Validation of Triaxial Accelerometer to Continuous Monitoring of Back Posture at Sagittal and Frontal Planes in Workplaces

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Abstract

Introduction: Musculoskeletal disorders are the most common work-related injuries and illnesses in workplaces. One of the important risk factors in creating low back pain during labor is undesirable postures. There are different methods for monitoring lumbar posture. The most important tools with high accuracy are direct measurement tools. The main aim of this study was to introduce and validate novel equipment in continuous monitoring of lumbar angles in the sagittal and frontal planes during work shift.

Methods and Materials: A standard hand-held goniometer was used to calibrate an inclinometer (Virtual Corset). Depending on the type of the measurement plate, an inclinometer was mounted on a movable arm of the goniometer and angles of the two devices were adjusted; and the rate of the accuracy of the inclinometer was determined. Flexion angles were measured to be 0º to 95º, and lateral and extension angles were measured to be 0º to 45º.

Results: The error obtained from the inclinometer in the sagittal and frontal planes were approximately 1º and 0.05º, respectively. In addition, Cronbach's alpha coefficient and regression line power was obtained to be 0.99.

Conclusions: Despite Cronbach's alpha being more than 0.75 and the high power of the regression line (0.99), VC is of sufficient validity for monitoring the angles of the lower back in a working shift. Additionally, the results of the study showed that the determined error was approximately identical to the error declared by the manufacturer.

Keywords: Triaxial accelerometer, manual goniometer, sagittal plane, posture.

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Introduction

Musculoskeletal disorders (MSDs) are prevalent in the various industries and are defined by the United States Department of Labor as an injury or disorders of the muscles, joints or tendons, nerves, vertebral discs. They are caused by repetitive movements of sudden bending, twisting, stroke etc. (1). With the development of modern life, the prevalence of back pain has not become more, but its speed rate has become higher than the rate of population growth. In the United States, back pain is the second cause of absenteeism, and has made 30 to80 million dollars decrease in production annually. About 90% of people have experienced back pain at least once in their lifetime, and 50 to 70% of people experience recurrent episodes of back pain during their lifetime, figures which are clearly higher in industrialized countries(2).

Postural assessment methods in increasing accuracy of data collection include self-report, observational methods and direct measurement methods (3).The data of self-report are collected through questionnaires and interviews, with no high accuracy due to personal opinions stated in it, and low validity and reliability(3). The simpler observational methods such as NIOSH (National Institute Occupational Safety & Health) and OWAS (Ovako Working Analysis System) and RULA (Rapid Upper Limb Assessment)etc. have higher accuracy than the previous methods; however, in these methods, the researcher's opinion is central and the results can be subjective, currently the applications of these methods are less common. Today, more advanced observational methods are videotaped based, in which a person's movements are recorded and later reviewed. High cost and low accuracy are the disadvantages of this method (4). Direct or instrumental measurement methods, despite their high cost, have high reliability; but a research done by Trask et al. on the accuracy and the cost of the measurement techniques of posture, showed that instrumental techniques compared with the direct observational methods had high precision and less cost (5). The use of direct measurement equipment for postures is increased along with the development of studies in the field of prevention and control of the work-related musculoskeletal injuries. Inclinometers provide objective and quantitative measures appropriate for continuously estimating trunk posture while working with minimal interference. It is affordable in terms of cost and accurate as recommended by manufacturers. It can be used as an efficient tool of high precision in evaluating posture.

This study aimed to introduce a portable electronic inclinometer for continuous monitoring of lumbar postures. Furthermore, the capability of the electronic inclinometer in measuring angles in frontal and sagittal plane is validated using hand-held goniometer. In other words, we determine the difference in the angles by two tools, i.e. standard goniometer and electronic inclinometer. This evaluation was conducted in a laboratory and in static conditions while goniometer was mounted on a table rather than a lumbar.

Study method

The first step to validate the electronic inclinometer is connecting two parts of goniometer in such a way that its movable arm is able to move, but this feature should not go beyond the experimenter's control, or so tight that it cannot move. Sample angles are selected, because lateral bending for lumbar vertebrae is less than 40° and flexion/extension is less than 95°. To decrease errors in different locations, the reading of angles was carried out five times.(15)

Tools and calibration
The triaxial accelerometer (inclinometer)[Virtual Corset VC)(Microstrain, Williston, VT,USA)]is a light (72 g),wireless, battery-powered, pager-sized (6.8×4.8×1.8cm) portable logger with 2MB memory, with data sampling frequency of 15 Hz.
Inclinometer is designed to calculate angles based on the acceleration of gravity. The VC is located on the sternum or behind the sixth thoracic vertebra and it records angles of the trunk bending in three dimensions with a frequency of 15 Hz (7). Movements of this point of spine (the sixth thoracic vertebra) show (lumbar) body bending.
Since the least body bending (front and back) is characterized by the sixth vertebra to the next, the tool is placed on the vertebra or over sternum that is in the range of motion of the same vertebra as shown in Figures 1 and2.
The other equipment used in testing was a standard hand-held goniometer (Sammons Preston Rolyan-USA). A goniometer is one of the simplest tools to measure the posture in different angles of the joints. Goniometer is made of clear plastic with two long arms and an angle meter in the center, which rotates by a movable arm. Each arm is stretched against a part of the body to the center of the joint, which is in the middle of angle meter.

Figure 1: Virtual Corset Figure 2: Positioning of virtual corset on sternum in harness

Methods and Materials
The VC is calibrated by standard goniometer to determine errors. For calibration, VC is fixed on a movable arm of the goniometer and is connected to the computer via a cable. Using VC software, angular momentum changes are monitored in both sagittal and frontal planes. A monitor displays the angular changes (Figure 3).

Data collection
There are two static and dynamic methods for calibrating electronic inclinometer to collect data. In this study, the laboratory and static methods (mounting VC on the movable arm of goniometer) were used.

Static method
Considering the sagittal plane, the calibration process was performed at zero angle of flexion to 90° and in zero to 45° of extension and lateral angle with an interval of 5°. After five seconds from start of calibration, the electronic inclinometer angles were recorded directly through the software installed on the computer.

Statistical Analysis
The calculation was performed with an interval of 5° and with repetition of 5 times for measuring the error rate of the VC for forward bending angles from zero to 110 ° and back bending angles and lateral bending angles from zero to 45 degrees. The Root

Mean Square (RMS) errors were calculated for both directions, because this error is more accurate than the other errors. RMS error is calculated as follows:

RMS Error = $\sqrt{\Sigma (Xo - X_a)^2 / n}$

Where Xo= observed values, X_a=actual values, andn=value numbers

In addition, regression-test was used for calibrating electronic inclinometer-dependent variable by an independent variable goniometer, and the power of the regression line (R2) was obtained. Moreover, the accuracy of the inclinometer was obtained using a Cronbach's alpha test. The accuracy of the inclinometer in the front, back, and lateral bending angles was obtained as 0.99, 1, and 0.99, respectively with Cronbach's alpha test. This test was assessed for each angle separately and the obtained result was 1°.

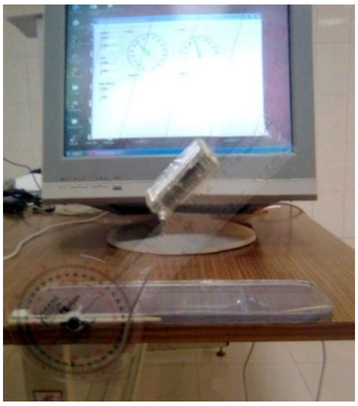


Figure 2: Virtual corset is placed on the movable arm of goniometer at the extension position

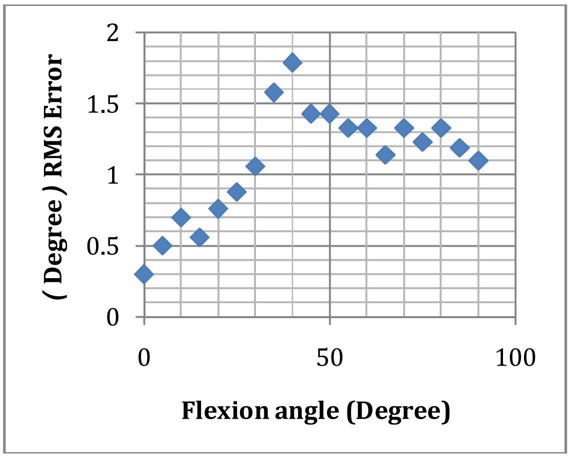
Results

The flexion-extension and lateral bending angles measured by the two devices for each plane motion are shown in Table 1.The RMS and maximum angles error values for VC and for each plane of motion are shown in Figures 3 to 6.

Generally, the errors estimated from the inclinometer in the sagittal and frontal planes were approximately 1° and 0.05, respectively, and Cronbach's alpha coefficient and regression line power was obtained at 0.99

Table 1: The calculated errors of virtual corset (VC) in calibration by standard goniometer

Goniometer	Flexion		Extension		Lateral-right		Lateral-left	
	VC	Error	VC	Error	VC	Error	VC	Error
0	3.33	0.3	1.875	2.14	0.7	0.14	0.7	0.2
5	6.075	0.5	4.65	0.34	4.73	0.093	4.77	0.082
10	10.78	0.7	10.1	0.32	9.7	0.054	9.7	0.037
15	15.8	0.56	14.73	0.3	14.73	0.034	14.6	0.045
20	21.6	0.76	20.6	0.57	19.73	0.025	19.83	0.017
25	26.53	0.88	26.1	0.53	24.8	0.015	24.63	0.026
30	31.53	1.06	31	0.94	29.8	0.016	29.63	0.023
35	36.075	1.58	36.3	1.18	34.9	0.0067	34.6	0.019
40	41.38	1.79	41.3	1.23	59.8	0.00935	39.4	0.026
45	45.8	1.43	46.6	1.53	44.77	0.01	44.57	0.02
50	51.4	1,43						
55	56.4	1.33						
60	61.4	1.33						
65	66.2	1.33						
70	71.4	1.14						
75	76.25	1.33						
80	81.35	1.23						
85	86.15	1.33						
90	90.45	1.19						
95	96.38	1.1						



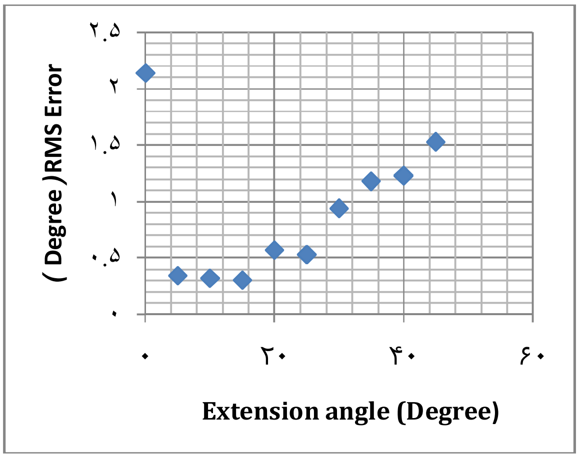
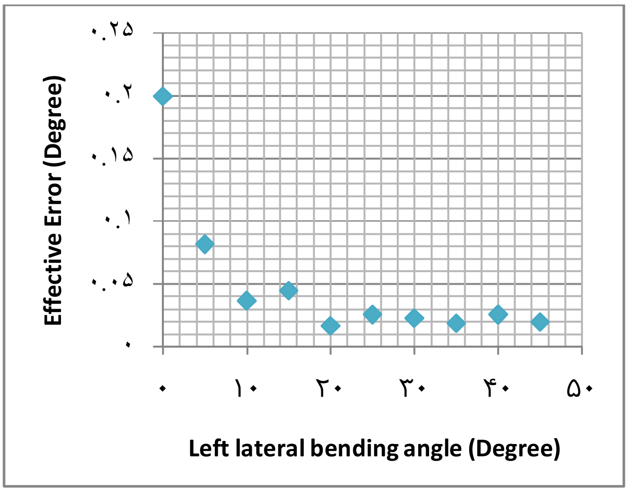


Figure 3 and 4: Comparison of the angles measured by VC and the goniometer at sagittal plane



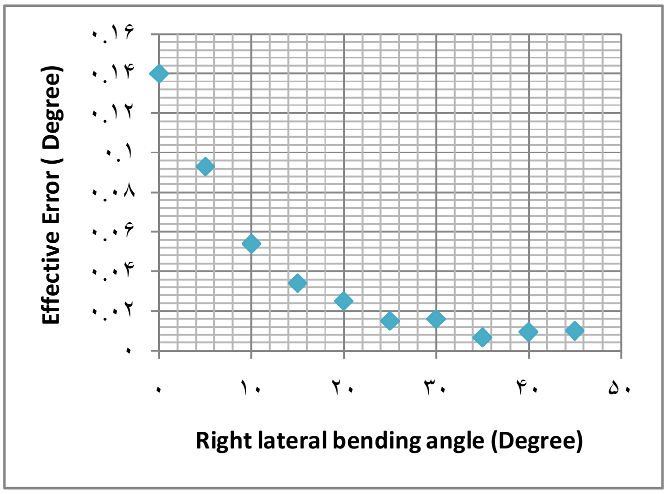


Figure 5 and 6: Comparison of the angles measured by VC1 and the goniometer at frontal plane

Discussion

Many studies have shown that there is a relationship between awkward trunk postures with job-related low back pains (2, 8). Besides, awkward postures cause an increase to the loads on the lower back (7).

Because of the importance of trunk posture assessment, it should be performed using modern techniques of high accuracy and with least interactions at work. Among the postural assessment methods, self-report and observational methods are the most common techniques compared to instrumental techniques.

Self-report method is easy to use, costs-effective, and is used in a broad extent of business situations, for variety of people. However, people's perception toward work exposures may be wrong and unreliable. Observational methods are divided into two categories: pen and paper (OWAS, RULA, PLIBLE, etc.) and advanced techniques (biomechanical models and video analyses, etc.). Observational techniques, including pen and paper are applicable in a wide range. Easy application and high accuracy have been mentioned as the benefits of pen and paper-based observation methods compared to the self-report techniques. Similarly, the advanced techniques are of more accuracy than pen and paper method. Recently, a study showed that the application of direct observational techniques has more cost and less accuracy than some other devices methods such as portable accelerometer (3). The inclinometer technique offers most accurate assessment of the physical workload exposures, and postures with repetitive movements in comparison with self-report observational techniques. In a study conducted by Dong et al., the use of the measurement tools equipped with an accelerometer had the best accuracy compared with optical-audio imaging-based equipment and hybrid systems. Zhou et al. proved that accelerometers, due to high precision and convenience and with the least interference with work activities, could be used in investigating the postures for a long period (9).

In the present study, precision of the inclinometer was assessed using the goniometer. The results showed that the RMS error rates in the flexion and extension positions were 1°and about 0.5°, respectively. In the lateral bending status, the error rate was remarkable. Manufacturing Company (Micro strain) has reported the accuracy of the virtual corset to be ±0.5°. This error is related to a motion range of ± 180° front bending of the trunk and ±70° lateral bending of the body. In a study conducted by Beaucage-Gauvreau in West Africa, the RMS error was calculated to be less than 1°, a result which is similar to the result of the present study (10).

Trask stated the VC is used in several field studies to determine the orientation of the trunk (18) and the shoulder (16) during different tasks. In another study conducted by Amasay and Driel, it was stated that, with the increase of the angular acceleration, angular error significantly increases. It was suggested that inclinometer should not be used for quick activities. Amasay et al. reported that the root mean square (RMS) angle error under static conditions was reported to be less than 1°. The experimental conditions for calculating the static and RMS angular error in that study were similar to those of the present study; however, another rotating primary standard with amounted VC was used in that study. During the rotation of both tools, the standard records the angles that are compared at the end (1). The error reported in that study is similar to the error obtained in the present study. In addition, Adolph stated that VC is a device with acceptable accuracy for monitoring physical activities.(17)

Due to the high precision of VC, this tool can be used for assessing postures in ergonomic applications and interventions. Many studies are conducted on the use of VC in biomechanical studies; for example, assessing the neck postures in air traffic controllers and dentists (12,13,16), or study of back postures in the weavers at different tasks during a work shift(19); due to the kinematics data collected in these studies, the physical workload level was estimated. Thus, by specifying the angles of the trunk and the duration of the sampling, other parameters such as speed and time of exposure at angles greater than 20 degrees can be estimated. So far, in the previous studies, pen and paper or observational techniques have been used for assessing postures; but instrumental techniques, due to their high cost and limited use, have not been used in the field studies. This study showed that due to a high precision and lower cost, inclinometers might be used as an efficient device for continuous monitoring of back postures, rather than other techniques such as surface electromyography.

Limitation and future researches

In this study, we used manual goniometer for calibration of inclinometer, while there exists a number of other tools for calibration, such as electronic goniometer, potentiometer, gimbal, and X-ray, which are considered gold standard but not available to us. Since, researchers' accuracy and environmental conditions vary in experiment time, for any future researches, we suggest applying calibration of inclinometer through various calibrators and compare their accuracy to select the best one. Considering costly procedures such as EMG, it is expected that as an accurate and cost-effective method, this technique will be applied for the future studies on estimation of spinal loading.

Conclusions

The VC was validated against a standard goniometer in a series angle of sagittal and frontal plane movement. The VC can be considered a good instrument for field research because of its high accuracy and other advantages such as small size, being wireless, memory capacity, and low weight.

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