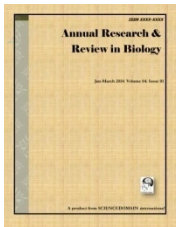

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Reaction Force Measurement in Milwaukee Brace during Daily Activities-Introduction of a New Measurement System

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Authors' contributions

This work was carried out in collaboration between all authors. All authors designed the study, performed the statistical analysis and the paragraph has been completed. Authors E. Gohari and A. Ataei managed the analyses of the study, managed the literature searched and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: The reaction forces of the Milwaukee Brace's (MB's) several areas were measured during normal daily activities (24 hr) by a new measurement device improved in order to force acquisition by groups of sensors distributed in all of the MB's internal areas.
Methodology: In the current study, a new measurement system using Force Sensitive Resistance (FSRs) distributed on the different areas of MB for scoliosis patients. Sensitivity

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analysis has been fulfilled to compare two different sensors arrangements placed in the basket of MB. A reliability analysis has been carried out for normal activities including sitting, walking and sleeping. Two healthy volunteers and two scoliosis patients were nominated to force acquisition from their MB during 23 hours of daily activities.

Results: In the sensitivity analysis, maximum value of Cronbach's Alpha was 0.775 for sitting at basket lateral side. In the reliability analysis, the maximum and minimum difference between the force values of the two arrangements is 1.37(N) and 0.19(N) respectively related to the sitting test. The tests for each subject commenced with 9-11 hours of sleeping and continued for 12-14 hours in which main activities were sitting and walking. The forces average values of each part of the tests were reported for different areas of MBs. The mean, median, mode, standard deviation and ratio of standard deviation on the mean have been calculated for each brace region for both time durations.

Conclusion: The brace different areas forces for sleeping and day time activities had normal distribution. The force value of the brace regions having direct contact with mattress surface was increased during sleeping with respect to day time activities. Other regions forces were decreased or remained constant in this time duration. The forces detected from the lumbar pad during most of the test time were constant.

Keywords: Adolescent idiopathic scoliosis; milwaukee brace; force measuring; clinical test.

1. INTRODUCTION

Adolescent Idiopathic Scoliosis (AIS) is three-dimensional torsional deformity of the spine and trunk [1-3]. Young girls are most susceptible to progressive scoliosis [4]. The index describing scoliosis intensity is known as "Cobb" angle [5]. Depending on the measured Cobb angle, treatment could be done through surgery (More than 50 degrees) or using a brace (20-50 degrees) [6]. Providing constraints, a Milwaukee Brace (MB) prevents increasing spine curvature and might have some corrective effects [7]. Whereas the correction of the scoliosis curve is a time-dependent procedure, patients have to wear their braces 23 hours a day for at least 6 months. Since biomechanical performance of braces is not well-recognized, the first step is to monitor the variation of forces at the interface of the patients' body and MB.

Many studies have been devoted to measuring the reaction forces in the Boston braces. Aubin and Perie et al. [8,9] measured the reaction forces using a sensor matrix consisting of 192 pressure sensors. The brace and torso interface forces were measured by Dansereau and Aubin [10] and applied to their finite element model. Thiong et al. [11] obtained the brace interface forces of 41 patients treated by Boston brace. Lou et al. [12- 14] developed a force measuring device for Boston and MB. They recorded the interface forces by a transducer on the main force pad.

Regarding the previous researches on this issue, reaction force recording was limited to static acquisition or few sensors size for time dependent measurement. There is no report of using sensor matrix to record forces dynamically in all regions of brace. In the current study, a new measurement device has been improved in order to force acquisition by groups of sensors distributed in the several areas of MB. As the first step, the new set up has been utilized within the braces made for two healthy volunteers and several experiences have been carried out to evaluate the sensitivity and reliability of the force measurement system. Afterward, two scoliosis patients were nominated to force acquisition from their MBs. All the subjects were monitored for 23 hours of daily activities while wearing their MBs.

2. MATERIALS AND METHODS

2.1 Subjects

Two healthy volunteers (one 20-year-old female: height: 160cm, weight: 52kg. One 25-year-old male: height: 170cm, weight: 65kg) and two AIS patients (one 13-year-old female: height: 167cm, weight: 53kg, lumbar scoliosis: 18 degree (sinistra)(level of Lumbar apex: L3), thoracic scoliosis: 20 degree (dextra)(level of Thoracic apex: T7), Kyphosis: 37 degrees and Hump:10 degrees. One 14-year-old male subject: height: 173cm, weight: 50kg, lumbar scoliosis: 22 degrees (dextra) (level of Lumbar apex: L3), no thoracic scoliosis and kyphosis: 57 degrees, Hump: 5 degrees) were nominated to participate in the study after signing consent forms. For all subjects, MB has been made through molding method. In order to set an acting area of forces created by the thoracic pad, a nominal curve apex at T7-T8 level was taken into account for the healthy subjects. For the patients, the locations of the thoracic and shoulder pad were determined according to their curve apex in lumbar and thoracic spine.

2.2 Sensors

FSRs (force sensitive resistance) were exploited to measure the body reaction forces in the MB. FSRs used in the present study were circle-shaped (radius equals 6.35 mm in their active area).Sensors were placed in the areas including the basket of brace, thoracic and shoulder pad, axillary band and back-head as shown in Fig. 1. The basket was divided into five regions of abdominal, lateral and lumbar (at both right and left sides).The average number of sensors used in the basket, thoracic pad, shoulder pad, axillary band and back-head was 30, 6, 4, 3 and 2respectively. Sensors were placed in to the center of 4*4 cm^2 square grids in the internal surface of the basket. Wires were conducted to outside of the basket through holes were devised in it. All wires were shielded so as to reduce the effects of surrounding noises.

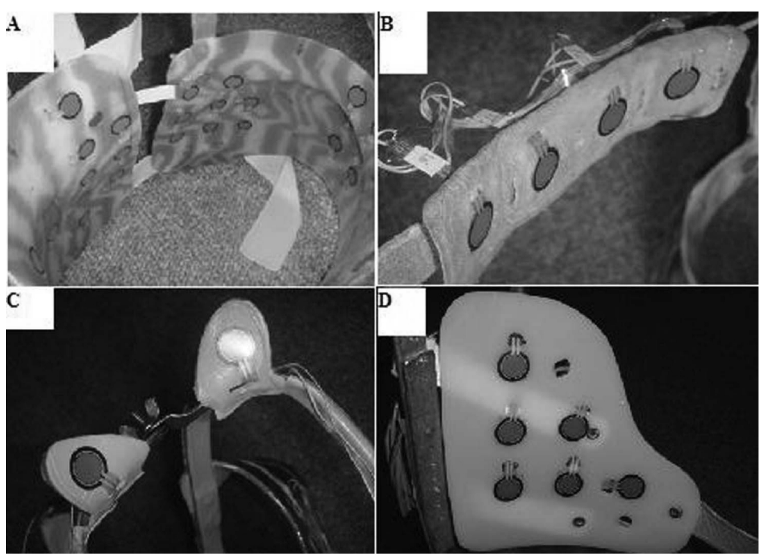

Fig. 1. Sensors placed in (A) basket of brace, (B) axillary band, (C) back- head process and (D) thoracic pad to measure the reaction forces in the MB

2.2.1 Calibration

All FSRs were calibrated at the range of 50 gr to 2 kg (by the step of 50 gr). The response of the sensors under loading, was extracted individually. The best curve fitting was exerted in MATLAB Commercial Software to determine the function describing the sensors behavior in general.

2.3 Recording System

One10-bit A to D convertor, having sample rate of 1/min and capability of recording sensors output on a memory stick was developed. The device could be used in each states of applying DC power supply or internal rechargeable battery. Also, a USB connection port was considered to real time data transfer to the LAB VIEW Commercial Software. The dimensions of the device are 12cm x 5cm x 2 cm and its weight is150 gr (Fig. 2).

Fig. 2. Shows the device to record and transfer data to computer.

2.4 Sensitivity Analysis

A sensitivity analysis was performed to evaluate the accuracy of the force measurement in a 4*4cm^2 square grid of basket by a sensor at the center of the square. To achieve this purpose, the force value of two different arrangements of sensors were compared with each other. First, one FSR was places at the center of 4*4cm^{2}square, then four FSRs were added to the square grid as shown in the Fig. 3.

For the first arrangement, the force value of the single FSR at the center of square multiplying by an area ratio was reported. For the second arrangement, the summation of five FSRs force value placed in the square was reported. Three activities of normal walking, sitting and sleeping were considered for the tests (Fig. 4). In each condition a normal subject wearing MB was monitored for ten minutes and each test was repeated 3 times.

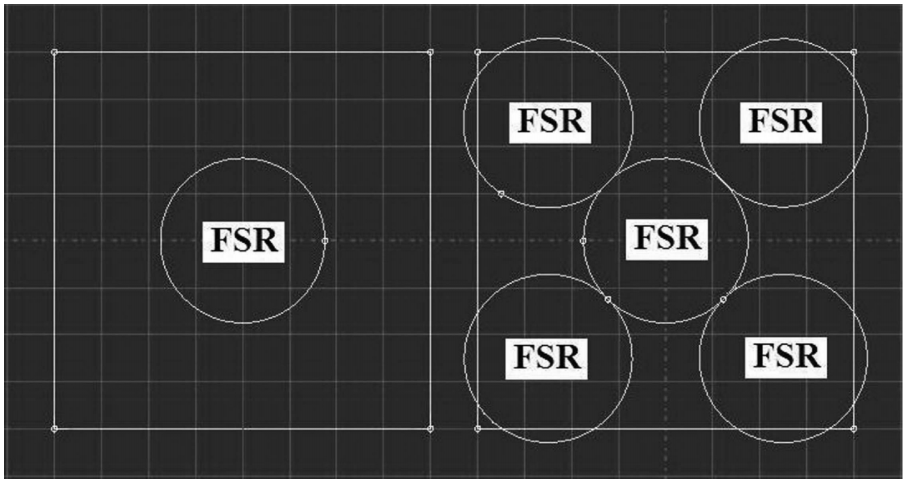

Fig. 3. Shows the schematic of two different arrangements of FSR in a 4*4 square for sensitivity analysis.

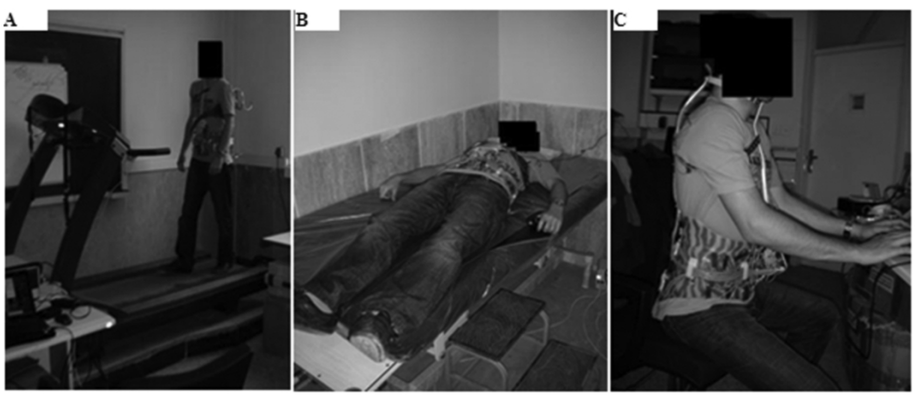

Fig. 4. Three activities of normal walking (A), sleeping (B) and sitting (C) considered for tests

2.5 Reliability Analysis

Reliability analysis was carried out on results over the three activities of normal walking, sitting and sleeping obtained from sensitivity analysis. The results of this section have been reported as the values of Cronbach's Alpha.

2.6 Daily Activity Test

All subjects were monitored while wearing their MBs during 23 hours of their normal daily activities. For the best interpretation of results, the patients' parents were asked to list major activities of their children over the test period with regard to the time of each activity. In order to be aware of the devices' well performance in force acquisition, a sound alarm was built during test time.

3. RESULTS

3.1 Sensitivity Analysis

The results of the sensitivity analysis have shown maximum and minimum difference of 1.17(N) and 0.19(N) respectively between the force values of one-sensor and five-sensor arrangement in the sitting, walking and sleeping tests(Fig. 5). The results in each activity have the same trends. According to regression analysis on the results of five sensor arrangement via five sensors arrangement, the coefficients of determination (R^2) were 0.71, 0.77 and 0.98 for walking, sitting and sleeping respectively.

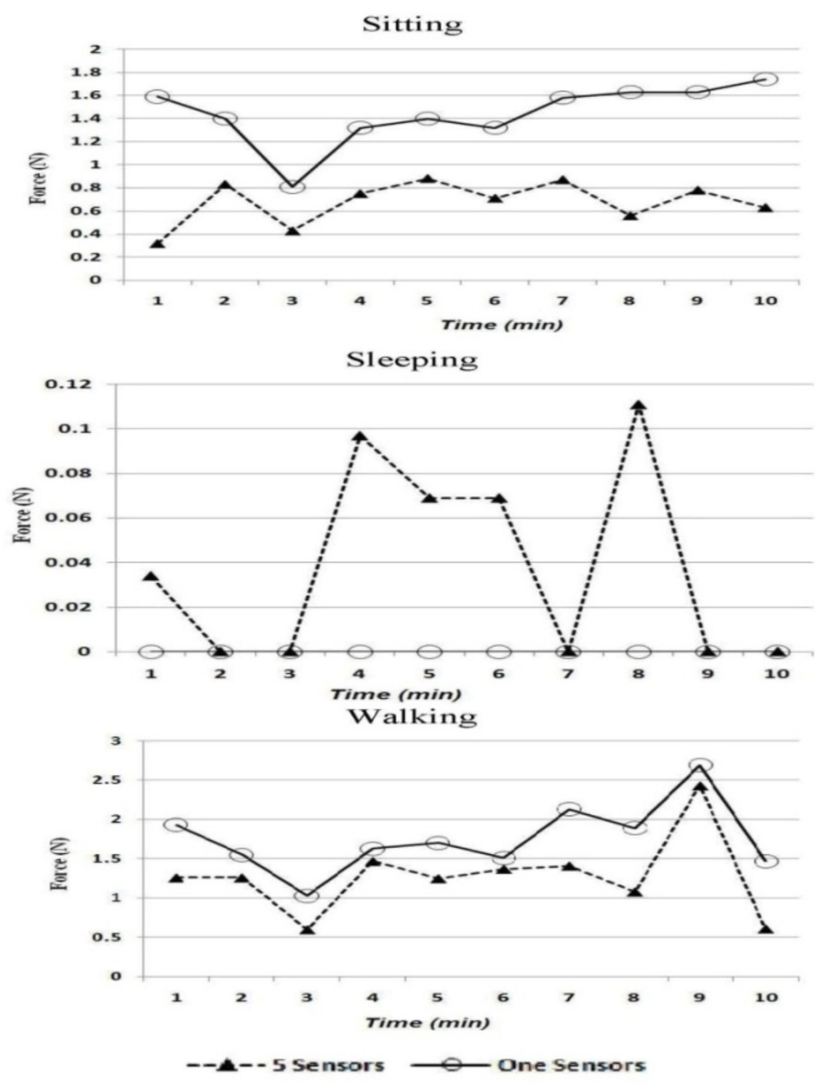

Fig. 5. Shows comparison between one-sensor and five-sensor arrangements for Sitting, walking and sleeping force acquisition

3.2 Reliability Test

For the reliability analysis, Cronbach's Alpha was calculated for each data group relating special area of measurement (Table 1). The maximum value of Cronbach's Alpha was 0.797 for sitting at the basket lumbar-left region. The forces averages in the brace different regions have been shown in Table 2 for three different activities (Sitting, Walking and sleeping) in 10 minutes (Table 2).

Table 1. Result of reliability analysis over three major activities of sleeping, walking and sitting have been reported as values of Cronbach's Alpha for different areas of MB

Brace Regions		Cronbach's Alpha
Thoracic Pad		0.610
Axillary Band		0.555
Basket	Lateral- right	0.368
	Lateral- left	0.277
	Abdominal	0.572
	Lumbar- right	0.775
	Lumbar- left	0.797

Table 2. Forces Averages, during three different activities (Sitting, Walking and Sleeping) in 10 minutes, have been shown

		Sitting Force Ave. (N)	Walking Force Ave. (N)	Sleeping Force Ave. (N)
Thoracic Pad		1.78	0.379279	1.548636
Axillary Band		9.779695	5.224263	0
Basket	Lateral Right	2.86	0.07632	0
	Lateral Left	10.22446	7.33874	1.588334
	Abdominal	1.774713	0.921647	2.044846
	Lumbar Right	17.03711	6.392868	2.40071
	Lumbar Left	1.892796	0.372268	0.175336
Back head	Right	0.288882	0.320906	0.037973
	Left	0	0	0

3.3 Daily Activity Test

Force values during 23 hours of daily activities corresponding to different areas of MB are reported as the results of this section for all subjects (Table 3). The tests for each subject commenced with 9-11 hours of sleeping (Part 1) and continued for 12-14 hours in which main activities were sitting and walking (Part 2). The forces average values of part 1 and part 2 of the tests were reported in Table 3 for different areas of MBs. In Table 4, the mean, median, mode, standard deviation and ratio of standard deviation on the mean have been calculated for each brace region for both time durations (Table 4).

Table 3. Average force values of sleeping and walking-setting durations of the tests separated by brace areas have been shown

Brace Regions		Force Average (N)							
		Healthy Normal Volunteer (Male)		**Healthy Normal Volunteer (Female)**		**Patient (Male)**		**Patient (Female)**	
		Sleeping (9hr)	**Sitting & walking (14hr)**	**Sleeping (9hr)**	**Sitting & walking (14hr)**	**Sleeping (11hr)**	**Sitting & walking (12hr)**	**Sleeping (11hr)**	**Sitting & walking (12hr)**
Shoulder Pad		-	-	-	-	2.03	2.57	-	-
Thoracic Pad		2.8	2.8	2.1	3.1	-	-	4.83	3.58
Axillary Band		2.4	5.8	0.45	1.6	1.64	1.15	1.32	1.32
Basket	Abdominal	6.4	5.0	1	3	1.64	1.15	1.32	1.32
	Lumbar Right	4.0	8.8	0.8	4.6	-	-	-	-
	Lumbar Left	0.5	2.8	1.2	6.0	-	-	-	-
	Lateral Right	0.3	1.1	0.1	0.8	1.77	0.16	1.79	0.56
	Lateral Left	3.2	5.0	0.1	0.6	0.24	0.24	2.51	7.43
	Lumbar Pad	-	-	-	-	1.60	1.64	1.72	1.78
Kyphosis Pad	Right	-	-	-	-	12.89	6.03	-	-
	Left	-	-	-	-	0.91	0.79	-	-

Table 4. Mean, median, mode, standard deviation and ratio of standard deviation on mean have been shown for each brace region for both time durations

Brace Regions		Male Patient					Female Patient		
		Shoulder Pad	Axillary Band	Lumbar Pad	Kyphosis Pad Left	Kyphosis Pad Right	Axillary Band	Thoracic Pad	Lumbar Pad
Sleeping	Mean	2.06	1.59	1.59	0.90	12.48	1.33	4.70	1.79
	Median	2.20	1.65	1.60	0.91	12.01	1.33	4.65	1.80
	Mode	2.30	1.65	1.60	0.92	-	1.34	-	1.78
	Std. Deviation	0.25	0.17	0.004	0.18	1.69	0.007	1.05	0.017
	R (S.D./mean)	0.12	0.11	0.003	0.2	0.14	0.005	0.22	0.01
Sitting & Walking	Mean	2.57	1.16	1.63	0.78	6.01	1.34	3.58	1.78
	Median	2.54	1.14	1.63	0.78	6.21	1.33	3.80	1.78
	Mode	2.50	1.4	1.64	0.78	6.3	1.33	4.01	1.78
	Std. Deviation	0.14	0.16	0.005	0.19	0.32	0.022	0.64	0.048
	R (S.D./mean)	0.05	0.14	0.003	0.24	0.05	0.016	0.18	0.03

4. DISCUSSION

The function of MB on idiopathic scoliosis treatment is based on applying forces to the patient's torso. Extracting of reaction forces at the interface of the patient's torso and the MB inner surface in order to analyze the biomechanical effect of MB was the main purpose of the present study. A new measurement system which could record forces during 24 hours from all areas of MB has been designed. The examination of the system performance as the reliability and sensitivity analysis on sensor arrangement has been carried out. All subjects wore their equipped MBs during the 23-hour period and carried out their normal daily activities. The MB regions forces saved in each minute by the new measurement system during this time.

To evaluate the assumption of one sensor instead of five sensors in the 4x4 cm^2 grid, a sensitivity analysis has been done. Range of 0 to 2.5 (N) for sitting, 0 to 3 (N) for walking and 0 to 1(N) for sleeping were recorded and a negligible difference between the force values of one- sensor and five-sensor arrangements have been seen. The coefficient of determination (R^2) for one sensor arrangement via five sensors arrangement is maximum in sleeping task and is minimum in walking task. The low amount of R^2 in walking and sitting can be increased by increasing the rate of data collecting and having more data point.

The highest value of Cronbach's Alpha in the reliability (Table 1) test was 0.797 the varying brace wearing conditions in each test and enumerable existing data due to low sampling rate of 1 data per minute (for this test) can be the causes of low Cronbach's Alpha value in some areas of MB.

In the reliability test (Table 2), the average of forces in each region of MB was calculated during 30 minutes for three activities (sitting, walking and sleeping). The average forces changed in the range of 0-17.03 N. The maximum average force amount for sitting and sleeping tasks was in the basket lateral right region. But for walking task, the maximum average force amount was in the basket lumbar left region.

Regarding the results of clinical tests on healthy subjects (Table 3), forces applied to female subject torso at all areas of brace (lumbar pad, axillary band and basket: abdominal, lumbar right, lumbar left, lateral right and lateral left) have lower values during night (sleeping time) in comparison with day (other normal activities). the described trend was also obtained for male healthy subject except for abdominal area of the basket in which force values at sleeping time were increased .The thoracic pad inserted a constant-value force during day and night to patient's body. Both male and female healthy subjects had the same sleeping position (supine) and their main activities at day time were sitting and walking.

The results of the female patient (Table 3) have shown different trends between day and night. Forces at kyphosis pad, abdominal area and lateral-left of the basket were decreased at night and showed constant values at axillary band and lumbar pad. Since the female patient had right-side sleeping position, forces at thoracic pad, abdominal and lateral-right of the basket were increased during night.

The results for the male patient (Table 3) showed a decrease in force values of axillary band and lateral-right of the basket, an increase in the shoulder pad, kyphosis pad and abdominal area of the basket and remaining constant in the lumbar pad and lateral left of the basket during day. This patient had supine sleeping position and his main activities during day were sitting and walking.

According to Table 4, force values for the sleeping and day time activities shows normal distribution at the different areas of MB. Hence, the average values of each time duration(sleeping duration and daily activities duration) were calculated and the average forces in each area was compared between two time durations.

5. CONCLUSION

The force value for the areas of basket in direct contact with mattress surface was increased during sleeping. Consequently, changing of patient sleeping position is necessary in order to avoid decreasing in brace effectiveness.

The lumbar pad used in subjects brace were made from foam layer (1.5 cm in thickness). The remarkable point is that the forces detected from this pad during most of the test time were constant. Appling constant force independent from daily activity is an important point in treatment of scoliosis through MB.

In future, for device modification, the number of sensors and the rate of data collecting will be increased. Moreover, the device will be used for measuring brace forces during carrying out patients' daily exercise and other special tasks. By modifying the power supply unit of electronic circuit, it will be possible to increase test time to more than 24 hours and more data will be achieved about brace forces.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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