ASSESSMENT OF SPINO-PELVIC MORPHOMETRY, A PREDICTOR OF LUMBOSACRAL INSTABILITY

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ABSTRACT

Background: Spino-pelvic malalignment may be responsible for accelerated degeneration of the lumbar spine and consequent instability. Previous studies have documented the high degree of variability in the sagittal alignment of the lumbar spine and specific parameters have been identified.

Objectives: To evaluate correlations between sagittal spino-pelvic parameters and development of lumbosacral degeneration and instability.

Design: Case-series radiographic study.

Methods: In the course of this study, consecutive anteroposterior and lateral radiographs of 197 symptomatic individuals (low back pain) were analyzed between January 2012 and December 2014. One hundred and twenty four plain X-ray films of these patients were selected for the study after undergoing MRI scanning. Parameters measurements on the lateral plain films were lumbar lordosis, sacral slope, pelvic tilt, pelvic incidence and sacral overhang.

Results: A total of 124 patients (mean age 43.8 years, SD 13.1) were enrolled. There were 56 males and 68 females. Patients were grouped as having instability (Group1) and those without instability (Group 2). The two groups were compared. Group 1 patients were found to be younger (58 vs. 45 years, $P < 0.0543$), had greater sacral inclination (41.3° vs. 33.8°, $P < 0.0232$), and a larger pelvic incidence (66.4° vs. 55.2°, $P < 0.00038$). The differences in pelvic tilt (24.3° vs. 21.6°, $P < 0.4503$) and sacral overhang (45.3mm vs. 39.8 mm, $P < 0.3670$) were not statistically significant. There was an increased pelvic incidence/lumbar lordosis mismatch in group compared to Group 2 (PI-LL; 29 vs. 18; $P < 0.0899$).

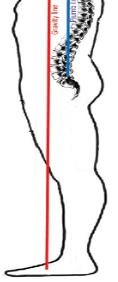
Conclusions: Sagittal spinopelvic morphometry, particularly a decreased sacral slope and an increased pelvic incidence are useful guide for identifying instability in patients with chronic low back pain. This will assist in planning operative management.

INTRODUCTION

The center of mass of the human body is located in front of the thoracic spine and runs down close to the lumbar region. This vertical line also known as "the line of gravity" passes through the centre of the femoral head to reach the ground at the feet which are the point of support. The plumb line on the other hand is the vertical line drawn from the front and touching the body of the seventh cervical vertebra and that passes tangential to the sacral plateau posteriorly. Normally, the gravity line is always in front of the plumb line (1) (Figure 1).

Figure 1

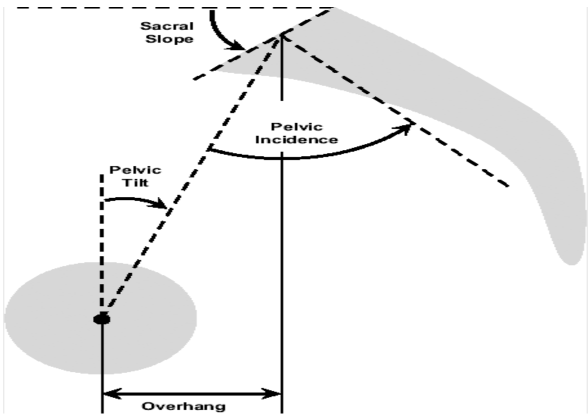
*The center of mass of the human body (red line) and the plumb line (blue line)**



*Ozer AF *et al*: Sagittal balance in the spine. *Turkish Neurosurgery.* 2014; **24** (Supplement 1): 13

The bipedal posture requires strict balancing while on prolonged standing, walking or running; an imbalance consumes energy. The body always attempts to compensate for any imbalance in order to maintain posture (2). Such compensatory mechanisms lead to muscle fatigue and pain, stress fractures and shearing forces especially across intervertebral segments leading to instability. Sagittal spino-pelvic parameters are divided into those that are morphological and remain constant despite position (Pelvic Incidence (PI)) and positional parameters Lumbar Lordosis (LL), Sacral Slope (SS) and Sacral Overhang (SO). Positional parameters are significantly reduced in instability with Pelvic Tilt (PT) increasing to compensate for reduced SS. Sagittal spino-pelvic parameters will therefore, detect spino-pelvic mal-alignment and predisposition to lumbarsacral junction instability. The sagittal shape and orientation of the spine will determine the overall sagittal balance and may be responsible for many spinal disorders (3-5). The association between sagittal shape of the spine and low back pain syndrome is well known (6,7). Severity of symptoms increases in a linear fashion with progressive sagittal imbalance (8). In addition, the shape and spatial orientation of the pelvis determines the organization of the lumbar-thoracic spine. Sagittal spino-pelvic morphometric measurements provide a complete assessment of sagittal balance. The parameters commonly measured are lumbar lordosis, sacral inclination or sacral slope, pelvic tilt, pelvic incidence and sacral overhang (Figure 2).

Figure 2
Sagittal spino-pelvic morphometric measurements (Spine. 2008; 33(14):1572-1578. © 2008 Lippincott Williams & Wilkins)

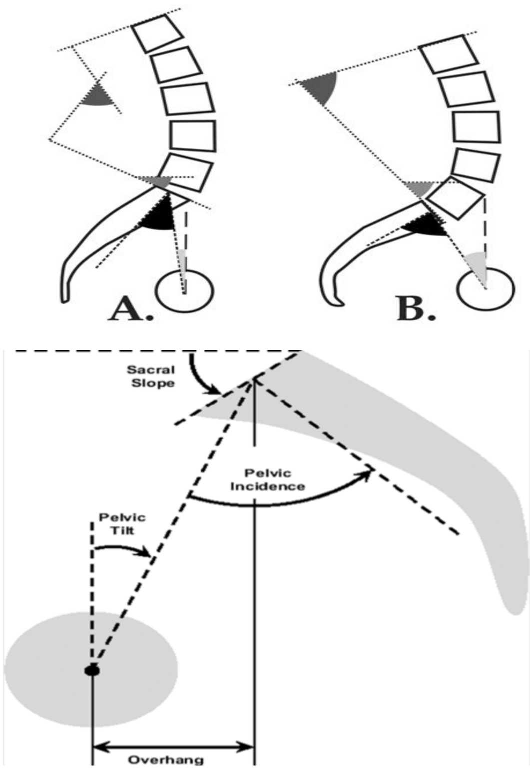


MATERIALS AND METHODS

A total of 197 patients were included in this study. They all had chronic low back pain of differing severity with or without leg pain. They were all examined by the same surgeon. They had their heights and weight taken together with physical examination. They all had plain radiography and MRI scanning of the lumbosacral spine. Lateral and anteroposterior radiographs of the pelvis and the lumbosacral spine were taken in the radiology department of The Mombasa Hospital, Mombasa, Kenya by the same technologist, using the same digital X-ray machine, with a fixed magnification of 70%. The lateral radiographs were taken with the femurs parallel and included the pelvis in order to show both femoral heads as one. The patient's right side was situated against the cassette. Each patient was positioned and asked to stand straight, but relaxed. The knees were extended as much as possible, with the hips perpendicular to the film, and the arms were held out slightly below the chest level. The lumbar spine was X-rayed in neutral, flexed and extended positions. Some of the patients underwent MRI scanning (GE 1.5 Teslar). Out of these, one hundred and twenty four patients (56 men and 68 women) were selected for the study. Exclusion criteria comprised previous spinal fusion, overt spondylolisthesis (worse than grade 1), age outside the range of 18 to 60 years, severe metabolic bone disease, spine fractures, tumour or obvious kyphosis or scoliosis. Patients with degenerative lumbar spinal disease without radiological signs of instability were excluded (n = 73).

All patients signed consent forms allowing their clinical data to be used for research. The study group consisted of those with signs of instability in both plain radiography and MRI scans (n = 56). Individuals with normal functional plain radiography and MRI scans formed the control group (n = 68). The measurements were done manually. Measurements were done using the Duval-Beaupere method as demonstrated in Figure 3.

Figure 3
Pelvic incidence measured using the Duval-Beaupere method



Data analysis: Custom computer application and IBM SPSS Statistics 20 were used to analyze the data. Two types of analysis were performed: a descriptive univariate analysis to characterize the angular parameters and multivariate analysis to check for any correlations between the parameters.

RESULTS

The 124 cases were divided into two groups. Group 1 consisted of individuals with radiological evidence of instability at L5/S1 OR L4/L5 on functional plain radiology while Group 2 consisted of those individuals with normal functional radiography and no signs of instability on MRI scans (Table 1).

Table 1
Groups according to MRI findings

	Group	No.
Instability at L5/S1 OR L4/L5	1	56
Normal	2	68
		124

The gender distribution was almost even between the groups (Table 2).

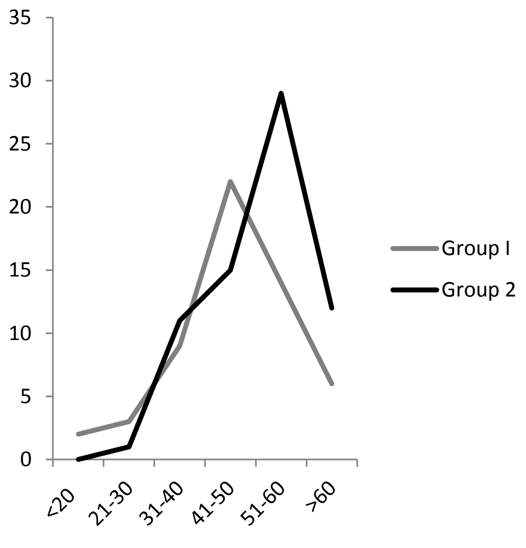
Table 2
Gender distribution

	Male	Female	Total	(%)
Group 1	24	32	56	45
Group 2	32	36	68	55
Total	56	68	124	100

Table 3 summarizes this distribution according to their age groups (Table 3). The group with intrinsic instability is younger than those with chronic back pain without signs of instability.

Table 3
Age distribution between the groups

	Group 1	Group 2	Total
<20	2	0	2
21-30	3	1	4
31-40	9	11	12
41-50	22	15	31
51-60	14	29	37
>60	6	12	17
Total	56	68	124
Mean	45	58	
CI	0.4	0.1	
SD	15	12.2	
F-Test		0.0543	



The weight distribution as presented by Body Mass Index (BMI) is shown in Table 4. The differences were not statistically significant.

Table 4
BMI distribution

BMI	Mean	CI	SD	P value
Group 1	28.4	0.1	7.3	
Group 2	29.2	0.1	4.9	0.7241

There was reduced lumbar lordosis in the unstable group although this reduction was not statistically significant (Table 5).

Table 5
Distribution of the angle of lumbar lordosis

Lumbar lordosis	Mean	CI	SD	P value
Group 1	36.9	0.2	20.5	
Group 2	41.9	0.3	22.4	0.3896

The angle of sacral slope was also reduced in the unstable group with a mean of 33.8° which was statistically significant (P = 0.0232) (Table 6).

Table 6
Distribution of the angle of sacral slope

Sacral slope	Mean	CI	SD	T Test
Group 1	33.8	0.1	13.2	
Group 2	41.3	0.1	12.3	0.0232

The angle of pelvic tilt (mean 24.3° vs. 21.6) was increased as expected to compensate for the reduced lordosis. This increase was not statistically significant (Table 7).

Table 7
Distribution of the angle of pelvic tilt

Pelvic tilt	Mean	CI	SD	P value
Group 1	24.3	0.2	12.7	
Group 2	21.6	0.2	15.3	0.45030

The angle of pelvic incidence was increased and this increase was statistically significant (mean 66.4° vs. 55.2 P = 0.00038) (Table 8).

Table 8
Distribution of the angle of pelvic incidence

Pelvic incidence	Mean	CI	SD	P value
Group 1	66.4	0.1	11.3	
Group 2	55.2	0.1	11.9	0.00038

The horizontal distance between the centre of sacrum and the bicoxo-femoral axis (sacral overhang) was increased in the unstable group but not statistically significant (mean 45.3° vs. 39.8 P = 0.3670) (Table 9).

Table 9
Sacral overhang

Sacral overhang	Mean	CI	SD	P value
Group 1	45.3	0.3	21.4	
Group 2	39.8	0.3	26.4	0.3670

Pearson correlation coefficient was calculated between the parameters. There was a strong positive correlation between pelvic incidence and sacral slope both of which determine lumbar lordosis (Table 10).

Table 10
Pearson correlation coefficients

Pelvic incidence vs.	r
Sacral slope	0.7
Lumbar lordosis	0.4
Pelvic tilt	0.4
Lumbar lordosis vs.	
Sacral slope	0.8
Pelvic tilt	-0.4

DISCUSSION

Forces acting on the erect human spine include the body weight, tension in the spinal ligaments and paraspinal muscles, intra-abdominal pressure, and any applied external loads. The major form of loading on the spine is axial as the lumbar spine supports the weight of the body above it. Most of the axial compression load on the spine is borne by the vertebral bodies and disks except in hyperextension when the facet joints may bear as much as a third of the load (9).

As the line of gravity passes anterior to the spinal column in the upright position, the spine is under a constant, forward bending moment so that as the trunk is progressively flexed, the line of gravity shifts further away from the spine. The further the line of gravity is from the spine, the larger the moment arm for body weight and the greater the bending moment generated. The larger the moment, the larger the shearing forces in the transition vertebral segments such as the lumbosacral junction. The sacrum is a double-lever arm which is supported by the sacroiliac joints and which allows the forces to pass from the spine to the pelvis and down to the lower limbs. Tension in the back muscles counteract the moment forces to maintain body position and stability. This straightens the body, hence, reduces lordosis. The more the tension is generated, the greater the compression load on the spine (9). The effect of this tension is reduction in lumbar lordosis, the sacral slope and the pelvic tilt. These parameters that constitute the sagittal balance can be assessed in order to predict stability in symptomatic patients.

This predication of instability is of ultimate consideration during planning for spine surgery. A simple discectomy would further destabilize an already unstable segment. This would result ultimately to failure of treatment. Maintenance of adequate lordosis is of considerable importance during spinal fusion to avoid adjacent segment disease.

Sagittal balance of the human body is defined by either pelvic parameters (Pelvic Incidence (PI), Pelvic Tilt (PT) and Sacral Slope (SS); or by the shape of the spine, Lumbar Lordosis (LL) (10). In this study the parameters for the study population measured as follows; LL 39±3, SS 37±2.8, PT 21±2.4, PI 59 ±2.6 and SO 38.4 ±3.4. Lafage *et al* (11) in a study of 219 symptomatic patients and 40 asymptomatic individuals arrived at the following measurements; LL 53±17, SS 34±11, PT 19±10, PI 53 ±12 and SO 41 ±21 mm. The main deviation in the two studies is in the lordosis and very high confidence intervals in the Lafage study. The discrepancy in lordosis may reflect ethnic or racial differences.

Tight hip muscles (flexors, tensor fasciae latae), weakened abdominal muscles and deep lumbar extensors are responsible for the exaggerated lumbar lordosis. Gelb *et al* (12) found total lumbar lordosis to average 40°, which is in keeping with findings of this study. In this study, the stable group had lumbar lordosis of 41.9° while the unstable group averaged 36.9°.

The anatomical parameter of pelvic incidence and the sacral slope, strongly determines the lumbar lordosis; the pelvic incidence being the main axis of the sagittal balance of the spine. It controls spinal curves in accordance with the adaptability of the other parameters (13). As the pelvic incidence is unchangeable it is regarded as an anatomic constant. The pelvic incidence is the sum of sacral slope and pelvic tilt. Pelvic incidence measures the thickness of the pelvis; a low pelvic incidence value reflects a thin pelvis and a small lumbar lordosis. The average pelvic incidence is reported to be 60°. If the pelvic incidence is 40°, the pelvis in question is narrow; while a pelvic incidence of 70° represents a broad pelvis. Young individuals (<45 years) with low pelvic incidence are reported to have a higher incidence of disc herniation while a high pelvic incidence is associated with degenerative spondylolisthesis (14). In this study, the stable group had a mean pelvic incidence of 55.2° compared to 66.4° in the unstable group. This was found to be statistically significant.

The high degree of the PI and PT shows an alteration in the spatial relation between the hips and the sacropelvis; with the two acetabula located well anterior of the lumbosacral junction. This instability leads to spondylolisthesis with the L5 vertebral body slipping anteriorly to regain balance by maintaining the gravity line above the hips (15). Anterior pelvic tilt is when the front of the pelvis drops and the back of the pelvis rises while the posterior pelvic tilt is the opposite. Pelvic tilt averages 20° but with excessive lordosis; this angle can increase to 40° (16). In this study the PT was 24.3° in the unstable and 21.6° in the stable; with corresponding LL of 36.9° and 41.9° respectively clearly demonstrating the relationship between the two parameters. An anterior pelvic tilt potentially leads to lower back pain, hip pain and knee pain because of the rotated femurs with knock-knee position (17).

The sacral slope and pelvic tilt are both positional parameters; and will therefore, change with position. A vertically oriented sacrum is described by low sacral slope values and high pelvic tilt values and *vice versa*. The average values of sacral slope are 40°. In this study, the stable group had sacral slope of 41.3° while the unstable group had a sacral slope of 33.8°, the difference was statistically significant.

The sacral overhang averages 40 mm. In this study, the stable group had a mean SO of 39.8 mm while the unstable group had a larger SO of 45.3 mm. Results were found to be statistically significant. There is a strong correlation between lumbar lordosis and sacral slope (r = 0.8) with a weakened negative correlation with pelvic tilt (r =-0.4). Both sacral slope and pelvic tilt correlate with pelvic incidence. Finally, there is no correlation between any of these parameters with BMI.

CONCLUSION

The main spino-pelvic parameters that predict lumbar sacral instability in individuals suffering from low back pain are decreased sacral slope (< 40°) and an increased pelvic incidence (> 60°). An increased PT and SO have final bearing on lumbar lordosis and the position of both the plumb line and the center of gravity of the body, however, this study did not demonstrate any correlation between PT or SO and instability. Individuals with instability also tend to be younger in age (< 50 years).

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