Determining the Center of Pressure Trajectories during Lumbar Spine Flexion

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Abstract— **The paper presents a preliminary study on a healthy female, performing back flexions, while standing on a force platform. The goal of the paper is to quantify how lumbar spine flexions influence the plantar center of pressure (CoP) distribution. Using Zebris CMS-HS ultrasound-based motion analysis system and FDM measuring system for force distribution the range of motion of lumbar spine flexion and CoP displacements during fully forward flexion were assessed simultaneously. Results showed a close symmetrical distribution of ground reaction forces on each subject foot.**

Keywords— **lumbar spine flexion, range of motion, center of pressure, force platform, ultrasound-based motion analysis system.**

I. INTRODUCTION

The ability to maintain balance is fundamental in uni- bipedal standing or in performing certain movements, some of them being essential in daily living.

Centre of pressure (CoP) is defined as the application point of the resultant of ground reaction forces acting on the base of support. The analysis of CoP displacements is used as an index of postural stability both in standing and walking. A common technique to determine the postural stability is represented by platform stabilometry. This implies a set of pressure transducers, contained into a force plate, which record the ground reaction forces and determines the centre of pressure (CoP) and body centre of mass (CoM). There are many commercial available instrumented force platforms that can be involved in gait analysis and postural stability studies, allowing accurate recordings of ground reaction force, CoP and CoM displacements.

The studies reviewed by Ruhe et al. [1] show that "bipedal static CoP measures may be used as a reliable tool for investigating general postural stability and balance performance under specific conditions". The influence of the CoP displacements during standing or performing certain exercises has been studied especially for elderly people. Seigle et al. have been investigated whether aging has an influence on the dynamics of the fluctuations of the displacement of the center of pressure (CoP), during quiet standing, taking into account the visual conditions of subjects [2].

The assessment of lumbar spinal disorders requires data about spinal range of motion. There have been proposed and developed several methods to measure the spinal mobility [3]. Some of these methods use an inclinometer, while others depend on measurements from different anatomical landmarks (original and modified Schober method), or use finger to floor distance to asses forward flexion (Viitanen, et al., Heikkilä et al.). In some cases, such measurements, using fixed anatomical points, are subject to errors. Moreover, these methods are not standardized or assessed for reliability, validity, and may not be feasible in clinical practice [3]. Even if some of these methods have good reliability and sensitivity, they do not correlate with radiographic changes.

The presented study proposes a method to simultaneously assess the range of motion of lumbar spine flexion and CoP displacements during fully forward flexion. Zebris CMS-HS ultrasound-based motion analysis system and FDM measuring system for force distribution are accurate and easy to use, allowing unrestricted and comfortable movements of the subject. This preliminary study quantifies the influence of the lumbar spine flexion on the CoP displacement and subject postural stability.

II. MATERIALS AND METHODS

To evaluate the angular amplitudes of lumbar spine flexion, one young healthy volunteer (female, 26 years old) performed exercises with self-selected velocity both overground and on force platform. Prior beginning the experiment, a series of anthropometrical parameters was measured, as shown in Table 1.

The measurements were realized in Motion analysis Laboratory of Politehnica University of Timisoara using two Zebris measuring systems (Zebris Medical GmbH): CMS-HS ultrasound-based motion analysis system and FDM measuring system for force distribution.

Table 1 Anthropometric data

Subject characteristics	
Weight [kg]	76
Height [cm]	167
Body Mass Index [kg/m^2]	26.9
Big toe distance – BTD [mm]	226
Inter-malleolar distance – IMD [mm]	78
Feet opening angle – α [°]	28

S. Vlad and R.V. Ciupa (Eds.): MEDITECH 2011, IFMBE Proceedings 36, pp. 384–387, 2011.
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The measuring method used by Zebris CMS-HS system is based on the determination of spatial coordinates of the miniature ultrasound receptors (markers), by measuring the time delay between the emission of sonic pulses by the transmitters and their reception at the microphone capsules. The spatial position of the lumbar spine was calculated by the WinSpine system's software.

The measurement starts with the attachment of two special marker triplets on the subject torso with elastic Velcro strips. The reference marker triplet is attached on the sacrum and triple measurement marker is applied in the area of the lower thoracic spine. The marker spatial positions are calculated and displayed during the subject movements, using the WinSpine Software. The measuring sensor was placed on the right hand side of the patient, according to the WinSpine Operating Instructions [4].

The second measuring system consists of a type 2 FDM platform integrated in a level walking area which contains high-quality capacitive pressure sensors arranged in a matrix form and WinFDM software enabling a simple static and dynamic analysis of the recorded measuring data [5].

The performed experiments consisted in two types of measurements of lumbar spine flexion range of motion (ROM): overground measurements only using the CMS-HS system, and on a force platform, using both the CMS-HS system and FDM platform.

Each experiment consisted in five valid trials, for each trial being recorded five free lumbar flexion movements. The sampling rate of the recordings was selected for both systems at 10 Hz, covering a period of 20 seconds per trial and 140 frames/trial. Each trial was preceded by a calibration, the subject standing in a neutral position. In order to adapt the subject movements to the measurement conditions a training session of five minutes was firstly performed.

Figure 1 illustrates the modules of Zebris CMS-HS system: measuring unit and the two special marker triplets, and neutral and maximum flexion position of the investigated subject.

The subject was free to choose her feet position to perform natural and comfortable movements. In order to obtain data about feet position during the measurements on the FDM platform and maintain the same subject position on the top half of the platform during the measurements, the static footprints were recorded by WinFDM software and drawn on a piece of paper fixed in place using adhesive tape.

The reference frame (RS) attached to the platform has the origin in the left lower corner of the platform, the x axis representing the platform width/medio-lateral (ML) direction, and y axis representing the platform length/antero-posterior (AP) direction, respectively, as shown in figure 2.

a) Neutral position and the modules of Zebris CMS-HS system b) Measurement of flexion ROM with subject on the force platform

Fig. 1 Measurements of lumbar flexion ROM

Using the footprints obtained by static measurement of plantar pressure distribution, the parameters of base support were determined (Table 1 and Figure 3): effective foot length, big toe distance, inter-malleolar distance, and feet opening angle was calculated [6]. These parameters influence the postural stability, being of great importance in balance control. They will be considered in future studies in order to establish their influence on overall body balancing.

Using the Zebris CMS-HS system, the angular amplitudes during lumbar flexion were determined. WinSpine software generates a report of each recorded trial. Using the Zebris FDM force platform, the ground reaction forces and time-varying displacements of CoP under each subject' foot during the flexion movement were determined. The displacements of CoP were determined along the antero-posterior (AP) and medio-lateral (ML) directions.

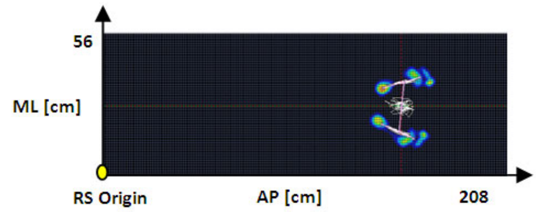

Fig. 2 2D representation of the FDM platform

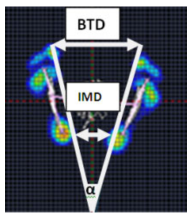

Fig. 3 Base of support measurements from the footprints

III. Results and discussions

Firstly, the angular amplitudes during lumbar flexion performed in overground conditions were obtained from the report generated by the Zebris WinSpine software as ASCII file. All data was processed in MatLab environment and evaluated. The flexion movements occur entirely within the normal range of motion according to normative data [4].

Next following, the same type of exercises were executed on the force platform. The corresponding mean curves of flexion angles with respect to the time for each trial are shown in figure 4 in frame representation, where T1 - T5 represent the trials recorded in overground conditions and on the force platform.

The mean intra-trial maximum flexion value was of 40.30° in overground movement while on the platform reached 39.28°. When comparing inter-trial maximum amplitudes, the mean values were 39.5° in overground movement, and 40.6° for measurements on the force platform. The minor differences obtained from intra- and inter-trial comparison show a good repeatability of the imposed exercise.

The variability of the flexion movements both overground and on the force platform was evaluated in figure 5. To evidence the average variability, the standard deviations are represented as vertical lines accompanying each frame.

In overground movements, the standard deviation of flexion angles ranges from 0.23° to 1.39°, while on the platform the standard deviation ranges from 0.07° to 2.45°, respectively. The mean inter-trial standard deviation of flexion angles was 0.72° in case of overground movements and 1.41° while standing on the platform.

Greater values of standard deviations in case of measuring on the platform are determined by the recording synchronization of the two measuring systems.

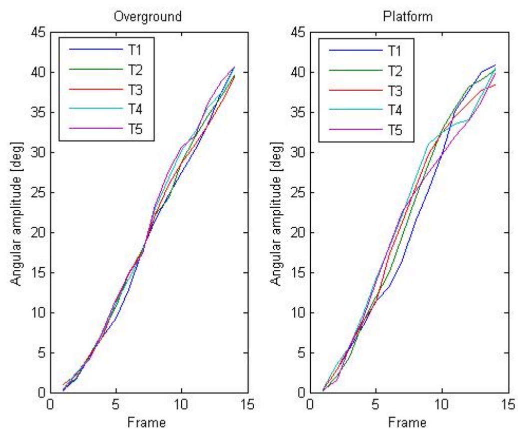

Fig. 4 Lumbar flexion angles measured overground and on the platform

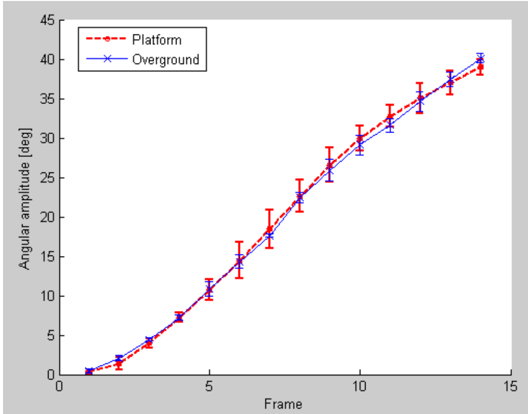

Fig. 5 Mean lumbar flexion angles in both cases

The means of values for discrete flexion angles in overground and force platform measurement conditions determined during the performed trials were compared by use of an unpaired t-test. The flexion angles were not significantly different (p = 0.9874) for the two studied cases.

During standing in neutral position, the platform recorded an unevenly distribution of ground reaction forces, the right foot being more loaded (55%) than the left one (45%).

For each flexion frame, both for the left and right foot, the CoP coordinates (x_{CoP}, y_{CoP}) were calculated using the classical mechanics method of determining the centre of parallel forces.

Figure 6 presents both the CoP distribution and mean CoP trajectory for each foot during lumbar flexion movement. The right foot is shown on the left side, with the toe covering the upper left region and the heel covering the lower right area. Analogically one can observe the left foot CoP distribution, as a mirror disposition.

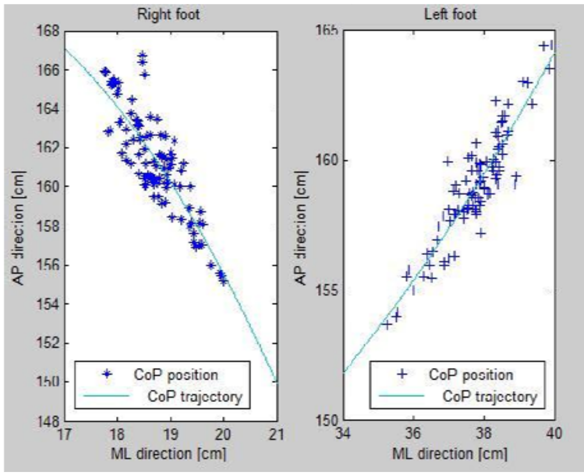

Fig. 6 CoP positions and trajectories overground and on the platform

Analyzing CoP distributions, one may observe the almost linear spread of positions, displayed in a symmetrical layout. The differences could be due to the feet initial pressure distribution (45%-left, 55%-right), or may be caused by a loss of balance during the exercise execution.

Taking into account that the flexion was performed along the AP direction, only these displacements of CoP were compared for the left and right foot. Thus, the means values of CoP positions in AP direction for both feet were compared by use of an unpaired t-test. The CoP positions were not significantly different ($p = 0.3134$) for the two feet. This indicates a strong correlation between both CoP distributions in AP direction during lumbar flexion.

Figure 7 presents the relationship between AP and ML displacements of CoP and flexion angles variation during spinal fully flexion. The CoP displacements along ML direction are almost linear, varying with less than 1 cm. The CoP trajectories in the AP direction show a slight turn, close to the maximum flexion angle. This is explained by the body tendency of maintaining the postural stability when reaching the lumbar flexion amplitude.

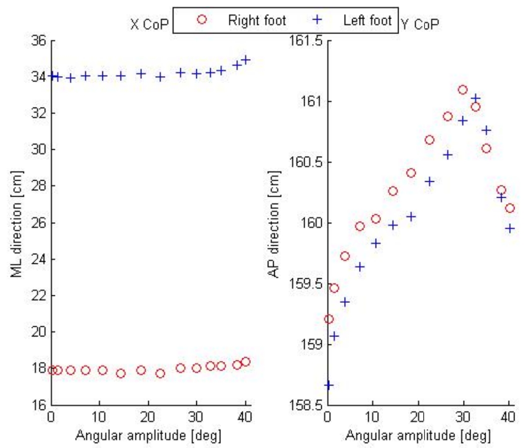

Fig. 7 Relationship between AP and ML displacements of CoP and flexion angles

IV. Conclusions

The presented study investigates a method to simultaneously and independently assess the range of motion of lumbar spine flexion and CoP displacements during the fully forward flexion.

Zebris CMS-HS ultrasound-based motion analysis system and FDM measuring system for force distribution were considered to be sufficiently accurate and easy to use, allowing unrestricted and comfortable movements of the subject.

Statistical analysis demonstrated that the flexion angles were not significantly different for measurements in overground and on platform conditions. The measuring accuracy is however influenced by the recording synchronization of the two measuring systems.

This preliminary study quantifies the influence of the lumbar spine flexion on the CoP displacement and subject postural stability. Results showed a close symmetrical distribution of ground reaction forces on each subject foot.

Further research will be performed with a representative lot of subjects, both healthy and having certain disorder to confirm the present results, collect reference data and validate the method across pathologies. Also, the influence of the subject weight on the CoP displacements will be taken into account. There will be considered different cases such as underweight, normal and overweight according to BMI category. Another index of postural stability both in standing and walking is the center of mass displacement, thus future studies will be focused on the analysis of center of mass dynamics.

Acknowledgment

This work was partially supported by the strategic grant POSDRU 6/1.5/s/13, (2008) of the Ministry of Labor, Family and Social Protection, Romania, co-financed by the European Social Fund – Investing in people.

References

1. Ruhe A, Fejer R, Walker B F (2010). The test–retest reliability of center of pressure measures in bipedal static task conditions – A systematic review of the literature. Gait & Posture, 32 (4). pp. 436-445 DOI:10.1016/j.gaitpost.2010.09.012
2. Seigle B, Ramdani S, Bernard P L, (2009). Dynamical structure of center of pressure fluctuations in elderly people. Gait & Posture 30, 223–226 DOI:10.1016/j.gaitpost.2009.05.005
3. Davis J C Jr, Gladman D D, (2007). Spinal Mobility Measures in Spondyloarthritis: Application of the OMERACT Filte, J Rheumatol Vol 34: No. 4, p. 666-670.
4. Zebris Medical GmbH (2006).WinSpine 2.x for Windows. Operating Instructions. Assessment of the mobility function of the cervical and lumbar spine.
5. Zebris Medical GmbH (2006). Measuring System for Analysis of Force Distribution FDM. Technical data and operating instructions.
6. Chiari L, Rocchi L, Cappello A, (2002) Stabilometric parameters are affected by anthropometry and foot placement, Clinical Biomechanics 17 666–677 doi:10.1016/S0268-0033(02)00107-9.

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