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ORIGINAL ARTICLE

Spinopelvic fusion surgery from lower thoracic spine to pelvis increased hip joint moment–motion analysis

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Abstract

Purpose Spinal fusion surgery is often performed with pelvic fixation to prevent distal junctional kyphosis. The inclusion of spinopelvic fixation has been reported to induce progression of hip joint arthropathy in a radiographic follow-up study. However, its biomechanical mechanism has not yet been elucidated. This study aimed to compare the changes in hip joint moment before and after spinal fusion surgery.

Methods This study was an observational study and included nine patients (eight women and one man) who were scheduled to undergo spinopelvic fusion surgery. We calculated the three-dimensional external joint moments of the hip during gait, standing, and climbing stairs before and 1 year after surgery.

Results During gait, the maximum extension moment was 0.51 ± 0.29 and 0.63 ± 0.40 before and after spinopelvic fusion surgery ($p = 0.011$), and maximum abduction moment was 0.60 ± 0.33 and 0.83 ± 0.34 before and after surgery ($p = 0.004$), respectively. During standing, maximum extension moment was 0.76 ± 0.32 and 1.04 ± 0.21 before and after spinopelvic fusion surgery ($p = 0.0026$), and maximum abduction moment was 0.12 ± 0.20 and 0.36 ± 0.22 before and after surgery ($p = 0.0005$), respectively. During climbing stairs, maximum extension moment was -0.31 ± 0.30 and -0.48 ± 0.15 before and after spinopelvic fusion surgery ($p = 0.040$), and maximum abduction moment was 0.023 ± 0.18 and -0.02 ± 0.13 before and after surgery ($p = 0.038$), respectively.

Conclusion This study revealed that hip joint flexion–extension and abduction–adduction moments increased after spinopelvic fixation surgery in the postures of standing, walking, and climbing stairs. The mechanism was considered to be adjacent joint disease after spinopelvic fusion surgery including sacroiliac joint fixation.

Keywords Adjacent joint disease · Spinopelvic fusion surgery · Adult spinal deformity · Hip osteoarthritis · Motion analysis

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Introduction

The number of spinal fusion surgeries for adult spinal deformities has increased with the aging of the population. Although spinopelvic fusion surgery for adult spinal deformity has improved lower back pain and quality of life, it had several problems [1–5]. Adjacent segment disease (ASD) has been reported as one of the major complications. It induces functional and neurogenic disorders and may require additional surgery [1]. Spinal fusion surgery is often combined with pelvic fixation to prevent distal junctional kyphosis and failure [2]. The inclusion of spinopelvic fixation has been reported to induce the progression of hip joint arthropathy in a one-year radiographic follow-up study of 118 patients with ASD [3]. The causative pathology was considered as adjacent joint disease (AJD) after spinopelvic fixation surgery [3]. One reason for this condition is that patients with spinal deformity are at a potential risk of hip-spine syndrome [4]. Patients with spinal kyphosis compensate for standing balance with knee flexion, which changes the orientation of the hip joint. Thus, the posterior coverage of the femoral head is increased [4]. Spinopelvic fixation surgery improved the spinal sagittal alignment and anterior coverage of the hip joint. It was attributed to the possibility of femoral-acetabular anterior impingement and the hip joint dislocation after total hip arthroplasty. It has been reported that femoral-acetabular impingement occurs during sit-to-stand or excessive anterior tilt of the trunk [5]. However, a quantitative evaluation of hip joint stress after spinopelvic fixation surgery has not been reported. Further, the effect of posture on the hip joint function needs to be assessed. This study aimed to evaluate the impact of posture on hip pathology after adult spinal deformity surgery.

Methods

Participants

Eight women and one man who were scheduled to undergo spinopelvic fusion surgery were included in this study from June 2019 to March 2020. All patients underwent spinal fusion surgery from T10 to pelvis, including S2 alar-iliac screw fixation. Motion capture was performed twice: before surgery and one year after surgery. Mean age at surgery was 71.2 ± 3.1 years, mean height 147.7 ± 3.7 cm, and mean weight 56.7 ± 9.0 kg. Informed consent was obtained from all participants before undergoing the intervention. This study was approved by the ethics committee of our hospital (No. 2511).

Experimental setup

A three-dimensional (3D) motion analysis system that included a 12-camera Raptor-E motion capture system (MAC 3D system, Motion Analysis Corporation, Santa Rosa, CA, USA) and six force plates (AMTI, Watertown, MW, USA) was used to record kinematic and kinetic data at a sample frequency of 100 Hz. The recorded data were low-pass filtered with a second-order recursive Butterworth filter with a cutoff frequency of 6 Hz [6]. A total of 23 reflective markers were attached to the following landmarks: top of the head, anterior superior iliac spine, posterior superior iliac spine, greater trochanter, thigh, medial femoral condyle, lateral femoral condyle, shank, medial malleus, lateral malleus, heel, and second metatarsal head (Fig. 1).

The pelvic segment contained four markers placed at the bilateral anterior superior iliac spine and posterior superior iliac spine. The thigh segment had four markers placed at the greater trochanter, thigh, medial femoral condyle, and lateral femoral condyle. The shank segment had four markers placed at the medial femoral condyle, lateral femoral condyle, shank, medial malleus, and lateral malleus.

We calculated the 3D external joint moments of the hip using Visual 3D software (Vicon Motion Systems Ltd. Oxford, England). The joint center of the hip was determined by first calculating a vector linking both the greater trochanter markers. The joint center was then determined at a point interpolated at a distance of 18% of the vector norm from each reflective marker of the superior aspect of the greater trochanter along the vector [7]. The joint moment was calculated using a link segment model, in which segments were connected at nodal points. To compute the joint moment, coordinate data were added to the ground reaction force data, in which the position of the center of mass, weight portion, and moment of inertia of each segment were used as the parameters. The peak external hip joint moment was calculated for gait, standing from 0.8-m chairs, and climbing stairs of 0.2-m step in each of the three planes (extension–flexion, abduction–adduction, and external rotation–internal rotation). Three trials were performed for each patient during each task. The hip joint moments were normalized according to the patient's height and weight [8]. The duration of each task was then evaluated. In addition, the stride length and step width were calculated.

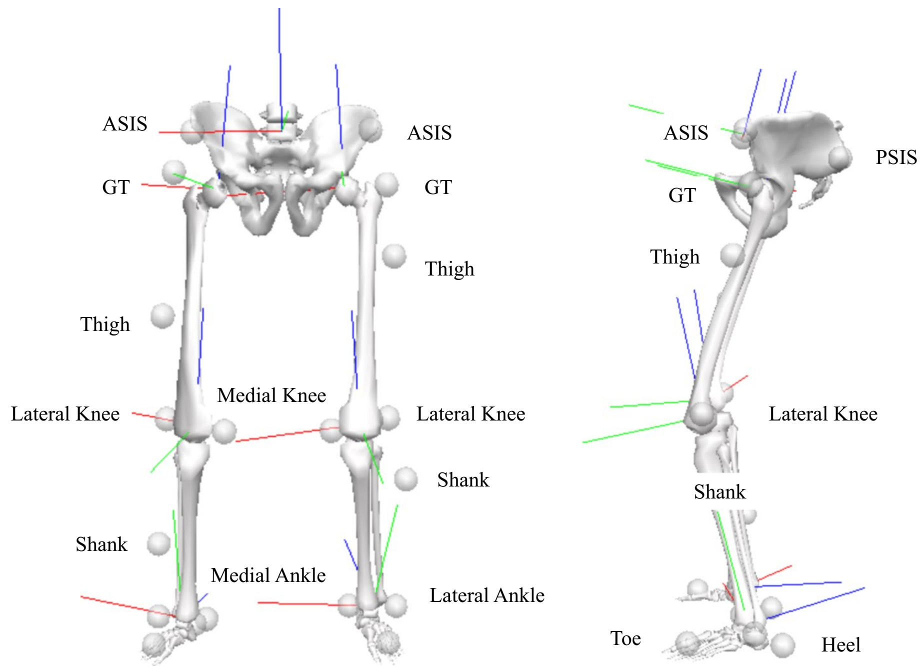

Fig. 1 Reflective markers set. A total of 23 reflective markers were attached to the following landmarks on the patients: the top of the head, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), greater trochanter (GT), thigh, medial femoral condyle (Medial Knee), lateral femoral condyle (Lateral Knee), shank, medial malleus (Medial Ankle), lateral malleus (Lateral Ankle), heel, and second metatarsal head (Toe)

Statistical analysis

Statistical analysis was performed using JMP Pro 14.1 (SAS Institute, Inc., Cary, NC, USA) software. Changes in moment and task durations were compared between those before and after spinopelvic fusion surgery using Mann–Whitney U test. The level of statistical significance was set at $p < 0.05$.

Results

Gait

The duration of one cycle gait decreased from 1.24 ± 0.19 s before surgery to 1.06 ± 0.64 s after surgery ($p = 0.019$). The stride length was significantly prolonged from 0.85 ± 0.12 m to 1.08 ± 0.14 m ($p < 0.0001$), and the step width significantly improved from 0.22 ± 0.10 m to 0.14 ± 0.075 m ($p < 0.0001$). However, the maximum extension moment of the hip joint was 0.51 ± 0.29 Nm/kg and 0.63 ± 0.40 Nm/kg before and after spinopelvic fusion surgery ($p = 0.011$), respectively. Maximum abduction moment of the hip joint was 0.60 ± 0.33 Nm/kg and 0.83 ± 0.34 Nm/kg before and after surgery ($p = 0.004$), respectively. Maximum external rotation moment of the hip joint did not change significantly from 0.20 ± 0.18 Nm/kg before surgery to 0.16 ± 0.18 Nm/kg after surgery ($p = 0.62$) (Table 1).

Standing

The duration of standing significantly improved from 2.16 ± 0.52 s before surgery to 1.61 ± 0.45 s after surgery ($p = 0.046$). However, the maximum extension moment of the hip joint was 0.76 ± 0.32 Nm/kg and 1.04 ± 0.21 Nm/kg before and after spinopelvic fusion surgery ($p = 0.0026$), respectively. Maximum abduction moment of the hip joint was 0.12 ± 0.20 Nm/kg and 0.36 ± 0.22 Nm/kg before and after surgery ($p = 0.0005$), respectively. Maximum external rotation moment of the hip joint did not change significantly from 0.18 ± 0.11 Nm/kg before surgery to 0.23 ± 0.12 Nm/kg after surgery ($p = 0.065$) (Table 1).

Climbing stairs

The duration of climbing stairs improved significantly from 3.01 ± 0.97 s before surgery to 2.42 ± 0.75 s after surgery ($p = 0.032$). However, the maximum extension moment of the hip joint was − 0.31 ± 0.30 Nm/kg and − 0.48 ± 0.15 Nm/kg before and after spinopelvic fusion surgery ($p = 0.040$), respectively. Maximum abduction moment of the hip joint was 0.023 ± 0.18 Nm/kg and − 0.02 ± 0.13 Nm/kg before and after surgery ($p = 0.038$), respectively. The maximum external rotation moment of the hip joint did not change significantly from 0.059 ± 0.046 Nm/kg before surgery to 0.073 ± 0.076 Nm/kg after surgery ($p = 0.26$) (Table 1).

Table 1 The moment at hip joint and duration time at each tasks

	Pre-operation	Post-operation	*p* value
Gait			
Maximum extension moment (Nm/kg)	0.51 ± 0.29	0.63 ± 0.40	0.011
Maximum abduction moment (Nm/kg)	0.60 ± 0.33	0.83 ± 0.34	0.004
Maximum external rotation moment (Nm/kg)	0.20 ± 0.18	0.16 ± 0.18	0.62
Duration for one gait cycle (s)	1.24 ± 0.19	1.06 ± 0.64	0.019
Stride length (m)	0.85 ± 0.12	1.08 ± 0.14	< 0.0001
Step width (m)	0.22 ± 0.10	0.14 ± 0.075	< 0.0001
Standing			
Maximum extension moment (Nm/kg)	0.76 ± 0.32	1.04 ± 0.21	0.0026
Maximum abduction moment (Nm/kg)	0.12 ± 0.20	0.36 ± 0.22	0.0005
Maximum external rotation moment (Nm/kg)	0.18 ± 0.11	0.23 ± 0.12	0.065
Duration for standing from sitting position (s)	2.16 ± 0.52	1.61 ± 0.45	0.046
Climbing stairs			
Maximum extension moment (Nm/kg)	− 0.31 ± 0.30	− 0.48 ± 0.15	0.040
Maximum abduction moment (Nm/kg)	0.023 ± 0.18	− 0.02 ± 0.13	0.038
Maximum external rotation moment (Nm/kg)	0.059 ± 0.046	0.073 ± 0.076	0.26
Duration for upstairs by one leg (s)	3.01 ± 0.97	2.42 ± 0.75	0.032

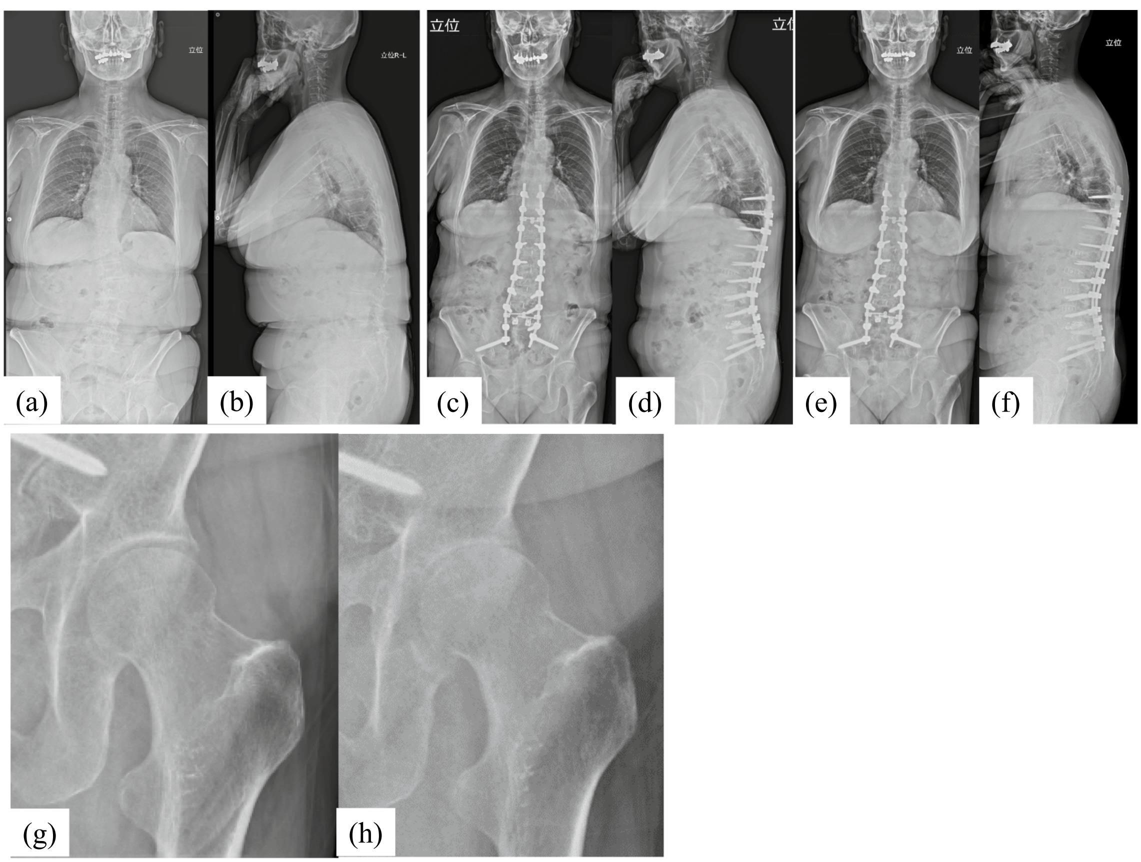

Fig. 2 Representative case. The 70-year-old female underwent spinopelvic fixation surgery from T10 to pelvis. Whole spine alignment improved after surgery (**c**, **d**), compared to before surgery (**a**, **b**). Three years later, spinal alignment was kept (**e**, **f**), but the left hip joint space was decreased (**g**, **h**)

Representative case

A 70-year-old woman visited our hospital because of low back pain and inability to walk for more than five minutes. Spinopelvic fusion surgery was planned from T10 to the pelvis. She underwent three tasks before and 12 months after surgery (Fig. 2a–f). Spinopelvic fixation surgery improved sagittal alignment and daily activity. The duration of one gait cycle improved by 24.8% (1.53 s before surgery and 1.15 s after surgery). The stride length was prolonged by 29.4% (0.85 m before and 1.10 m after surgery). The step width decreased by 50% (0.1 m before and 0.05 m after surgery). However, the maximum extension moment when walking was increased by 22.4% (0.49 Nm/kg before and 0.60 Nm/kg after surgery). The maximum extension moment when standing was increased by 38.6% (0.7 Nm/kg before and 0.97 Nm/kg after surgery). The maximum flexion moment when climbing stairs was increased by 26.3% (0.38 Nm/kg before and 0.48 Nm/kg after surgery) (Fig. 3). Three years later, the joint space decreased in the left hip joint, and she experienced hip joint pain (Fig. 2g, h).

Discussion

This study revealed that hip joint flexion–extension and abduction–adduction moments increased after spinopelvic fixation surgery in the postures of standing, walking, and while climbing stairs, despite the shorter duration for the posture after surgery. The spinopelvic fixation surgery achieved ideal sagittal balance in adult spinal deformity patients, which improved gait ability. The results of this study also illustrated the duration of gait, stride length, and step width was improved. A previous study reported that sacroiliac joint fixation was a risk factor for the occurrence of adjacent joint disease at the hip joint after spinal fusion surgery at one-year follow-up [3]. The results of this study also illustrate adjacent joint disease after spinal fusion surgery, including the sacroiliac joint.

ASD is one of the major complications of spinal fusion surgery. ASD typically develops at the mobile segment superior or inferior to the fused spine [9, 10], which is caused by the transition of motion from the fusion segments to the

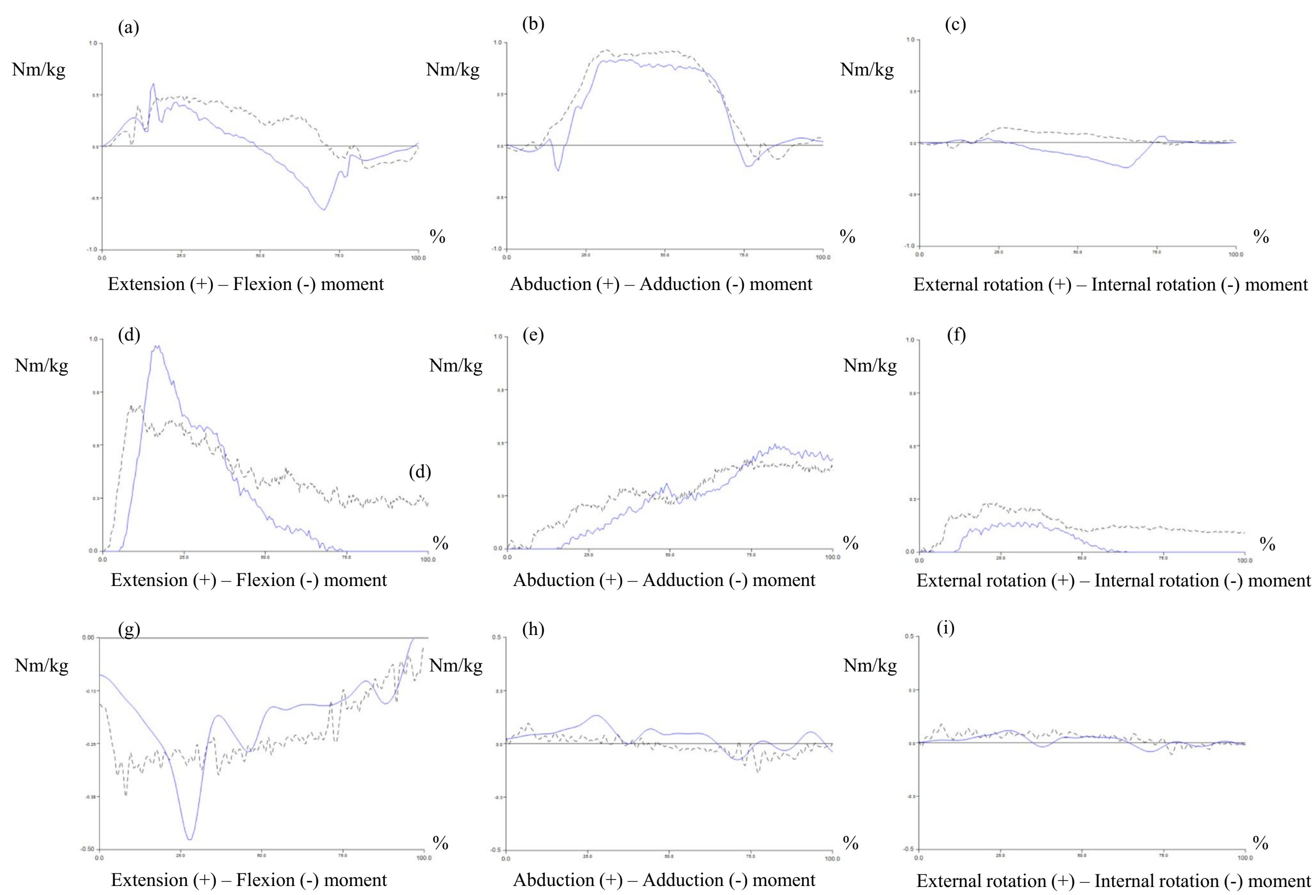

Fig. 3 Left hip joint moment of representative case during walking (**a**–**c**), standing (**d**–**f**), and climbing stairs (**g**–**i**). When walking, the hip joint extension moment was increased (**a**). During standing, the hip joint extension moment was increased after surgery. (**d**) During climbing stairs, the hip joint extension moment was increased after surgery (**g**). Black line; before surgery, blue dotted lines; after surgery

subsequent mobile segments [11, 12]. Similarly, hip joint pain after spinal fusion surgery has been reported [13]. A radiological study reported that sacroiliac joint fixation in adult spinal long fusion surgery decreased the hip joint cartilage in one-year follow-up study [3] and the prevalence was 10.0% in mean 50 months of follow-up study [14, 15]. The pathology was thoght to be the AJD. A previous finite element study also revealed that the contact pressure of the hip joint was highest in the spinopelvic fixation model, compared with lumbar fusion model without pelvic fixation [16]. However, there were no reports about the hip-spine relation in three-dimensional motion analysis. This study included the daily activity: walking, standing, and climbing stairs, and revealed that hip joint moment increased considerably more after adult spinal fusion surgery than before surgery, especially in the flexion–extension and adduction-abduction moment. The rotational moment has less impact on the hip joint, but it was thought not to be problem because the value of rotational moment was smaller than the flexion–extension and adduction–abduction moment. In a previous study, daily hip joint moment was associated with radiographic progression of secondary hip osteoarthritis in motion analysis [17]. Therefore, the results of this study might suggest the possibility of hip osteoarthritis after spinopelvic fixation surgery.

This study has several limitations. First, this study has limited generalizability. This study only reflects loading during standing, walking, and climbing stairs, and not loading during other movements, such as lifting, running, and one-leg standing. However, it is technically difficult to evaluate all daily activities. This study was based on only nine patients (eight women and one man), which was too small sample size to clear the new relation between spinal fusion surgery and the hip lesions, which was because of the spread of the coronavirus disease 2019 (COVID-19) from March 2020 on Japan and we could not include new subjects. The follow-up period of 12 months was minimal to evaluate degenerative changes in the hip joint. A longer follow-up period is needed to establish the relationship between the loading and degenerative changes at the hip joint. The severely off-balance subjects were not included in this study. Second, we could not evaluate other reported risk factors of hip osteoarthritis, such as physical activity [17], impingement in the pincer [18], and cam morphology [19, 20]. Studies with a larger population and longer follow-up duration are necessary to establish the relationship between adjacent joint disease after ASD surgery and risk factors. Third, this study included only Japanese patients. The pelvic incidence is lower in the Japanese population than that in the Western population, which is representative of the differences in skeletal structure, although the Japanese lifestyle is becoming more similar with the Western lifestyle. Further large-scale multinational studies are necessary to address these differences. Forth, we included the adult spinal deformity patients without hip lesion. This study could not clear the influence of the spinopelvic fusion surgery on total hip arthroplasty (THA), but which have several problems for example, loosening, or increasing of the wearing [21, 22]. The following study is needed to clear the relation between spinopelvic fusion surgery and implant failure of THA on the view of the biomechanics.

Conclusions

This study revealed that daily motion has been improved, but hip flexion–extension moment and abduction–adduction moment has increased one year after the spinopelvic fusion surgery. We should pay attention to the hip joint pathology after spinopelvic fusion surgery in case could not avoid the pelvic fixation.

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Authors' contribution TK, HH, and HO designed experiments. TK, KK, and MT performed the experiments, derived the models and analyzed the data. IH, ST, MT, KN, and YI performed surgical procedure. TT, DN, DF and MY encouraged TK to investigate. JK supervised the data of this work. RT, SM, YM, YN, and TK assisted with measurements. TK wrote the manuscript in consultation with all authors.

Data availability The datasets during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest None.

Ethics approval All patients provided informed consent prior to surgery, and the study protocol was approved by the institutional ethics board of Wakayama Medical University (No. 2511).

Consent to participate All patients provided informed consent prior to surgery.

Consent to publish All patients provided informed consent for publication.

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