



Article

Risk Factors for Progressive Spinal Sagittal Imbalance in the Short-Term Course after Total Hip Arthroplasty: A 3 Year Follow-Up Study of Female Patients

Satoshi Nagatani, Satoru Demura , Satoshi Kato *, Tamon Kabata, Yoshitomo Kajino, Noriaki Yokogawa , Daisuke Inoue, Yuki Kurokawa, Motoya Kobayashi, Yohei Yamada, Masafumi Kawai and Hiroyuki Tsuchiya

Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kanazawa University, 13-1 Takara-machi, Kanazawa 920-8641, Japan

* Correspondence: skato323@gmail.com; Tel.: +81-76-265-2374

Abstract: Total hip arthroplasty (THA) for patients with hip osteoarthritis improves hip flexion contracture, subsequently improving spinal sagittal balance. However, in some cases, spinal sagittal imbalance develops in the course after THA, and its risk factors remain unknown. We aimed to investigate the risk factors of progressive spinal sagittal imbalance after THA. This retrospective cohort study of a prospectively maintained database included female patients aged ≥ 50 years who underwent THA. Before performing THA, we obtained each patient's anthropometric and muscle strength measurements and whole-spine radiographs. Three years postoperatively, patients underwent whole-spine radiography to examine changes in the spinal sagittal balance. Patients were assigned into groups on the basis of their preoperative and 3 year postoperative sagittal vertical axis (SVA) values. Patients with 3 year postoperative SVA values ≥ 40 mm with an increase ≥ 30 mm were categorized into the imbalance group; the other patients were categorized into the non-imbalance group. Of 103 patients, 11 (10.7%) were in the imbalance group. In multiple logistic regression analysis, preoperative weak abdominal trunk muscle strength (ATMS) ($p = 0.007$) and small sacral slope (SS) ($p = 0.005$) were significant risk factors for progressive spinal sagittal imbalance. In conclusion, risk factors for progressive spinal sagittal imbalance after THA were weak preoperative ATMS and small SS.

Keywords: total hip arthroplasty; spinal sagittal imbalance; spinopelvic parameters; sacral slope; sagittal vertical axis; abdominal trunk muscle strength; short-term follow-up; female patients



Citation: Nagatani, S.; Demura, S.; Kato, S.; Kabata, T.; Kajino, Y.; Yokogawa, N.; Inoue, D.; Kurokawa, Y.; Kobayashi, M.; Yamada, Y.; et al. Risk Factors for Progressive Spinal Sagittal Imbalance in the Short-Term Course after Total Hip Arthroplasty: A 3 Year Follow-Up Study of Female Patients. *J. Clin. Med.* **2022**, *11*, 5179. <https://doi.org/10.3390/jcm11175179>

Academic Editor: Moshe Salai

Received: 26 July 2022

Accepted: 30 August 2022

Published: 1 September 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Hip osteoarthritis (OA) is one of the most common musculoskeletal diseases in an aging society [1]. In recent years, it has been recognized that pelvic and spinal alignments affect each other, and many studies have been conducted on spinopelvic alignment in hip OA [2–6]. Patients with hip OA often have hip flexion contracture, pelvic anteversion, and a high sagittal vertical axis (SVA), suggesting spinal sagittal imbalance [7]. As OA progresses and the range of motion of the hip decreases, spinal sagittal imbalance progresses [4,8].

Total hip arthroplasty (THA) is the standard procedure for hip OA, and the number of THAs being performed is increasing [9]. In general, THA reduces flexion contracture of the hip joint, resulting in a retroverted pelvis, decreased SVA, and improved spinal sagittal balance [10–12]. However, in some cases, spinal sagittal imbalance with lumbar kyphosis develops in the course after THA. Corrective surgery for lumbar kyphosis, which increases the risk of hip dislocation after THA [13–15], can be necessary for these patients. Therefore, it is important to understand the characteristics of the patients with progressive spinal sagittal imbalance after THA; this has not been studied to date. This study aimed to investigate the risk factors for progressive spinal sagittal imbalance in the short-term course after THA.

2. Materials and Methods

2.1. Participants

A total of 156 female patients aged ≥ 50 years who underwent THA for hip OA at our hospital between 2016 and 2019 and agreed to participate in a preoperative examination were included in this study. Patients who had previously undergone spinal surgery or were diagnosed with rheumatic diseases were excluded from the study; 46 patients who did not have the 3 year standing whole-spine radiographs were excluded from the study. Finally, 103 patients were evaluated in this study (Figure 1). Surgical procedures included anterior ($n = 76$), posterior ($n = 27$), unilateral only ($n = 83$), and bilateral simultaneous ($n = 20$) approaches.

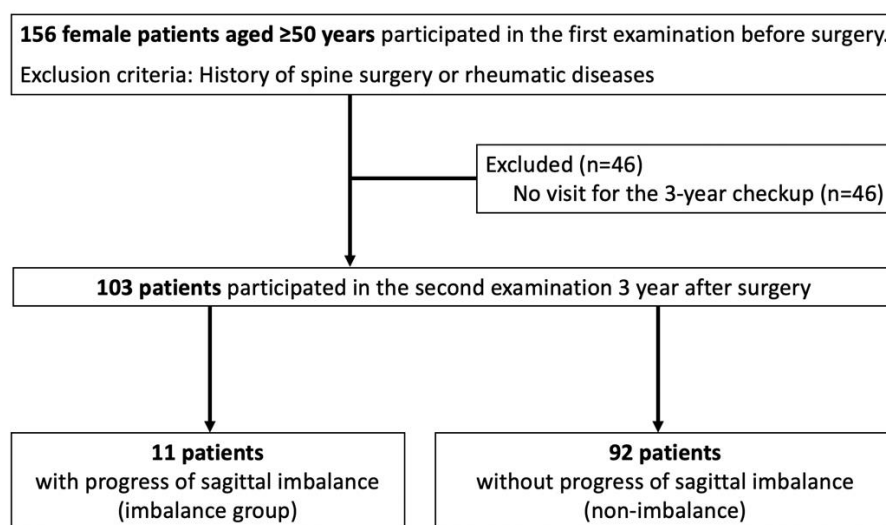


Figure 1. Flowchart describing the selection process of study participants and their assignment to the two groups.

2.2. Evaluation of the Demographic and Radiographic Parameters of Participants

Clinical information was collected through a retrospective review of a prospectively maintained database. Before the surgery, participants underwent physical measurements, standing whole-spine radiography, and other assessments as described below. We obtained anthropometric measurements, including body height, body weight, and body mass index. Grip power was measured using a TTM dynamometer (Tsutsumi, Tokyo, Japan). The knee extensor muscle strength (KEMS) was measured using a handheld dynamometer (μ Tas F-1; ANIMA Corp., Tokyo, Japan); KEMS values were divided by the body weight (N/kg). To measure KEMS, subjects were seated in an elevated chair with 90° of knee flexion and their feet above the floor. With the dynamometer placed on the anterior surface of their leg, 10 cm proximal to the malleoli, subjects were instructed to push against the dynamometer by attempting to straighten their knees [16]. The right and left grip power and KEMS were measured once, and the higher strength values were recorded. Abdominal trunk muscle strength (ATMS) was measured using an exercise device for the abdominal trunk muscles (RECORE: Nippon Sigmax Co., Ltd., Tokyo, Japan). As previously described [17], this device enables patients to perform strength measurement or strengthening exercises involving their abdominal trunk muscles in a sitting position without movement of the trunk or load on the spine. A previous study showed that this device had excellent intra- and inter-rater reliabilities to measure ATMS, and strengthening exercises using the device activate and increase diaphragmatic, abdominal, and pelvic floor muscle strength [18]. ATMS was measured twice, and the higher strength values were recorded. Locomotive syndrome, defined as a condition of reduced mobility due to an impairment of a locomotive organ, was assessed using the 25-question Geriatric Locomotive Function Scale (GLFS-25) and a two-step test in each patient [19]. In addition, the functional reach test (FRT)

was performed to measure the stability of the patients while reaching forward in the standing position [20]. Other assessments included 10 m walking speed, one-leg standing time, lumbar bone mineral density measured using dual-energy X-ray absorptiometry, and the presence of osteoporotic vertebral fracture evaluated using standing whole-spine radiography. Sagittal spinal alignment was evaluated using whole-spine radiography. Sagittal balance was assessed using the SVA, defined as the distance between the postero-superior corner of S1 and the plumb line drawn from the vertebral midbody of C7 [21]. The following spinopelvic sagittal parameters were measured: lumbar lordosis (LL), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and PI minus LL.

Three years after surgery, participants underwent a follow-up standing whole-spine radiography. Patients were assigned into two groups on the basis of their preoperative and 3 year postoperative SVA values. Patients with a 3 year postoperative SVA value ≥ 40 mm with an increase ≥ 30 mm were categorized into the imbalance group, while the others were assigned to the non-imbalance group.

2.3. Statistical Analysis

Continuous variables are expressed as the mean \pm standard deviation. Between-group differences in continuous variables were examined using the Mann–Whitney U test. Categorical data are expressed as percentages, and comparisons between groups were performed using the chi-squared test. A multiple logistic regression model was used to obtain odds ratios (ORs) with 95% confidence intervals (CIs) to identify the factors associated with progressive spinal sagittal imbalance after THA. Lastly, receiver operating characteristic (ROC) curve analysis was used to determine the optimal cutoff for the occurrence of spinal sagittal imbalance. IBM SPSS Statistics for Macintosh, Version 27.0 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses, with a level of statistical significance of $p < 0.05$.

3. Results

A total of 103 patients were included and evaluated in this study. The mean change in SVA was -2.6 mm (range: -103.7 to 156.5 mm). Of the 103 patients, 11 (10.7%) were assigned to the imbalance group, while the other 92 (89.3%) patients were assigned to the non-imbalance group (Figure 1). Preoperatively, the imbalance group had lower ATMS and KEMS values, a shorter FRT distance, and smaller SS and LL values than the non-imbalance group (Table 1). There were no significant differences in the preoperative SVA between the two groups. In the multiple logistic regression analysis using the five items that showed significant differences in the univariate analysis as explanatory variables, preoperative weak ATMS and small SS were significant risk factors for progressive spinal sagittal imbalance after THA (Table 2).

Table 1. Demographic and radiographic parameters of 103 patients.

	Imbalance Group	Non-Imbalance Group	<i>p</i> -Value
No. of subjects	11	92	
Age (years), mean \pm SD	64.7 \pm 9.3	63.8 \pm 8.7	0.902
BMI (kg/m ²), mean \pm SD	25.0 \pm 7.7	23.1 \pm 3.8	0.860
Bilateral simultaneous THA, No. (%)	2 (18.2)	18 (19.6)	0.946
Anterior approach, No. (%)	9 (81.8)	67 (72.8)	0.48
Grip strength (kg), mean \pm SD	20.5 \pm 4.9	21.1 \pm 4.8	0.435
KEMS (N/kg), mean \pm SD	2.9 \pm 1.4	3.9 \pm 1.2	0.026
ATMS (kPa), mean \pm SD	2.5 \pm 1.6	5.2 \pm 2.9	0.013

Table 1. Cont.

	Imbalance Group	Non-Imbalance Group	<i>p</i> -Value
FRT (cm), mean ± SD	26.1 ± 6.4	30.9 ± 7.1	0.019
Walking speed (m/s), mean ± SD	0.8 ± 0.4	0.9 ± 0.2	0.359
1-leg standing time (s), mean ± SD	25.7 ± 21.4	36.7 ± 22.9	0.142
2-step score (point), mean ± SD	0.8 ± 0.3	1.0 ± 0.3	0.342
GLFS-25 score (point), mean ± SD	52.6 ± 18.7	43.8 ± 18.5	0.173
L-BMD (g/cm ²), mean ± SD	1.2 ± 0.2	1.1 ± 0.2	0.275
Presence of OVF before THA, No. (%)	1 (9.0)	11 (12.0)	0.624
Occurrence of OVF after THA, No. (%)	0 (0.0)	2 (2.1)	0.797
SVA (mm), mean ± SD	47.9 ± 26.1	45.3 ± 47.2	0.665
LL (degrees), mean ± SD	40.1 ± 18.7	53.3 ± 17.9	0.019
PI (degrees), mean ± SD	51.0 ± 12.6	57.2 ± 11.6	0.075
SS (degrees), mean ± SD	32.7 ± 10.2	42.7 ± 12.4	0.006
PT (degrees), mean ± SD	18.3 ± 8.9	14.4 ± 11.4	0.175
PI-LL (degrees), mean ± SD	10.9 ± 15.2	3.9 ± 16.9	0.172

ATMS, abdominal trunk muscle strength; BMI, body mass index; FRT, functional reach test; GLFS-25, 25-question Geriatric Locomotive Function Scale; KEMS, knee extensor muscle strength; L-BMD, bone mineral density of the lumbar spine; LL, lumbar lordosis; OVF, osteoporotic vertebral fracture; PI, pelvic incidence; PT, pelvic tilt; SD, standard deviation; SVA, sagittal vertical axis; SS, sacral slope; THA, total hip arthroplasty.

Table 2. Multiple logistic regression analysis of factors associated with progressive spinal sagittal imbalance.

	OR	<i>p</i> -Value	95% CI
ATMS (kPa)	0.504	0.007	0.307–0.827
SS (degrees)	0.924	0.005	0.875–0.976

ATMS, abdominal trunk muscle strength; CI, confidence interval; OR, odds ratio; SS, sacral slope.

ROC analyses showed that ATMS \leq 4.3 kPa (Figure 2, 95% CI 0.643–0.909, $p = 0.004$, area under the curve 0.776) and SS \leq 31.9° (Figure 3, 95% CI 0.607–0.897, $p = 0.001$, area under the curve 0.752) best predicted the progression of sagittal imbalance in the study cohort. The progression rate of sagittal imbalance was significantly higher ($p = 0.002$) in participants with ATMS \leq 4.3 kPa (20.4%, 10/49) than in those with ATMS $>$ 4.3 kPa (1.9%, 1/54). Similarly, the progression rate of sagittal imbalance was significantly higher ($p = 0.001$) in participants with SS \leq 31.9° (40.0%, 6/15) than in those with SS $>$ 31.9° (5.7%, 5/88).

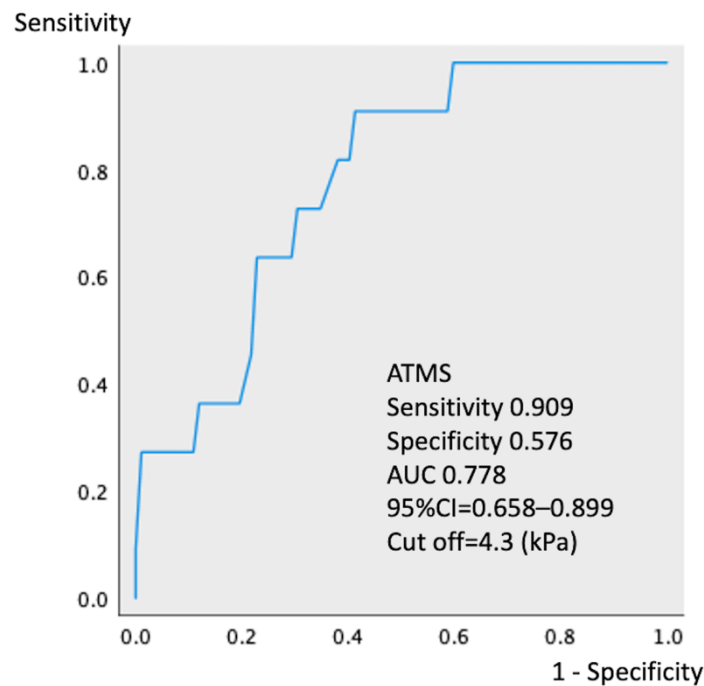


Figure 2. Receiver operating characteristic analysis showing that the cutoff value for abdominal trunk muscle strength is 4.3 kPa (95% confidence interval 0.643–0.909, $p = 0.004$, AUC 0.776). The sensitivity and specificity are 0.909 and 0.576, respectively. ATMS, abdominal trunk muscle strength; AUC, area under the curve; CI, confidence interval.

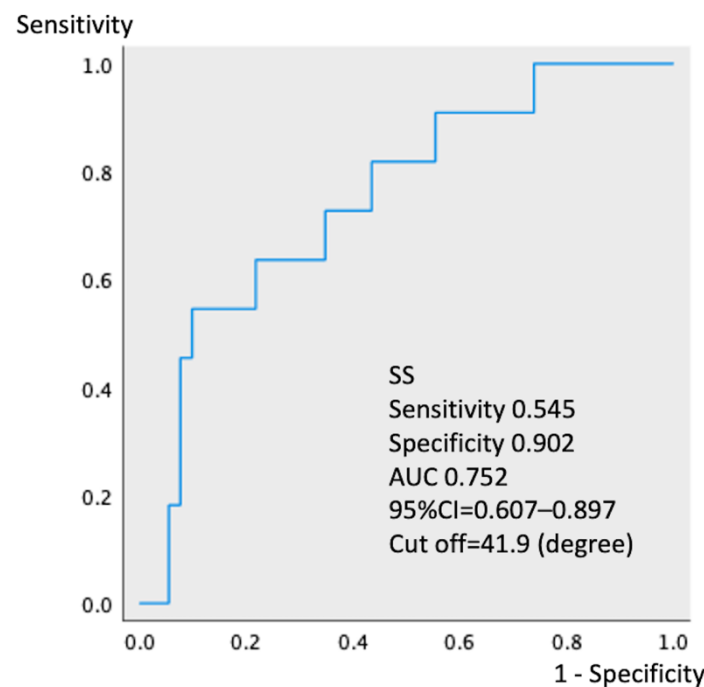


Figure 3. Receiver operating characteristic analysis showing that the cutoff value for sacral slope is 31.9° (95% confidence interval 0.607–0.897, $p = 0.001$, AUC 0.752). The sensitivity and specificity are 0.545 and 0.902, respectively. SS, sacral slope; AUC, area under the curve; CI, confidence interval.

4. Discussion

This retrospective cohort study with a prospectively maintained database aimed to investigate risk factors associated with progressive spinal sagittal imbalance after THA in middle-aged women. In this study, spinal sagittal imbalance progressed in 11 patients

(10.7%) 3 years postoperatively, and multivariate analysis showed that the risk factors were preoperative weak ATMS and small SS. Furthermore, ROC analysis showed that $ATMS \leq 4.3$ kPa and $SS \leq 31.9^\circ$ were associated with spinal sagittal imbalance and may be useful predictors of progressive spinal sagittal imbalance before THA. Although many reports evaluated spinopelvic alignment immediately after THA [10–12,22–26], to our knowledge, no studies have reported the risk of spinal sagittal imbalance in the long-term course after THA. Spinal sagittal imbalance after THA may lead to a demand for corrective surgery. Correction of lumbar kyphosis changes the pelvic tilt, resulting in an increased risk of dislocation of the artificial hip [13–15]. Therefore, assessing the trunk function and spinopelvic alignment before THA is important to predict the progression of spinal sagittal imbalance according to the results of this study.

The results of this study suggested that a weak ATMS is a risk factor for spinal sagittal imbalance after THA. The relationship between trunk muscle strength and spinal sagittal balance has been reported in the past, and these studies concluded that weak back muscles are associated with sagittal imbalance [27–30]. A previous study showed that the device used in this study (RECORE) could quantify ATMS, and strengthening exercises using the device increased ATMS and activated the abdominal, diaphragmatic, and pelvic floor muscles [18]. Muscle contraction during the ATMS measurement or strengthening exercise was comparable to that involved during abdominal bracing with the abdominal and paraspinal muscles activated [31]. The core can be described as a muscular box whose anterior wall is represented by the abdominal muscles, with the posterior wall represented by the paraspinal muscles, the roof represented by the diaphragm, and the floor represented by the pelvic floor muscles [32]. The contraction of the diaphragm increases intra-abdominal pressure, thus contributing to spinal stability [32]. ATMS is created through the coordinated contraction of trunk muscles comprising the muscular box. This muscle contraction creates a semirigid cylinder located anterior to the spinal column that can support the spinal column from the front and prevent a progression of sagittal spinal imbalance in the lower thoracic or lumbar spines. Although several studies have described the contribution of these anterior trunk muscles to spinal stability [32,33], there have been no previous reports of ATMS being associated with spinal sagittal imbalance. On the basis of the study's results, the functional assessment of the trunk, including ATMS measurements in patients with hip OA, is important for predicting progressive spinal sagittal imbalance after THA, which is clinically problematic. The device allows for easy and safe ATMS measurements [34], and the ATMS measurement has great potential to be used in assessing trunk dysfunctions related to the future progression of spinal sagittal imbalance after THA.

This study showed that a small SS causes spinal sagittal imbalance 3 years after THA in female patients. Patients with hip OA usually have increased SVA due to anterior pelvic tilt caused by hip flexion contracture [11]. The mean values of SS and PT of Japanese women in their 60s were 31° and 18° , respectively [35]. In contrast, those in the non-imbalance group in this study had values of 42° and 14° , respectively, indicating that the pelvis was tilted anteriorly. On the other hand, the mean values of SS and PT of the imbalance group were 32° and 18° , respectively, similar to those of the general population of the same age, despite the presence of hip OA. In cases of anterior pelvic tilt due to flexion contracture, as in the non-imbalance group in this study, SVA decreased immediately after THA because flexion contracture improved, and the pelvis rotated backward [10–12] (Figure 4). However, since patients with a small SS have a smaller capacity for retroversion of the pelvis [33], their spinal sagittal balance did not improve. In addition, patients with a small SS are less capable of compensating for the progressive decrease in lumbar lordosis over time, making it difficult for them to maintain spinal sagittal balance (Figure 5). These results may explain why spinal sagittal imbalance is more likely to progress in patients with a small SS in the long term after THA.

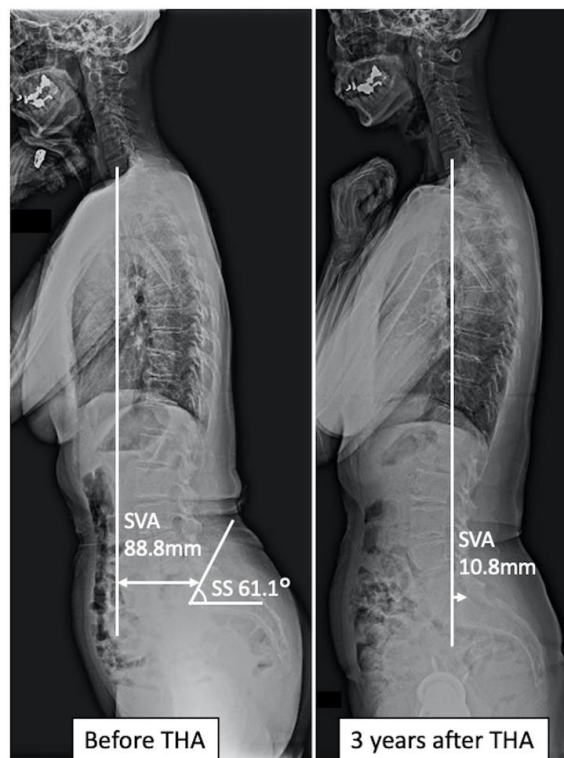


Figure 4. A case with improved spinal sagittal balance after total hip arthroplasty. Preoperatively, the sacral slope, sagittal vertical axis (SVA), and abdominal trunk muscle strength were 61.1°, 88.8 mm, and 5.2 kPa, respectively. Postoperatively, SVA decreased to 10.8 mm.

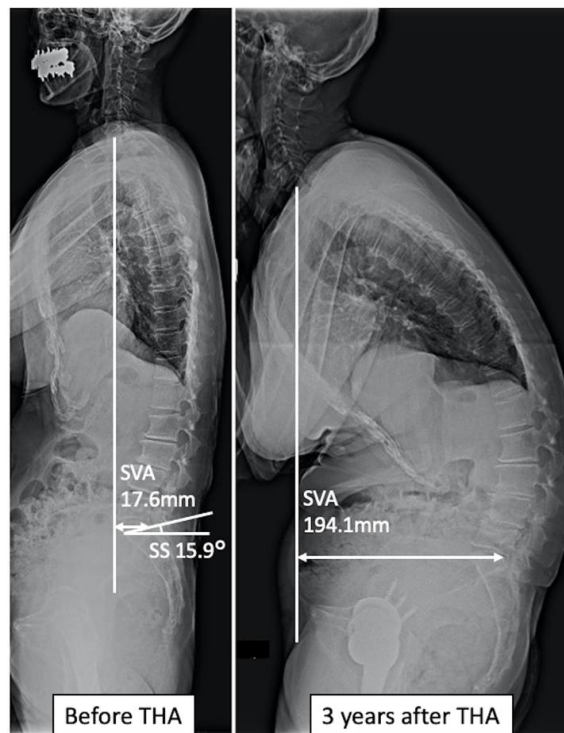


Figure 5. A case of progressive spinal sagittal imbalance after total hip arthroplasty. Preoperatively, the sacral slope, sagittal vertical axis (SVA), and abdominal trunk muscle strength were 15.9°, 17.6 mm, and 3.2 kPa, respectively. Postoperatively, SVA increased to 194.1 mm.

This study had several limitations. First, the back muscle strength, considered a risk factor for spinal sagittal imbalance, was not measured. Thus, it is impossible to compare the effects of ATMS and back muscle strength on the progression of sagittal imbalance. Second, the spinopelvic alignment was not measured immediately after surgery. Therefore, it is unclear to what extent the immediate postoperative changes and the 3 year course after surgery affect sagittal balance. Third, since this study did not include nonsurgical patients, it is not certain whether the change in sagittal balance was the effect of surgery or a natural course.

5. Conclusions

Spinal sagittal imbalance progressed in approximately 10% of patients 3 years after THA. Preoperative weak ATMS and small SS were risk factors for progressive spinal sagittal imbalance in the short-term course after THA in female patients. Preoperative assessments of trunk function and spinopelvic alignment are important predictors of progressive sagittal imbalance after THA.

Author Contributions: Conceptualization, S.K.; methodology, S.K. and S.N.; validation, S.N. and Y.K. (Yuki Kurokawa); formal analysis, S.N.; investigation, S.K. and S.N.; resources, T.K., Y.K. (Yoshitomo Kajino) and D.I.; data curation, N.Y., M.K. (Motoya Kobayashi), Y.Y. and M.K. (Masafumi Kawai); writing—original draft preparation, S.N.; writing—review and editing, S.D. and S.K.; supervision, H.T.; project administration, S.K. and H.T. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by a research grant from the Japanese Orthopaedic Association (Japanese Orthopaedic Association-Subsidised Science Project Research 2020-4). The organization did not have any role in the design of the study; the collection, analysis, and interpretation of data; or the writing of the manuscript.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the university hospital ethics committee (No. 2015-109).

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

Data Availability Statement: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request. The data are not publicly available due to privacy or ethical restrictions.

Conflicts of Interest: Nippon Sigmax Co., Ltd. provided the exercise device used in this clinical study. The company did not have any control over the content of this article or the decision to approve or submit the manuscript for publication.

References

- Guillemin, F.; Rat, A.C.; Mazieres, B.; Pouchot, J.; Fautrel, B.; Euler-Ziegler, L.; Fardellone, P.; Morvan, J.; Roux, C.H.; Verrouil, E.; et al. Prevalence of symptomatic hip and knee osteoarthritis: A two-phase population-based survey. *Osteoarthr. Cartilage* **2011**, *19*, 1314–1322. [[CrossRef](#)]
- Ochi, H.; Homma, Y.; Baba, T.; Nojiri, H.; Matsumoto, M.; Kaneko, K. Sagittal spinopelvic alignment predicts hip function after total hip arthroplasty. *Gait Posture* **2017**, *52*, 293–300. [[CrossRef](#)]
- Buckland, A.J.; Steinmetz, L.; Zhou, P.; Vasquez-Montes, D.; Kingery, M.; Stekas, N.D.; Ayres, E.W.; Varlotta, C.G.; Lafage, V.; Lafage, R.; et al. Spinopelvic Compensatory Mechanisms for Reduced Hip Motion (ROM) in the Setting of Hip Osteoarthritis. *Spine Deform.* **2019**, *7*, 923–928. [[CrossRef](#)]
- Day, L.M.; DelSole, E.M.; Beaubrum, B.M.; Zhou, P.L.; Moon, J.Y.; Tishelman, J.C.; Vigdorichik, J.M.; Schwarzkopf, R.; Lafage, R.; Lafage, V.; et al. Radiological severity of hip osteoarthritis in patients with adult spinal deformity: The effect on spinopelvic and lower extremity compensatory mechanisms. *Eur. Spine J.* **2018**, *27*, 2294–2302. [[CrossRef](#)]
- Innmann, M.M.; Merle, C.; Phan, P.; Beaulé, P.E.; Grammatopoulos, G. Differences in Spinopelvic Characteristics Between Hip Osteoarthritis Patients and Controls. *J. Arthroplast.* **2021**, *36*, 2808–2816. [[CrossRef](#)]
- Sculco, P.K.; Windsor, E.N.; Jerabek, S.A.; Mayman, D.J.; Elbuluk, A.; Buckland, A.J.; Vigdorichik, J.M. Preoperative spinopelvic hypermobility resolves following total hip arthroplasty. *Bone Jt. J.* **2021**, *103-B*, 1766–1773. [[CrossRef](#)]
- Weng, W.J.; Wang, W.J.; Wu, M.D.; Xu, Z.H.; Xu, L.L.; Qiu, Y. Characteristics of sagittal spine-pelvis-leg alignment in patients with severe hip osteoarthritis. *Eur. Spine J.* **2015**, *24*, 1228–1236. [[CrossRef](#)]
- Miyagi, M.; Fukushima, K.; Inoue, G.; Nakazawa, T.; Imura, T.; Saito, W.; Takahira, N.; Takaso, M. Hip-spine syndrome: Cross-sectional-study of spinal alignment in patients with coxalgia. *Hip Int.* **2019**, *29*, 21–25. [[CrossRef](#)]

9. Sloan, M.; Premkumar, A.; Sheth, N.P. Projected Volume of Primary Total Joint Arthroplasty in the U.S.; 2014 to 2030. *J. Bone Jt. Surg. Am.* **2018**, *100*, 1455–1460. [[CrossRef](#)]
10. Kim, Y.; Pour, A.E.; Lazennec, J.Y. How do global sagittal alignment and posture change after total hip arthroplasty? *Int. Orthop.* **2020**, *44*, 267–273. [[CrossRef](#)]
11. Jain, D.; Vigdorichik, J.M.; Abotsi, E.; Montes, D.V.; Delsole, E.M.; Lord, E.; Zuckerman, J.D.; Protopsaltis, T.; Passias, P.G.; Buckland, A.J. The Impact of Global Spinal Alignment on Standing Spinopelvic Alignment Change after Total Hip Arthroplasty. *Glob. Spine J.* **2021**, *18*, 21925682211026633. [[CrossRef](#)] [[PubMed](#)]
12. Piazzolla, A.; Solarino, G.; Bizzoca, D.; Montemurro, V.; Berjano, P.; Lamartina, C.; Martini, C.; Moretti, B. Spinopelvic parameter changes and low back pain improvement due to femoral neck anteversion in patients with severe unilateral primary hip osteoarthritis undergoing total hip replacement. *Eur. Spine J.* **2018**, *27*, 125–134. [[CrossRef](#)]
13. Furuhashi, H.; Togawa, D.; Koyama, H.; Hoshino, H.; Yasuda, T.; Matsuyama, Y. Repeated posterior dislocation of total hip arthroplasty after spinal corrective long fusion with pelvic fixation. *Eur. Spine J.* **2017**, *26*, 100–106. [[CrossRef](#)] [[PubMed](#)]
14. Furuhashi, H.; Yamato, Y.; Hoshino, H.; Shimizu, Y.; Hasegawa, T.; Yoshida, G.; Banno, T.; Arima, H.; Oe, S.; Ushirozako, H.; et al. Dislocation rate and its risk factors in total hip arthroplasty with concurrent extensive spinal corrective fusion with pelvic fixation for adult spinal deformity. *Eur. J. Orthop. Surg. Traumatol.* **2021**, *31*, 283–290. [[CrossRef](#)]
15. Bedard, N.A.; Martin, C.T.; Slaven, S.E.; Pugely, A.J.; Mendoza-Lattes, S.A.; Callaghan, J.J. Abnormally High Dislocation Rates of Total Hip Arthroplasty After Spinal Deformity Surgery. *J. Arthroplast.* **2016**, *31*, 2884–2885. [[CrossRef](#)]
16. Suzuki, T. Reliability of measurements of knee extensor muscle strength using a pull-type handheld dynamometer. *J. Phys. Ther. Sci.* **2015**, *27*, 967–971. [[CrossRef](#)]
17. Kato, S.; Murakami, H.; Inaki, A.; Mochizuki, T.; Demura, S.; Nakase, J.; Yoshioka, K.; Yokogawa, N.; Igarashi, T.; Takahashi, N.; et al. Innovative exercise device for the abdominal trunk muscles: An early validation study. *PLoS ONE* **2017**, *12*, e0172934. [[CrossRef](#)]
18. Kato, S.; Inaki, A.; Murakami, H.; Kurokawa, Y.; Mochizuki, T.; Demura, S.; Yoshioka, K.; Yokogawa, N.; Yonezawa, N.; Shimizu, T.; et al. Reliability of the muscle strength measurement and effects of the strengthening by an innovative exercise device for the abdominal trunk muscles. *J. Back Musculoskelet. Rehabil.* **2020**, *33*, 677–684. [[CrossRef](#)]
19. Nakamura, K.; Ogata, T. Locomotive Syndrome: Definition and Management. *Clin. Rev. Bone Miner. Metab.* **2016**, *14*, 56–67. [[CrossRef](#)]
20. Duncan, P.W.; Weiner, D.K.; Chandler, J.; Studenski, S. Functional reach: A new clinical measure of balance. *J. Gerontol.* **1990**, *45*, M192–M197. [[CrossRef](#)]
21. Schwab, F.; Patel, A.; Ungar, B.; Farcy, J.P.; Lafage, V. Adult spinal deformity-postoperative standing imbalance: How much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. *Spine* **2010**, *35*, 2224–2231. [[CrossRef](#)] [[PubMed](#)]
22. Kanto, M.; Maruo, K.; Tachibana, T.; Fukunishi, S.; Nishio, S.; Takeda, Y.; Arizumi, F.; Kusuyama, K.; Kishima, K.; Yoshiya, S. Influence of Spinopelvic Alignment on Pelvic Tilt after Total Hip Arthroplasty. *Orthop. Surg.* **2019**, *11*, 438–442. [[CrossRef](#)] [[PubMed](#)]
23. Buckland, A.J.; Fernandez, L.; Shimmim, A.J.; Bare, J.V.; McMahon, S.J.; Vigdorichik, J.M. Effects of Sagittal Spinal Alignment on Postural Pelvic Mobility in Total Hip Arthroplasty Candidates. *J. Arthroplast.* **2019**, *34*, 2663–2668. [[CrossRef](#)]
24. Tateiwa, T.; Endo, K.; Matsuoka, Y.; Ishida, T.; Shishido, T.; Yamamoto, K. Pelvic tilt after total hip arthroplasty in patients with osteoarthritis of the hip. *J. Orthop. Surg.* **2020**, *28*, 2309499020918317. [[CrossRef](#)]
25. Parratte, S.; Pagnano, M.W.; Coleman-Wood, K.; Kaufman, K.R.; Berry, D.J. The 2008 Frank Stinchfield award: Variation in postoperative pelvic tilt may confound the accuracy of hip navigation systems. *Clin. Orthop. Relat. Res.* **2009**, *467*, 43–49. [[CrossRef](#)]
26. Weng, W.; Wu, H.; Wu, M.; Zhu, Y.; Qiu, Y.; Wang, W. The effect of total hip arthroplasty on sagittal spinal-pelvic-leg alignment and low back pain in patients with severe hip osteoarthritis. *Eur. Spine J.* **2016**, *25*, 3608–3614. [[CrossRef](#)]
27. Kim, W.J.; Shin, H.M.; Lee, J.S.; Song, D.G.; Lee, J.W.; Chang, S.H.; Park, K.Y.; Choy, W.S. Sarcopenia and Back Muscle Degeneration as Risk Factors for Degenerative Adult Spinal Deformity with Sagittal Imbalance and Degenerative Spinal Disease: A Comparative Study. *World Neurosurg.* **2021**, *148*, e547–e555. [[CrossRef](#)]
28. Jun, H.S.; Kim, J.H.; Ahn, J.H.; Chang, I.B.; Song, J.H.; Kim, T.H.; Park, M.S.; Kim, Y.C.; Kim, S.W.; Oh, J.K.; et al. The Effect of Lumbar Spinal Muscle on Spinal Sagittal Alignment: Evaluating Muscle Quantity and Quality. *Neurosurgery* **2016**, *79*, 847–855. [[CrossRef](#)]
29. Imagama, S.; Ito, Z.; Wakao, N.; Seki, T.; Hirano, K.; Muramoto, A.; Sakai, Y.; Matsuyama, Y.; Hamajima, N.; Ishiguro, N.; et al. Influence of spinal sagittal alignment, body balance, muscle strength, and physical ability on falling of middle-aged and elderly males. *Eur. Spine J.* **2013**, *22*, 1346–1353. [[CrossRef](#)]
30. Banno, T.; Yamato, Y.; Hasegawa, T.; Kobayashi, S.; Togawa, D.; Oe, S.; Mihara, Y.; Kurosu, K.; Yamamoto, N.; Matsuyama, Y. Assessment of the Cross-Sectional Areas of the Psoas Major and Multifidus Muscles in Patients with Adult Spinal Deformity: A Case-Control Study. *Clin. Spine Surg.* **2017**, *30*, E968–E973. [[CrossRef](#)]
31. Kurokawa, Y.; Kato, S.; Demura, S.; Shinmura, K.; Yokogawa, N.; Yonezawa, N.; Shimizu, T.; Kitagawa, R.; Miaki, H.; Tsuchiya, H.; et al. Validation and comparison of trunk muscle activities in male participants during exercise using an innovative device and abdominal bracing maneuvers. *J. Back Musculoskelet. Rehabil.* **2022**, *35*, 589–596. [[CrossRef](#)] [[PubMed](#)]

32. Akuthota, V.; Ferreiro, A.; Moore, T.; Fredericson, M. Core stability exercise principles. *Curr. Sports Med. Rep.* **2008**, *7*, 39–44. [[CrossRef](#)]
33. Roussouly, P.; Pinheiro-Franco, J.L. Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. *Eur. Spine J.* **2011**, *20*, 609–618. [[CrossRef](#)]
34. Kato, S.; Demura, S.; Kurokawa, Y.; Takahashi, N.; Shinmura, K.; Yokogawa, N.; Yonezawa, N.; Shimizu, T.; Kitagawa, R.; Tsuchiya, H. Efficacy and Safety of Abdominal Trunk Muscle Strengthening Using an Innovative Device in Elderly Patients with Chronic Low Back Pain: A Pilot Study. *Ann. Rehabil. Med.* **2020**, *44*, 246–255. [[CrossRef](#)]
35. Oe, S.; Togawa, D.; Nakai, K.; Yamada, T.; Arima, H.; Banno, T.; Yasuda, T.; Kobayasi, S.; Yamato, Y.; Hasegawa, T.; et al. The Influence of Age and Sex on Cervical Spinal Alignment among Volunteers Aged Over 50. *Spine* **2015**, *40*, 1487–1494. [[CrossRef](#)]