Noninvasive Optoelectronic Assessment of Induced Sagittal Imbalance Using the Vicon System

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■ OBJECTIVE: **Spinal diseases often induce gait disorders with multifactorial origins such as lumbar pain, radicular pain, neurologic complications, or spinal deformities. However, radiography does not permit an analysis of spinal dynamics; therefore, sagittal balance dynamics during gait remain largely unexplored. This prospective and controlled pilot study assessed the Vicon system for detecting sagittal spinopelvic imbalance, to determine the correlations between optoelectronic and radiographic parameters.**

■ METHODS: **Reversible anterior sagittal imbalance was induced in 24 healthy men using a thoracolumbar corset. Radiographic, optoelectronic, and comparative analyses were conducted.**

■ RESULTS: **Corset wearing induced significant variations in radiographic parameters indicative of imbalance; the mean C7-tilt and d/D ratio increased by 15° ± 7.4° and 359%, respectively, whereas the mean spinosacral angle decreased by 16.8° ± 8° (all $P < 0.001$). The Vicon system detected the imbalance; the mean spinal angle increased by 15.4° ± 5.6° ($P < 0.01$), the mean floor projection of the C7S1 vector (C7′S1′) increased by 126.3 ± 51.9 mm ($P < 0.001$), and the mean C7-T10-S1 angle decreased by 9.8° ± 3° ($P < 0.001$). Variations in C7′S1′ were significantly correlated with d/D ratio ($\rho = 0.58$; $P < 0.05$) and C7-tilt ($\rho = 0.636$; $P < 0.05$) variations.**

■ CONCLUSIONS: **Corset wearing induced radiographically confirmed anterior sagittal imbalance detected using the Vicon system. Optoelectronic C7′S1′ correlated with radiographic C7-tilt and d/D ratio.**

INTRODUCTION

Specific interactions between the spine and pelvis have been clearly established.[1-4] Degenerative spinal disease management relies on sagittal posture analysis using spinopelvic radiographic parameters.[1,5,6] Most degenerative spinal processes decrease lumbar lordosis (LL), and despite compensatory mechanisms such as the loss of thoracic kyphosis (TK), pelvic tilt (PT) increase, or subpelvic flexion, patients might develop anterior sagittal imbalance.[7] Spinal diseases often induce gait disorders with multifactorial origins such as lumbar pain, radicular pain, neurologic complications, or spinal deformities. However, radiography does not permit an analysis of spinal dynamics; therefore, sagittal balance dynamics during gait remain largely unexplored.[8]

Vicon (Biometrics France Ltd., Gometz le Châtel, France) is a three-dimensional (3D) motion capture system with high accuracy for gait and motion analysis,[9-11] but its application in spinal balance analysis has not been evaluated. The primary objective of this study was to assess the Vicon system in detecting a sagittal spinopelvic imbalance. Reversible anterior sagittal imbalance was induced in healthy volunteers using a molded thoracolumbar corset. The secondary objective was to identify optoelectronic parameters that were correlated with standard radiographic parameters.

METHODS

Study Population

Twenty-four healthy males without spinal symptoms or deformities were enrolled. After the radiation-related risks were described,

Key words
- Optoelectronic analysis
- Sagittal balance
- Spine
- Spine disease
- Vicon

Abbreviations and Acronyms
3D: Three-dimensional
LL: Lumbar lordosis
PT: Pelvic tilt
SSA: Spinosacral angle
TK: Thoracic kyphosis

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informed consent was obtained from all participants. Females were excluded because radioprotection of the ovaries can obscure the spinopelvic view on radiographs. Exclusion criteria included a body mass index >30 kg/m², and any neurologic, vestibular, rheumatologic, or orthopedic diseases that might disturb gait or balance. Standard demographic data were recorded.

Induction of Noninvasive, Reversible Sagittal Imbalance

A removable thoracolumbar corset was molded in a lumbar kyphosis position to induce anterior sagittal imbalance (Figure 1A and B). Apertures at the anterior superior iliac spine, sacrum, and T10 allowed access to bony landmarks for sensor placement. Each subject underwent radiographic and optoelectronic analyses with and without corset wearing.

Radiographic Study

Standing, anteroposterior, whole-spine radiographs were obtained, with and without the corset, using a local protocol. Patients stood in a standardized erect posture with the knees extended, hands placed on the clavicles, and the eye level horizontal. Images contained the entire spinopelvic skeleton extending from the external meatus to the proximal femur. Radiographs were imported to Keops Software (SMAIO, Lyon, France), which is an update of the previously validated Optispine software (Optispine, Paris, France).[12] Spinal parameters were measured after identification of the transitional vertebra, defined as the inflexion point between kyphosis and lordosis. TK measured from the upper end plate of T1 to the lower end plate of the transitional vertebra and LL measured from the upper end plate of the transitional vertebra to the upper end plate of S1 were assessed using the Cobb method (Figure 2). Usual pelvic parameters such as the pelvic incidence, PT, and sacral slope were measured. Global sagittal balance was assessed using 3 validated parameters. The spinosacral angle (SSA) was defined as between the line from the center of the C7 vertebral body to the center of the upper sacral end plate and sacral end plate tangent. The d/D ratio[13] was calculated as d representing the horizontal distance between the C7 plumb line and the posterior corner of the sacral end plate and D representing the horizontal distance between the vertical bicoxofemoral axis and the vertical line passing through the posterior corner of the sacral end plate. The C7 tilt was defined as the angle between the center of the vertebral body of C7 and the middle of the sacral end plate, demarcated with a vertical reference line. Measurements were conducted with and without the corset.

Optoelectronic Study

A labelized gait laboratory was set up to assess the optoelectronic parameters. The Vicon system consisted of 6 infrared cameras (Vicon Motion Systems Ltd., Oxford, United Kingdom). Each participant was equipped with 38 reflective spherical markers placed on anatomic bony landmarks to facilitate whole-body analysis. Anthropometric data were computed using Nexus software (Biometrics France Ltd.). The Vicon system was calibrated using a standard procedure. A static recording was performed in the T position for a few seconds, corresponding to the standing position with elbows extended and shoulders abducted by 90° (Figure 3), and then Nexus was used for 3D reconstruction. After

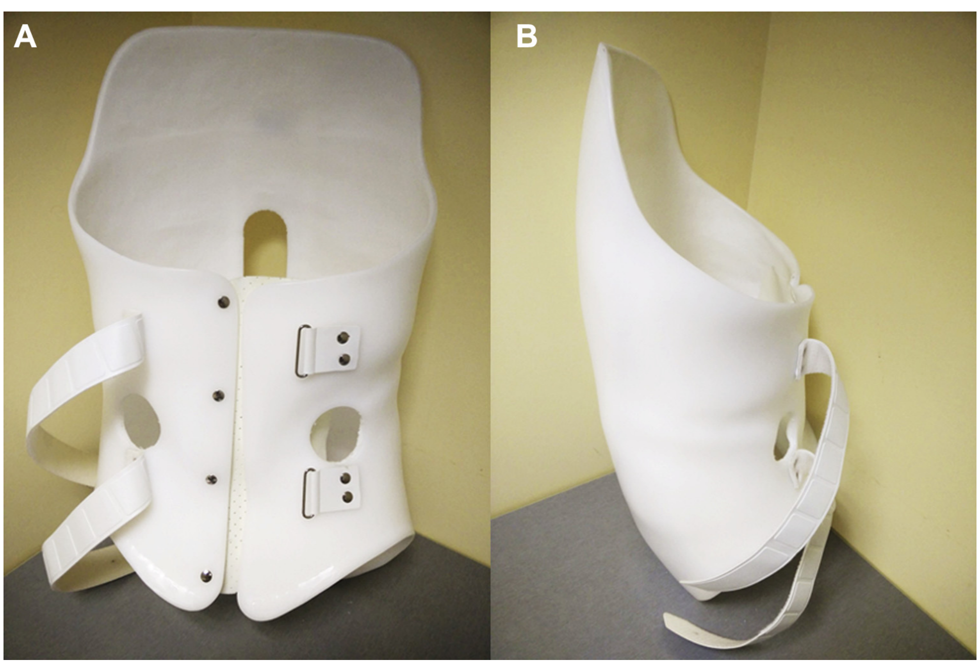

Figure 1. The immobile kyphosing thoracolumbar corset with apertures for marker placement anteroposterior visualization (**A**) and sagittal visualization (**B**).