the obvious need to determine thoracic cage posture in scoliotic deformity, the neglect in determining rotations and translations of posture, especially for the thoracic cage, is its affect on the lumbar spine.

For biomechanical studies on spinal movement, it often goes unstated that posture (main motion) results in spinal coupling (segmental coupled motion). Thoracic cage movements (main motion rotations and translations) cause specific lumbar spine coupled motion [12, 15, 18, 22, 40, 43, 46, 51, 52].

It is becoming accepted that initial posture affects spinal coupling, and therefore thoracic cage posture (as rotations and translations) affects lumbar spine coupling [12, 41, 42, 46, 49, 52]. Thus, initial thoracic cage posture as rotations and translations must be identified before lumbar biomechanical studies are performed on human subjects and before range of lumbar motion is evaluated clinically.

Conclusion

The PosturePrint™ Internet-based computer system is accurate for measuring a mannequin's thoracic cage postures. Computed values compared to mannequin thoracic cage positions have average errors less than 1.2° for all rotations and less than 1.6 mm for all translations.

Table 1 Mean Errors of the PosturePrint™ mean errors and standard deviations for all 68 thoracic cage evaluations comparing positions of a mannequin rib cage with computed values by the PosturePrint™ computer system

Result for all 68 rib cage positions	Rx (°)	Ry (°)	Rz (°)	Tx (mm)	Tz (mm)
Average error	0.32	1.16	0.62	1.48	1.56
Standard deviation	0.10	1.00	0.40	0.59	0.73

The PosturePrint™ uses a set of three digital photographs as input data. Using all 68 of the mannequin positions and PosturePrint™ calculations, mean errors (and standard deviation) for each of 5 thoracic cage degrees of freedom are presented. Using a right-handed Cartesian coordinate system, with the positive y-axis vertical, positive z-axis forward, and positive x-axis to the left, rotations are designated as Rx (flexion–extension), Ry (axial rotation), and Rz (lateral bending)

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