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Trunk and Lower-Extremity Kinematics During Gait After Posterior Fixation for Thoracolumbar Fracture †

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Abstract

Posterior fixation is usually performed to restore spinal stability and decompress the spinal canal for unstable thoracolumbar burst fractures. The purpose of this study was to compare trunk and lower-extremity kinematics during gait between healthy adults and patients who had undergone posterior fixation surgery after thoracolumbar fractures. Optical motion capture was used to record joint kinematics during walking. The trunk, hip, knee, and ankle joint angles and excursions in sagittal, frontal, and transverse planes were calculated, averaged, and compared between patients and control groups. The patient group had significantly increased total hip excursion in the frontal plane and reduced ankle dorsiflexion in the sagittal plane, with mean differences of 4.2° and 6.4°, respectively. However, there were no differences in knee joint kinematics. The patient group exhibited a more upright trunk position during walking than the control group, with both peak trunk flexion and extension significantly different, possibly indicating stiffer trunk movement. This study provides the fundamentals of the joint kinematics of the trunk and lower extremities after posterior surgical treatment for thoracolumbar fractures, which may help in evaluating surgical outcomes.

Keywords: gait analysis; trunk; lower extremity; posterior fixation; thoracolumbar fracture

1. Introduction

Thoracolumbar fractures are the most common spinal injuries and are mostly associated with motor vehicle accidents and falls [1,2]. Posterior fixation and fusion techniques are usually performed to restore spinal stability and decompress the spinal canal for unstable thoracolumbar burst fractures. There was no significant difference identified between fixations with and without fusion [3,4]. Most studies have reported clinical complications and radiographic and functional outcomes of short (SS)- or long-segment (LS) posterior fixation techniques for thoracolumbar burst fractures [5–7]. Kanna et al. [5] found that posterior fixation efficiently restored radiological parameters, such as the kyphosis angle and anterior and posterior vertebral heights, in patients with severe unstable thoracolumbar fractures. Liang et al. [8] also showed the clinical effects of long-segment pedicle instrumentation

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for treating thoracolumbar fractures. Clinically, the visual analogue scale and Oswestry disability index are used to assess functional outcomes [3,6].

Clinical gait analysis is often used to quantify gait abnormalities in patients who have undergone surgery. Haddas et al. [9] performed gait analysis after surgical correction in patients with severe kyphosis from ankylosing spondylitis. Yagi et al. [10] assessed gait patterns in patients with adult spinal deformities (ASDs) and the effect of corrective spinal surgery on gait. Mahaudens et al. [11] compared pre- and post-surgery conditions in thoracolumbar scoliosis patients. The effect of decompression surgery on lumbar spinal stenosis was evaluated through three-dimensional (3D) motion analysis [12–14]. However, only one study assessed the gait parameters of patients who had undergone posterior fixation and fusion surgery after thoracolumbar burst fractures [2]. They reported that characteristics of patients undergoing short- and long-segment fusion were similar to those of healthy matched controls, but slight differences were observed on pelvic and hip excursions. This study was limited to assessing lower-extremity movement patterns. To fully understand the effect of posterior fixation on gait patterns, both lower-extremity and the trunk joint movement patterns should be assessed by gait analysis. The purpose of this study was to compare trunk and lower-extremity kinematics during gait between healthy adults and patients who had undergone posterior fixation surgery after thoracolumbar fractures.

2. Materials and Methods

2.1. Participants

We recruited nine male patients (age, 42.9 ± 8.1 years; height, 170.5 ± 4.7 cm; weight, 79.0 ± 13.1 kg) who had undergone posterior fixation after traumatic thoracolumbar burst fractures under the same team at the National Trauma and Orthopaedics Research Center. Spine fractures were evaluated on pre-operative CT scans using the AO classification [1]. All patients had incomplete burst fractures (AO type A3) involving T11–L2 vertebral bodies. Patients with displacement injuries (AO type C) underwent LS, whereas those without displacement underwent SS. The study evaluated a non-homogeneous cohort consisting of one patient who underwent SS fixation and eight who underwent LS fixation.

It has also been reported that LS fixation is typically chosen for patients with more severe fractures, such as those involving adjacent structure distraction, dislocation, or complete burst fracture [15]. Studies have shown that either short or long fixation had less effect on gait parameters [2] and radiological parameters [15]. Study inclusion was limited to neurologically intact patients with no lower-extremity dysfunction or changes. Nine healthy male participants (age 43.7 ± 6.3 years; height, 173.5 ± 3.6 cm; weight, 75.2 ± 8.7 kg) were also recruited, matched for age, height, and weight. The study was approved by the Institutional Review Board of the Mongolian National University of Medical Science, and informed consent was obtained from all subjects. All research was performed in accordance with the relevant guidelines and regulations.

2.2. Experimental Setup and Data Processing

The gait analysis was performed at 18.1 ± 2.5 months after surgery. An OptiTrack motion capture system with ten cameras (OptiTrack, NaturalPoint, Inc., Corvallis, OR, USA) and 43 reflective markers was used to record trunk and lower-extremity movements during walking at a sampling rate of 100 Hz, where the markers were attached to anatomical landmarks as per previous studies [16,17]. The markers were attached to the lower extremity (bilateral anterior superior iliac spines, posterior superior iliac spines, lateral/medial femoral condyles, lateral/medial malleolus, 1st/2nd/5th of metatarsus, posterior surface of calcaneus, four tracking markers on left/right thigh and shank) and the upper body (right/left acromion, deepest point of incisura jugularis, xiphoid process, C7 vertebra, T2

vertebra, T7 vertebra, and L1, L3, and L5 vertebrae). Subjects walked three times at a comfortable walking speed along a 6 m walkway, where the first and last 1.5 to 2 m were considered a transition zone, which left enough space to capture a single gait cycle.

The recorded optical marker data were exported to Visual 3D software (C-Motion, Inc, USA) to develop a musculoskeletal model, where 3D joint kinematics were calculated. The 3D trunk angle was calculated as the orientation of the thorax relative to the pelvis segment (Figure 1) [18]. After the experiment, walking data were trimmed to one full gait cycle (right-heel strike to the next right-heel strike). The trunk, hip, knee, and ankle joint angles in the sagittal (SP), frontal (FP), and transverse plane (TP) were calculated, averaged, and compared between patients and the control group. Total excursion motion was estimated as per previous studies [19,20]. A statistical difference between the two groups was determined using an independent T-test, since the control and patient groups were unrelated. To account for multiple comparisons, Bonferroni correction was applied within each plane (maximum, minimum, and excursion), yielding an adjusted significance threshold of $\alpha = 0.0167$ ($p < 0.05/3$) [21]. A Cohen d effect size statistic was calculated for kinematic parameters between control and patient groups. Effect sizes were interpreted as small = 0.2, medium = 0.5, and large = 0.8 [22].

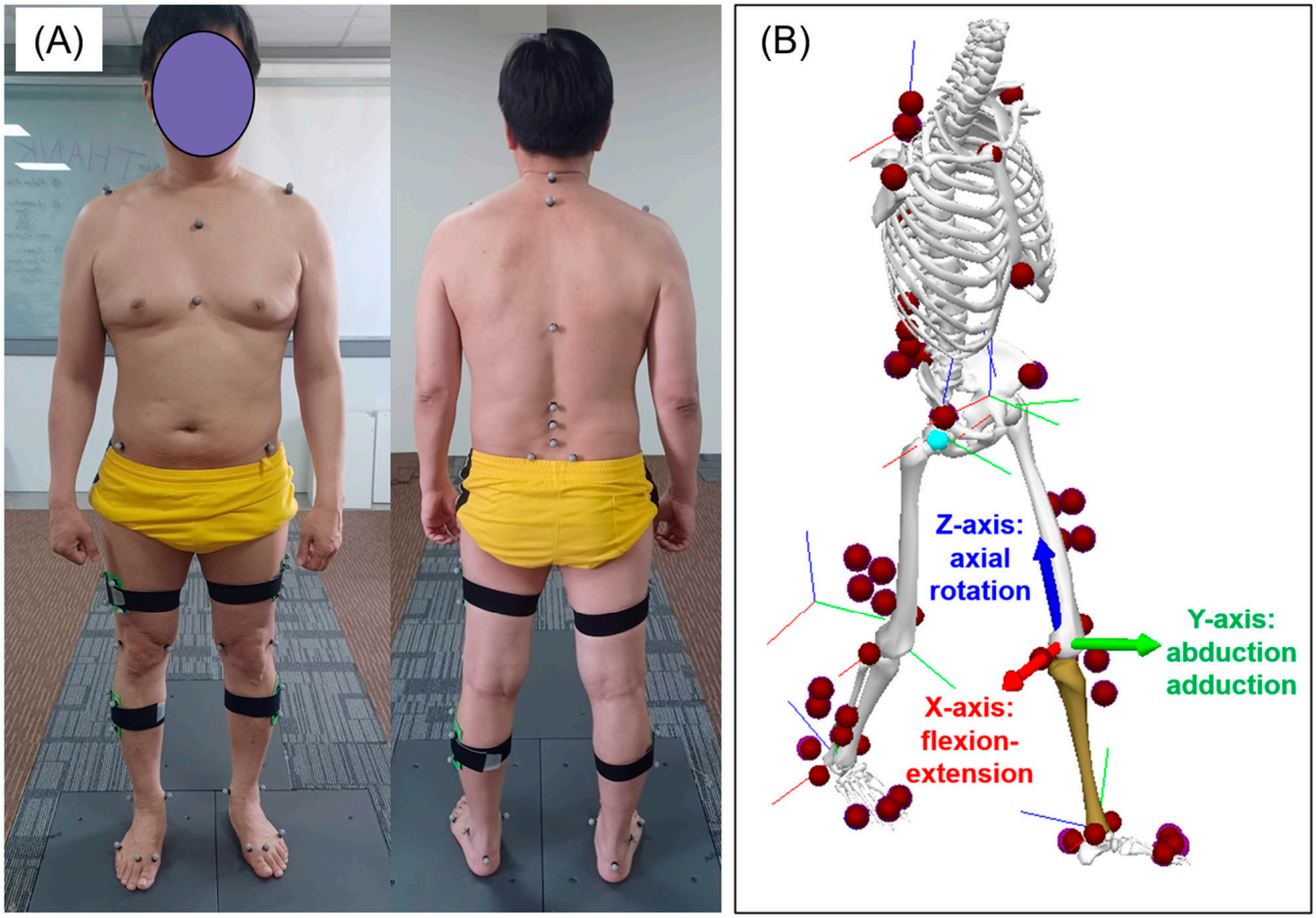


Figure 1. Marker set and joint angle definition. (**A**) Subject with reflective markers. (**B**) The skeletal model shows the markers' locations on the body segments and the definition of joint angles.

3. Results

The joint angles and total excursion motion in each anatomical plane are presented in Table 1. The hip, knee, ankle, and trunk joint angles in the SP, FP, and TP for the control group are shown in Figure 2a. The total excursion of the hip, knee, ankle, and trunk in

the SP was 35.3 ± 3.5°, 57.6 ± 4.6°, 30.5 ± 4.3°, and 3.2 ± 1.3°. The hip, knee, ankle, and trunk joint angles in the SP, FP, and TP for the patient group are shown in Figure 2b. The total excursion of the hip, knee, ankle, and trunk in the SP was 33.3 ± 6.1°, 58.5 ± 6.6°, 35.8 ± 5.5°, and 3.1 ± 1.0°.

Table 1. Hip, knee, ankle, and trunk joint angles and total excursion in SP, FP, and TP for control and patient groups.

Joints	Plane	Motions	Control Group (°)	Patient Group (°)	Mean Differences (°)	*p*-Value	Cohen's d
Hip	SP	Total excursion	35.3 ± 3.5	33.3 ± 6.1	2.0	0.468	0.40
		Peak flexion	30.9 ± 5.6	35.9 ± 6.9	5.0	0.166	−0.79
		Peak extension	−4.4 ± 4.7	2.6 ± 5.1	7.0	0.021	−1.41
	FP	Total excursion	10.7 ± 2.0	14.9 ± 2.0	4.2	0.002	−2.08
		Peak abduction	7.5 ± 3.7	9.7 ± 4.4	2.2	0.328	−0.54
		Peak adduction	−3.2 ± 2.7	−5.2 ± 4.2	2.0	0.306	0.57
	TP	Total excursion	13.1 ± 4.0	14.0 ± 7.1	0.9	0.782	−0.15
		Peak internal rotation	−2.7 ± 4.6	1.8 ± 13.6	0.9	0.878	0.08
		Peak external rotation	−10.4 ± 6.3	−12.2 ± 9.6	1.7	0.698	0.21
Knee	SP	Total excursion	57.6 ± 4.6	58.5 ± 6.6	0.9	0.764	−0.16
		Peak flexion	62.0 ± 4.9	62.1 ± 8.8	0.1	0.984	−0.01
		Peak extension	4.5 ± 3.5	3.6 ± 5.2	0.9	0.728	0.19
	FP	Total excursion	7.5 ± 2.3	10.9 ± 4.1	3.4	0.092	−1.00
		Peak abduction	2.1 ± 2.6	6.0 ± 5.6	4.0	0.121	−0.92
		Peak adduction	−5.4 ± 2.7	−4.8 ± 3.3	0.6	0.712	−0.20
	TP	Total excursion	14.9 ± 4.4	15.4 ± 4.3	0.6	0.794	−0.14
		Peak internal rotation	0.1 ± 2.1	0.3 ± 6.4	0.3	0.907	−0.06
		Peak external rotation	−14.8 ± 2.7	−15.1 ± 3.2	0.3	0.845	0.10
Ankle	SP	Total excursion	30.5 ± 4.3	35.8 ± 5.5	5.3	0.581	0.30
		Peak dorsiflexion	25.5 ± 4.1	19.0 ± 2.5	6.4	0.005	1.89
		Peak plantarflexion	−5.1 ± 4.1	−10.4 ± 4.0	5.3	0.030	1.31
	FP	Total excursion	9.4 ± 2.0	9.3 ± 4.5	0.1	0.398	−0.47
		Peak inversion	5.2 ± 2.7	6.5 ± 2.3	1.3	0.342	−0.52
		Peak eversion	−4.2 ± 2.7	−4.1 ± 2.3	0.1	0.949	−0.03
	TP	Total excursion	12.9 ± 5.0	13.2 ± 4.9	0.3	0.041	−1.23
		Peak internal rotation	8.5 ± 4.0	15.6 ± 5.6	7.1	0.020	−1.45
		Peak external rotation	−4.5 ± 2.2	−4.7 ± 2.4	0.3	0.823	0.12
Trunk	SP	Total excursion	3.2 ± 1.3	3.1 ± 1.0	0.1	0.928	0.04
		Peak flexion	8.6 ± 4.3	−0.9 ± 4.5	9.5	0.002	2.16
		Peak extension	5.5 ± 3.7	−3.9 ± 3.8	9.4	0.001	2.51
	FP	Total excursion	11.5 ± 2.4	12.6 ± 4.6	1.1	0.574	−0.31
		Peak right bending	4.6 ± 2.1	5.8 ± 4.2	1.2	0.511	−0.36
		Peak left bending	−6.9 ± 2.6	−6.8 ± 6.9	0.1	0.978	−0.01
	TP	Total excursion	11.4 ± 2.5	13.3 ± 6.0	1.9	0.466	−0.40
		Peak right rotation	3.8 ± 2.7	7.4 ± 3.1	3.6	0.040	−1.23
		Peak left rotation	−7.6 ± 2.9	−5.9 ± 3.3	1.7	0.330	−0.54

Kinematic comparisons between the control and patient groups are shown in Figure 2c. The patient group had significantly increased total hip excursion in FP ($p = 0.002$), with mean differences of 4.2°. At the ankle joint, dorsiflexion was significantly reduced ($p = 0.005$) in the patient group (Figure 2c). This reduction was more prominent in dorsiflexion (6.4°) than in plantar flexion (5.3°). In contrast, no significant differences were observed in

knee joint kinematics (Table 1). Patients exhibited a more upright trunk position during walking than the control group, where both peak trunk flexion and extension were significantly different ($p < 0.0167$), possibly indicating stiffer trunk movement. Moreover, patients tended to exhibit greater right-trunk rotation than healthy subjects, but this was not significantly different.

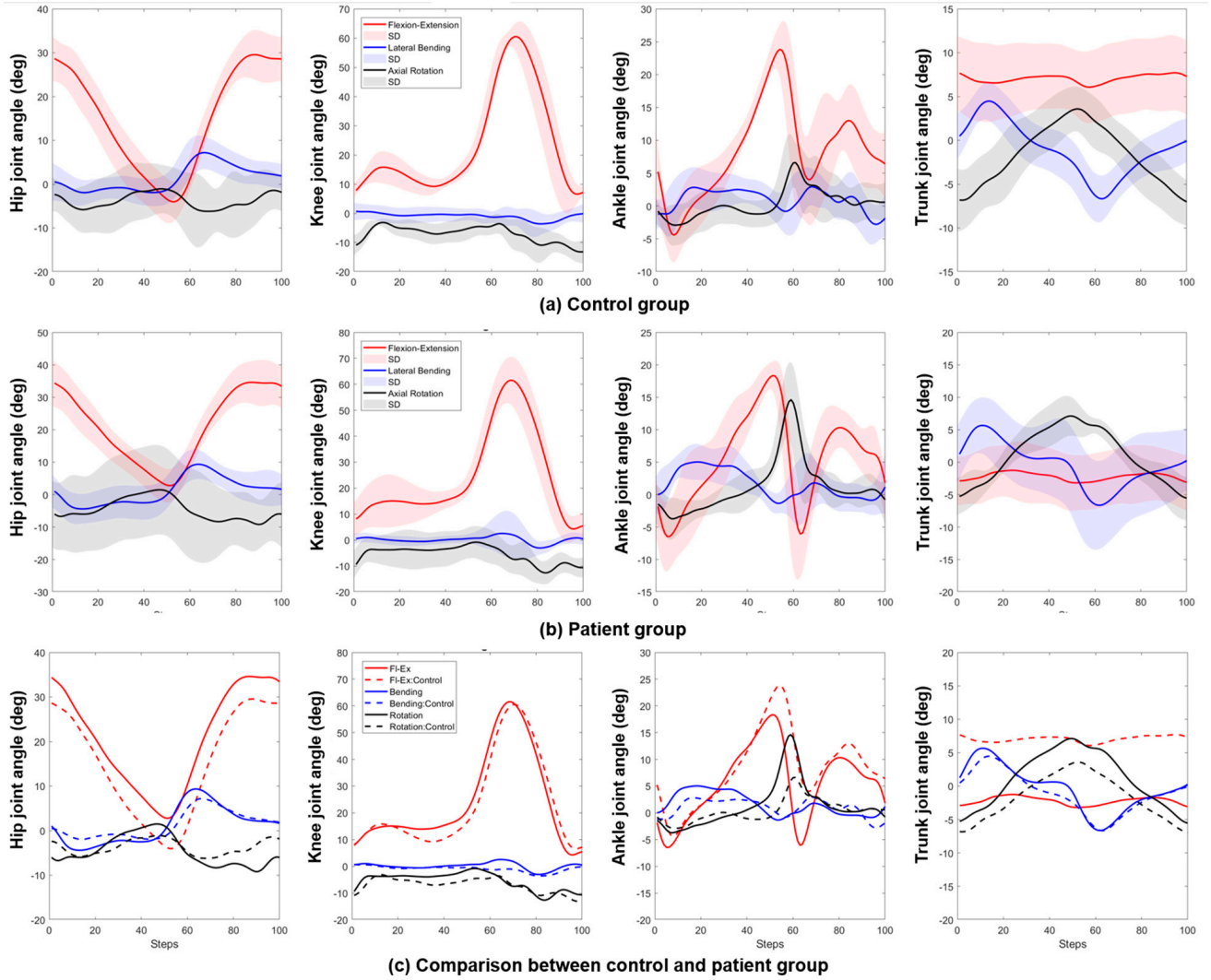


Figure 2. Hip, knee, ankle, and trunk joint angles in controls (**a**) and patients (**b**) and comparison (**c**).

4. Discussion

This study investigated trunk and lower-extremity kinematics during gait after posterior fixation for thoracolumbar fractures with an optical motion capture system. Our results showed that patients who underwent surgery exhibited more upright trunk positions and increased total hip excursion in the FP and reduced hip extension and ankle dorsiflexion compared with healthy subjects. Specifically, a statistical difference was observed during hip total excursion in the FP, ankle dorsiflexion in the SP, and trunk flexion and extension in the SP, respectively. The main changes were observed in the trunk, hip, and ankle joints in the SP after surgery. This could be explained by patients who had undergone surgery having stiffened upper bodies to compensate for increased total hip excursion in the FP and reduced hip extension and ankle dorsiflexion while walking. This likely arises from reduced trunk and lumbopelvic mobility due to thoracolumbar constraints, which limit proximal contribution to gait propulsion and balance, thereby increasing the distal joints

to maintain progression and stability. These adaptations reflect regional interdependence between the trunk and lower limbs, whereby changes in trunk mechanics propagate distally to preserve functional gait. Various studies have noted that the compensation mechanism for walking differs between patients who underwent surgery and healthy individuals. Yagi et al. [10] found compensatory flexion of the hip and a posterior pelvic shift in ASD patients. Mahaudens et al. [11] also noted that range-of-motion increases in unaffected joints in spinal fusion for adolescent idiopathic scoliosis.

Although few studies have reported gait parameters in patients after posterior fixation and fusion for thoracolumbar fractures, similar trends were observed for lower-extremity joint angles. Oken et al. [2] reported that pelvic and hip excursions in the SP differed slightly between control and patients who underwent posterior fixation and fusion surgery. Similarly to that study, the present study showed a difference in hip and trunk rotation in the SP, which may explain why the posterior fixation method leads to a more upright trunk position. Then, the pelvis is more anteriorly tilted and the hip is more extended during walking.

The study has several limitations. First, few participants were recruited because it was difficult to find patients, as gait analysis was performed about 18 months after surgery. Studies have shown that lower-extremity gait parameters did not change significantly between 1 and 2 years after spinal surgery. Second, only male participants with short-and long-segment fixations were included. Moreover, we only investigated joint kinematics, but comprehensive gait analysis should include kinetics [11]. Various daily activities should be analyzed, in addition to walking, to elucidate the effect of posterior fixation on the trunk. Furthermore, few gait studies are available for patients with posterior fixation for thoracolumbar fractures, making comparison and interpretation difficult. Future studies should combine gait biomechanical parameters with patient-reported and functional outcomes to establish clinically meaningful thresholds for postoperative gait changes.

Our results showed differences in trunk and lower-extremity kinematics between patients with posterior fixation and healthy individuals. Patients who had undergone surgery tended to have a more upright trunk posture than healthy people. This study provides fundamentals of the joint kinematics of the trunk and lower extremities after a posterior surgical operation for a thoracolumbar fracture, which may help in evaluating surgical outcomes and planning further reconstruction surgery if needed.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of the Mongolian National University of Medical Sciences.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are contained within the article.

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Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Aebi, M. Classification of Thoracolumbar Fractures and Dislocations. *Eur. Spine J.* **2010**, *19*, 2–7. [CrossRef] [PubMed]
2. Oken, F.; Yildirim, O.; Oken, O.; Gulcek, M.; Yavuzer, G.; Ucaner, A. Short or Long Fusion after Thoracolumbar Burst Fractures Does Not Alter Selected Gait Parameters: A Preliminary Study. *J. Orthop. Res.* **2011**, *29*, 915–918. [CrossRef] [PubMed]
3. Tian, N.; Wu, Y.; Zhang, X.; Wu, X.; Chi, Y.; Mao, F. Fusion versus Nonfusion for Surgically Treated Thoracolumbar Burst Fractures: A Meta-Analysis. *PLoS ONE* **2013**, *8*, e63995. [CrossRef] [PubMed]
4. McLain, R.F. The Biomechanics of Long versus Short Fixation for Thoracolumbar Spine Fractures. *Spine* **2006**, *31*, 70–79. [CrossRef] [PubMed]
5. Kanna, R.M.; Shetty, A.P.; Rajasekaran, S. Posterior Fixation Including the Fractured Vertebra for Severe Unstable Thoracolumbar Fractures. *Spine J.* **2015**, *15*, 256–264. [CrossRef] [PubMed]
6. Jeon, C.H.; Lee, H.D.; Lee, Y.S.; Seo, J.H.; Chung, N.S. Is It Beneficial to Remove the Pedicle Screw Instrument after Successful Posterior Fusion of Thoracolumbar Burst Fractures? *Spine* **2015**, *40*, E627–E633. [CrossRef] [PubMed]
7. Leduc, S.; Mac-Thiong, J.M.; Maurais, G.; Jodoin, A. Posterior Pedicle Screw Fixation with Supplemental Laminar Hook Fixation for the Treatment of Thoracolumbar Burst Fractures. *Can. J. Surg.* **2008**, *51*, 35–40. [PubMed]
8. Liang, J.Z.; Corso, N.; Turner, E.; Zakhor, A. Image Based Localization in Indoor Environments. In Proceedings of the 2013 4th International Conference on Computing for Geospatial Research and Application, COM.Geo, San Jose, CA, USA, 19 September 2013; pp. 70–75. [CrossRef]
9. Haddas, R.; Xu, M.; Lieberman, I.; Yang, J. Finite Element Based-Analysis for Pre and Post Lumbar Fusion of Adult Degenerative Scoliosis Patients. *Spine Deform.* **2019**, *7*, 543–552. [CrossRef] [PubMed]
10. Yagi, M.; Ohne, H.; Konomi, T.; Fujiyoshi, K.; Kaneko, S.; Takemitsu, M.; Machida, M.; Yato, Y.; Asazuma, T. Walking Balance and Compensatory Gait Mechanisms in Surgically Treated Patients with Adult Spinal Deformity. *Spine J.* **2017**, *17*, 409–417. [CrossRef] [PubMed]
11. Mahaudens, P.; Detrembleur, C.; Mousny, M.; Banse, X. Gait in Thoracolumbar/Lumbar Adolescent Idiopathic Scoliosis: Effect of Surgery on Gait Mechanisms. *Eur. Spine J.* **2010**, *19*, 1179–1188. [CrossRef] [PubMed]
12. Loske, S.; Nüesch, C.; Byrnes, K.S.; Fiebig, O.; Schären, S.; Mündermann, A.; Netzer, C. *Decompression Surgery Improves Gait Quality in Patients with Symptomatic Lumbar Spinal Stenosis*; Elsevier Inc.: Amsterdam, The Netherlands, 2018; Volume 18.
13. Kuwahara, W.; Deie, M.; Fujita, N.; Tanaka, N.; Nakanishi, K.; Sunagawa, T.; Asaeda, M.; Nakamura, H.; Kono, Y.; Ochi, M. Characteristics of Thoracic and Lumbar Movements during Gait in Lumbar Spinal Stenosis Patients before and after Decompression Surgery. *Clin. Biomech.* **2016**, *40*, 45–51. [CrossRef] [PubMed]
14. Lamas, V.; Gueugnon, M.; Fournel, I.; Grelat, M.; Maillefert, J.F.; Ornetti, P.; Martz, P. Dynamic Global Sagittal Alignment in Patients with Lumbar Spinal Stenosis: Analysis of the Effects of Decompression Surgery on Gait Adaptations. *Gait Posture* **2021**, *88*, 272–279. [CrossRef] [PubMed]
15. Borkhuu, B.; Batochir, B.; Sonomjamts, M.; Tsevegmid, E.; Lkhagvasuren, N. Long Versus Short-Segment Stabilization in Patients with Traumatic Thoracolumbar Fractures. *Ortop. Traumatol. Rehabil.* **2023**, *25*, 173–179. [CrossRef] [PubMed]
16. Jan, S.V.S. *Color Atlas of Skeletal Landmark Definitions*; Churchill Livingstone: London, UK; Elsevier: Amsterdam, The Netherlands, 2007.
17. Lewis, C.L.; Sahrmann, S.A. Effect of Posture on Hip Angles and Moments during Gait. *Man. Ther.* **2015**, *20*, 176–182. [CrossRef] [PubMed]
18. Dambadarjaa, B.; Khuyagbaatar, B.; Bayartai, M.-E.; Purevsuren, T.; Shambaljamts, T.; Kim, Y.H. Kinematic Comparison between People with and without Low Back Pain during Functional Activities. *J. Mech. Sci. Technol.* **2024**, *38*, 2781–2787. [CrossRef]
19. Malone, A.; Meldrum, D.; Bolger, C. Gait Impairment in Cervical Spondylotic Myelopathy: Comparison with Age- and Gender-Matched Healthy Controls. *Eur. Spine J.* **2012**, *21*, 2456–2466. [CrossRef] [PubMed]
20. Khuyagbaatar, B.; Tumurbaatar, M.; Tsenkherjav, K.; Purevsuren, T.; Shambaljamts, T.; Kim, K.; Danjkhuu, T.; Danaa, G.; Hyuk Kim, Y. Kinematic Comparison of Snatch and Clean Lifts in Weightlifters Using Wearable Inertial Measurement Unit Sensors. *Phys. Act. Health* **2024**, *8*, 1–9. [CrossRef]
21. Beaulieu, M.L.; Lamontagne, M.; Beaulé, P.E. Lower Limb Biomechanics during Gait Do Not Return to Normal Following Total Hip Arthroplasty. *Gait Posture* **2010**, *32*, 269–273. [CrossRef] [PubMed]
22. Khuyagbaatar, B.; Dambadarjaa, B.; Altan-Ochir, Z.; Battumur, G.; Batbaatar, E.; Kim, Y.H. Assessment of Functional Movement Screen and Performance Parameters of Wrestlers Using Inertial Sensors. *Front. Sports Act. Living* **2025**, *7*, 1560924. [CrossRef] [PubMed]

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