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Research Article

Motion Analysis after Minimally Invasive Sacroiliac Joint Fusion in Patients with Postpartum Sacroiliac Joint Dysfunction: an Observational Case-Control Study

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Abstract

Introduction: The Sacroiliac Joint (SIJ) can be an important and significant cause of low back pain. A dysfunctional SIJ is initially treated with conservative treatment options, although known to have limited effectiveness and durability. Therefore, surgical approaches such as minimally invasive sacroiliac joint fusion (MISJF) have emerged and outcomes appear to be promising in terms of pain reduction and improvement of self-reported mobility. To date, little is known about the effects of MISJF on balance and motion patterns reflective of daily life activities.

Methods: A prospective, longitudinal study was conducted to analyze motion patterns in patients with postpartum SIJ dysfunction before and three months after MISJF, and compare these data with age-, BMI- and postpartum-matched controls. Motion was analyzed throughout the execution of three tasks; (1) normal gait, (2) alternated single leg stance (SLS), and (3) sit-to-stance (STS). Spatiotemporal parameters, center of pressure and mass, pelvic angles and other joint angels were measured using a twelve-camera, three-dimensional motion capture system and ground reaction force platforms.

Results: Gait analysis revealed no improvement in any of the measured parameters when comparing pre- and postoperative. Patients had a shorter step and stride length and a slower walking speed compared to matched controls. During SLS, improvements in balance were observed after surgery in the patient group, reaching comparable values to the matched control group. Total execution time of an STS improved in patients following MISJF and was comparable to that of matched controls.

Conclusion: This study suggests that motion patterns seem to improve after MISJF in patients with postpartum SIJ dysfunction. Most notable differences were an improved balance during SLS and a faster STS performance. Additional studies with longer follow-up and larger sample sizes should provide more detailed insights on motion analysis in patients with postpartum SIJ dysfunction following MISJF.

Introduction

The Sacroiliac Joint (SIJ) can be an important and significant cause of low back pain. [1,2] Patients with SIJ dysfunction experience a high burden of disease, which is comparable to other common orthopedic conditions, such as hip and knee osteoarthritis, degenerative spondylolisthesis and spinal stenosis. [3] In all cases, SIJ dysfunction is initially treated with conservative measures such as oral analgesic use, physical therapy, pelvic compression belts, radiofrequency denervation and intraarticular steroid injections. [4-8] Since conservative treatment options are known to have limited effectiveness and durability, surgical approaches such as Minimally Invasive Sacroiliac Joint Fusion (MISJF) are on the rise. [9,10] The initial outcomes of MISJF are promising in terms of pain reduction and improvement of self-reported mobility. [11] Currently, little is known about the effects of MISJF on (dynamic) balance and motion patterns reflective of daily life activities. Previously, we demonstrated that patients with postpartum SIJ dysfunction have impaired motion patterns compared to healthy controls. [12] As such, we observed a disturbed gait, with a slower walking speed and longer double support phase, balance problems during a Single Leg Stance (SLS) and a slow sit to stance (STS) performance. The aim of this study is to evaluate whether these observed disturbances improve three months after MISJF in patients with postpartum SIJ dysfunction. The following research question was formulated; is there a difference in spatiotemporal parameters, center of pressure and mass, pelvic angles and hip and knee joint angles in patients with SIJ dysfunction before and three months after MISJF at predefined tasks, including gait, SLS and STS.

Materials & Methods

Study Design

This was a prospective, longitudinal study to analyze motion patterns in patients with SIJ dysfunction before and three months after MISJF, and compare these data with matched controls. Baseline conditions, motion analysis tasks, data collection and data analysis were described in detail in a previous publication. [12] Three months following MISJF surgery, patients returned to the motion lab to re-perform motion tasks (gait, SLS and STS) and report quality of life. Quality of life was assessed by the validated Dutch EQ-5D-5L-questionnaire (-0.329 to 1.00, 1.00 indicates 'best health state') and the EQ self-reported health status, visual analogue scale (VAS), that records the respondent's self-rated health (0 - 100, 100 being 'best imaginable health state'). [13] Motion analysis existed of three tasks: (1) normal gait, (2) alternated single leg stance (SLS), and (3) sit-to-stance (STS). This study was registered in the Clinical Trial Register (registration number: NCT04824534) and was written in accordance with the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines. [14] Ethical approval of this study was obtained by the METC Z (registration number: METCZ20210010) at Zuyderland Medical Center and Zuyd University of Applied Sciences (Heerlen, the Netherlands). All subjects were informed on the purpose of the study and gave written informed consent before participation.

Intervention

Final diagnosis of SIJ dysfunction was based on physical examination and at least a 50% reduction of SIJ pain 30 to 60 minutes following fluoroscopy-guided injection with lidocaine 2%. If eligible, patients were treated with MISJF using a series of triangular titanium, porous titanium plasma spray coated implants (iFuse Implant System®; SI-BONE, Inc., San Jose, CA, USA). After administration of general anesthesia, the patient was placed in prone position. During MISJF, intraoperative fluoroscopy was used for optimal placement of implants. A lateral incision was made across the sacral midline. Under lateral fluoroscopy view the first guide pin was positioned at the appropriate starting point. Pelvic in- and outlet view were used to place the guide across the ilium and across the SIJ until correct dept was reached. Length of the implant was measured. Subsequently a drill followed by a triangular broach were used to decorticate the bone and prepare the pathway to receive the first implant. This implant was mostly seated within the sacral ala. Same procedure was repeated for the second and third implant. The second implant was generally located above or adjacent to the S1 foramen and the third between the S1 and S2 foramen. Because of the highly variable anatomy of the SIJ, implant location may differ between patients. The incision was then irrigated with saline and the tissue layers were sequentially closed.

Statistical Analysis

Statistical analyses were carried out using IBM SPSS statistics 27 (Inc., Chicago, IL). Descriptive data were generated for all variables and all data were tested for normal distribution. All descriptive data were presented as frequencies (%) or medians with interquartile ranges (IQ), as Shapiro-Wilk-tests demonstrated non-normal distribution. To compare data between groups linear mixed models were used with postoperative measurements as reference. Categorical data was assessed using Chi-Square test. A p-value ≤ 0.05 was considered statistically significant.

Results

This study included ten patients and ten matched controls. One patient was lost to follow-up, as she waived surgery. No intra- or postoperative complications are reported. Patient demographics are summarized in Table 1. Quality of life and self-reported health status improved statistical significantly following surgery (Table 2).

	Patients	**Matched controls**	**p-value**
Age (years)	40.0 (33.0:44.0)	34.5 (31.8:36.0)	0.107
BMI (kg/m^2)	27.9 (22.8:32.2)	22.7 (21.8:23.7)	0.095
Number of previous pregnancies			
One	2	6	
Two	4	3	0.508
Three	2	1	
Four	1	-	
Years postpartum	12.4 (4.7:20.5)	4.0 (1.3:5.5)	0.187

All values are median with interquartile range (1:3). P-value refers to Kolmogorov-Smirnov test or Chi-Square test for number of pregnancies.

Table 1: Characteristics of subjects.

	Preoperative	**Postoperative**	**p-value**
EQ-5D-5L score	0.384 (0.291:0.516)	0.735 (0.690:0.818)	0.008
EQ-5D-5L VAS	46 (35:61)	72 (58:85)	0.005

All values are median with interquartile range (1:3). P-value refers to Wilcoxon-Signed Ranks test.

Table 2: Quality of life results.

Gait

Gait analysis revealed no differences in parameters between pre- and postoperative data. Postoperatively, step length and stride length were shorter as compared to matched controls. Walking speed was significantly slower in postoperative patients compared to matched controls. Other outcome parameters were not different between postoperative patients and matched controls. Table 3 outlines the complete outcome data regarding gait. In Supplementary file 1 the results of individual gait analysis are depicted in graphs. Although not statistically significant, a trend of improvement can be observed in these graphs. For example, it is noticeable that cadence and walking speeds increase, and double support phase and stride time decrease in most patients. When excluding the two main outliers (patient number 8 and 9) the improvement becomes more obvious (Supplementary file 2).

	Preoperative (1)	Postoperative-2	Matched controls (3)	p-value
Cadence (steps/min)	101 (91:104)	106 (105:109)	116 (114:120)	1-2: 0.839 2-3: 0.054
Double support phase (s)	0.33 (0.30:0.35)	0.31 (0.25:0.39)	0.21 (0.19:0.21)	1-2: 0.480 2-3: 0.149
Single support phase (s)	0.44 (0.43:0.50)	0.43 (0.40:0.47)	0.41 (0.40:0.42)	1-2: 0.293 2-3: 0.254
Step length (m)	0.56 (0.53:0.59)	0.58 (0.57:59)	0.66 (0.64:0.71)	1-2: 0.941 2-3: 0.013*
Step time (s)	0.59 (0.58:0.66)	0.59 (0.58:0.66)	0.51 (0.50:0.53)	1-2: 0.423 2-3: 0.155
Step width (m)	0.15 (0.14:0.16)	0.17 (0.13:0.18)	0.12 (0.11:0.16)	1-2: 0.732 2-3: 0.286
Stride length (m)	1.11 (1.06:1.20)	1.16 (1.12:1.24)	1.32 (1.30:1.42)	1-2: 0.959 2-3: 0.012*
Stride time (s)	1.19 (1.15:1.32)	1.14 (1.11:1.15)	1.03 (1.00:1.05)	1-2: 0.432 2-3: 0.154
Walking speed (m/s)	0.96 (0.80:1.05)	1.01 (0.98:1.13)	1.33 (1.23:1.41)	1-2: 0.637 2-3: 0.009*

All values are medians with interquartile range (1:3). P-value refers to linear mixed model analyses.

Table 3: Outcomes of gait analysis.

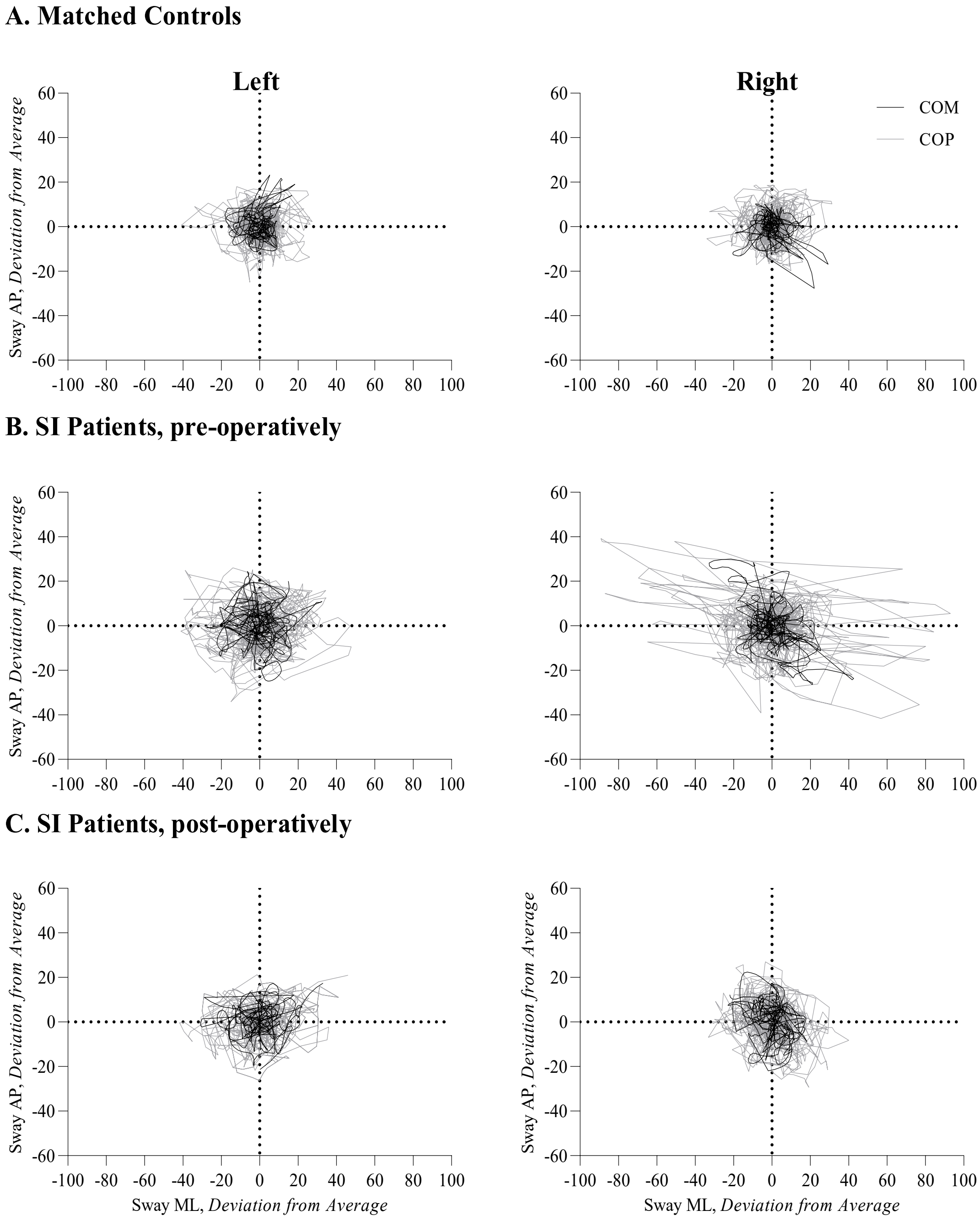
Single Leg Stance

Postoperatively, patients reached a lower mean hip angle than matched controls. None of the study groups reached a hip angle of 90° over the task duration of 10 seconds, as was instructed. None of the parameters of interest improved following MISJF in the patients group. Table 4 outlines the complete outcome data regarding SLS. Center of pressure and center of mass during SLS are depicted in stabilographs for all study groups (Figure 1). A statistically significant difference in sway in center of mass in medial-lateral range for left leg ($p < 0.013$) was observed between study groups, in which postoperative patients approached matched control data.

	Preoperative (1)	Postoperative (2)	Matched controls (3)	p-value
Pelvic obliquity L (°)	10.1 (7.2:12.9)	7.6 (4.1:11.3)	9.5 (8.0:12.4)	1-2: 0.143 2-3: 0.216
Pelvic obliquity R (°)	11.5 (6.9:16.3)	10.6 (6.0:14.4)	7.9 (5.5:10.3)	1-2: 0.438 2-3: 0.237
Hip angle L (°)	76.9 (72.1:80.3)	75.4 (67.4:81.5)	84.2 (81.1:87.0)	1-2: 0.168 2-3: <0.001*
Hip angle R (°)	71.1 (67.8:75.9)	71.7 (62.3:77.3)	83.4 (79.4:86.9)	1-2: 0.132 2-3: <0.001*
Knee angle L (°)	17.7 (7.8:21.0)	15.8 (13.5:18.8)	13.8 (7.2:16.4)	1-2: 0.839 2-3: 0.179
Knee angle R (°)	15.1 (12.4:20.3)	15.6 (13.3:19.8)	14.8 (12.8:16.3)	1-2: 0.839 2-3: 0.445

All values are medians with interquartile range (1:3). P-value refers to linear mixed model analyses.

Table 4: Outcomes of SLS.



COM: Center of Mass; COP: Center of Pressure Right; AP: Anterior-Posterior; ML: Medial-Lateral

Figure 1: Stabilographs of study groups during SLS.

Sit-to-Stance

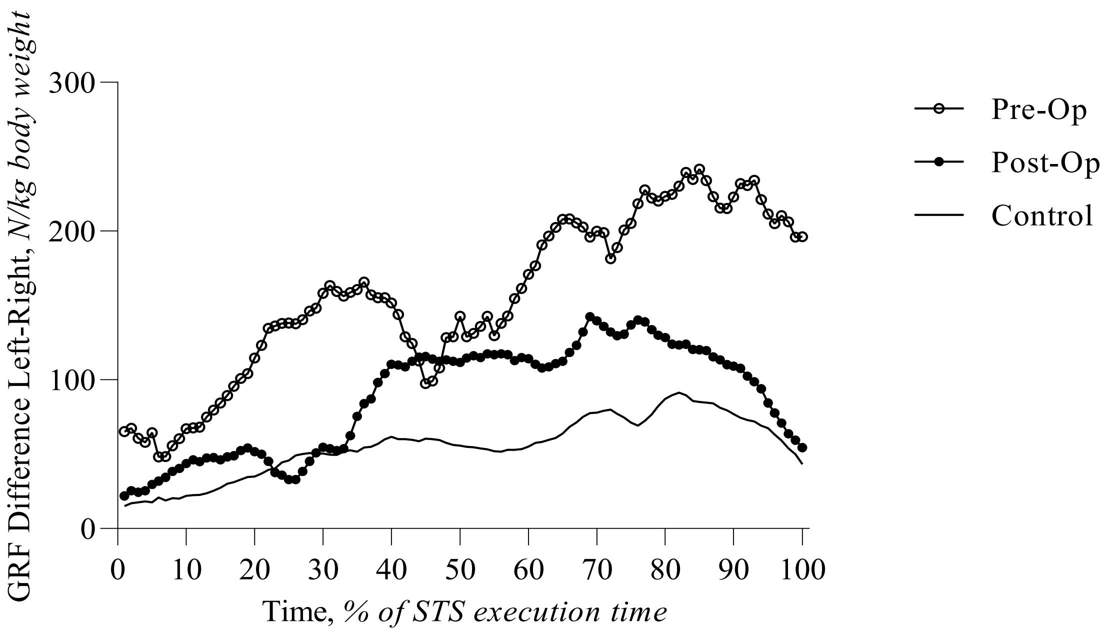
Patients improved their total STS time after the operation by more than 1 second (Table 5). This difference was caused by improvements in the leaning phase. The momentum and extension phase remained unimproved and slower than matched controls. Disbalance during STS, measured as the absolute difference in GRF between both legs, is visualized in Figure 2. GRF distribution showed improvement, but the change did not reach statistical significance.

	Preoperative (1)	Postoperative (2)	Matched control group (3)	p-value
Leaning phase (s)	1.11 (0.97-1.31)	0.57 (0.39-0.75)	0.66 (0.58-0.78)	1-2: 0.031* 2-3: 0.134
Leaning (%)	31.2 (28.7-40.7)	27.6 (22.0-29.0)	35.9 (34.1-40.5)	1-2: 0.155 2-3: 0.002*
Momentum phase (s)	0.37 (0.30-0.56)	0.36 (0.32-0.41)	0.20 (0.17-0.25)	1-2: 0.605 2-3: 0.016*

Momentum (%)	11.3 (9.2-18.4)	18.0 (15.2-25.9)	9.8 (8.7-14.5)	1-2: 0.017 2-3: 0.011
Extension phase (s)	1.83 (1.70-2.37)	1.09 (0.71-1.39)	0.89 (0.84-1.01)	1-2: 0.077 2-3: 0.277
Extension (%)	51.6 (49.4-62.9)	56.6 (46.0-61.9)	50.8 (46.6-54.3)	1-2: 0.969 2-3: 0.217
Total STS time (s)	3.41 (3.11-4.57)	2.21 (1.74-2.50)	1.92 (1.69-1.99)	1-2: 0.037* 2-3: 0.269

All values are medians with interquartile range (1:3). P-value refers to linear mixed model analyses.

Table 5: Outcomes of STS.



Pre-op: preoperatively, Post-op: postoperatively, GRF: ground reaction force, N: newton, kg: kilogram, STS: sit-to-stance

Figure 2: Absolute left-right difference in GRF during STS across study groups.

Discussion

Although the implementation of MISJF in SIJ dysfunction is still increasing and evidence for the effectiveness strengthens, controversy remains. [15,16] Current studies mainly focus on subjective outcome measures, such as pain, mobility and quality of life through questionnaires. [17] To evaluate the effectiveness of MISJF using objective measures of mobility and function, objective outcome measures should be investigated in addition to patient-reported outcome measures. In this small cohort of postpartum SIJ dysfunction patients, quality of life improved significantly three months following MISJF. These improvements are comparable to current literature, in which 6 and 12 months follow-up is mostly implemented. [18,19] Although these subjective outcome measures are crucial in the assessment of the effects of MISJF, there is an increasing interest for objective outcome data. This study is one of the first to give insights in such data. Prior studies have evaluated the effect of pelvic belts on SIJ dysfunction and noted improvements in quality of life and postural steadiness during locomotion. [20,21] The main finding of the present study is comparable, as MISJF results in overall better task execution in patients with postpartum SIJ dysfunction in addition to an improved quality of life. Improvements are most apparent in dynamic balance during SLS and STS execution time. The results of this study therefore strengthen the evidence of effectiveness for MISJF in SIJ dysfunction. In gait analysis, most parameters improved postoperatively compared to preoperatively, however no statistical significance was reached. In our previously published feasibility study, we noted that nearly all parameters (e.g. cadence, double support phase, walking speed) were statistically significantly different between preoperative patients and matched controls during gait. These differences are not found in the current study, indicating that postoperative patients show a more natural gait, comparable to healthy individuals. The data in Supplementary files 1 and 2 confirm the latter, as individual data mostly shows improvements in gait parameters. Walking speed is one of the parameters that universally increases when looking at Supplementary file 2. An increased walking speed may indicate less back pain or referred leg pain postoperatively, as we know patients that suffer from those complaints walk slower [22].

No improvement in joint angle was observed in the performance of a SLS following MISJF. Although mean hip angle was statistically significantly lower in postoperative patients compared to matched controls, none of the study groups reached a mean hip angle of 90°, as was instructed. This was also the case in our preoperative motion analysis paper, where we also investigated motion patterns in healthy students. [12] These data thus suggest that performing a SLS with a hip angle of the risen leg of 90° for 10 seconds is a challenging task, even among healthy individuals. A potential explanation of a decreased hip angle in postoperative patients might be surgically induced gluteal damage, in which strength still needs to be fully restored three months following surgery. [23] This is one of the reasons we recommend physical therapy programs following MISJF to largely focus on strengthening gluteal muscles. Potentially, measuring the effects of MISJF and supplementary physical therapy three months postoperatively, in a challenging task like SLS, might be too soon to expect improvement. Altered function of the gluteus musculature has been found in patients with SIJ dysfunction. [24] Consequently, differences in pelvic obliquity are expected between study groups, as gluteal function is heavily involved in pelvic obliquity. However, in both our studies concerning motion analysis in SIJ dysfunction, we found no differences in pelvic obliquity angle. Perhaps, pelvic obliquity movement is too small to measure significant differences across study groups. Further differences in SLS task execution (e.g. different mean hip angle) also influence the requirement of pelvic obliquity, subsequently making it more difficult to assess differences. Although the parameters of joint angles did not improve following MISJF, stabilographs in Figure 1 indicate balance improvements in patients after surgery, as the sway decreases compared to preoperatively. This is not only visually apparent, but also present in statistical analysis for center of mass in medial-lateral range for left leg.

Total time to perform an STS improved in patients following MISJF and was comparable to that of matched controls. Most improvement was reached in the leaning phase, which was even faster in postoperative patients than in matched controls. Patients with SIJ dysfunction often describe pain by getting up of a chair. [2] The improved total time to perform an STS might therefore indicate that the task is less painful following MISJF. In terms of force distribution, Figure 2 indicates notable, yet statistically unsignificant differences in GRF between both legs during STS across study groups. GRF differences decrease in postoperative patients compared to preoperatively and are more in line with that of matched controls. This indicates that the load capacity is more evenly distributed across both legs. A potential explanation might be that postoperative patients experience less complaints in their SIJ and are therefore less occupied with relieving their (most) symptomatic leg.

Limitations

A limitation of the current study is the small sample size. We previously performed a feasibility study with the same patient group as in the current study. In this feasibility study we were able to measure statistically significant differences in motion patterns between patients with postpartum SIJ dysfunction and matched controls. Therefore, we performed similar analyses in the same group following MISJF, to evaluate the effects of this intervention. Although several significant differences were observed, for other parameters larger sample sizes may be needed to overcome intra- and inter-individual variability. Frequently observed trends in the present data support the need for larger samples. Larger sample sized studies may also identify which individual patients benefit more from MISJF in terms of improvement in motion patterns. Another limitation to the current study is the short follow-up period. Three months postoperatively might be too early to expect large improvements in motion analyses. In a large number of patients bilateral SIJ complaints are present, for which a second surgery is needed, where the contralateral SIJ is fused to further alleviate complaints. In these patients further improvement can still be expected following second surgery

Conclusion

This study suggests that motion patterns improve in patients with postpartum SIJ dysfunction three months following MISJF. Most notable differences were an improved balance during SLS and a faster STS performance. Additional studies with longer follow-up and larger sample sizes should provide more detailed insights on motion analysis in patients with postpartum SIJ dysfunction following MISJF.

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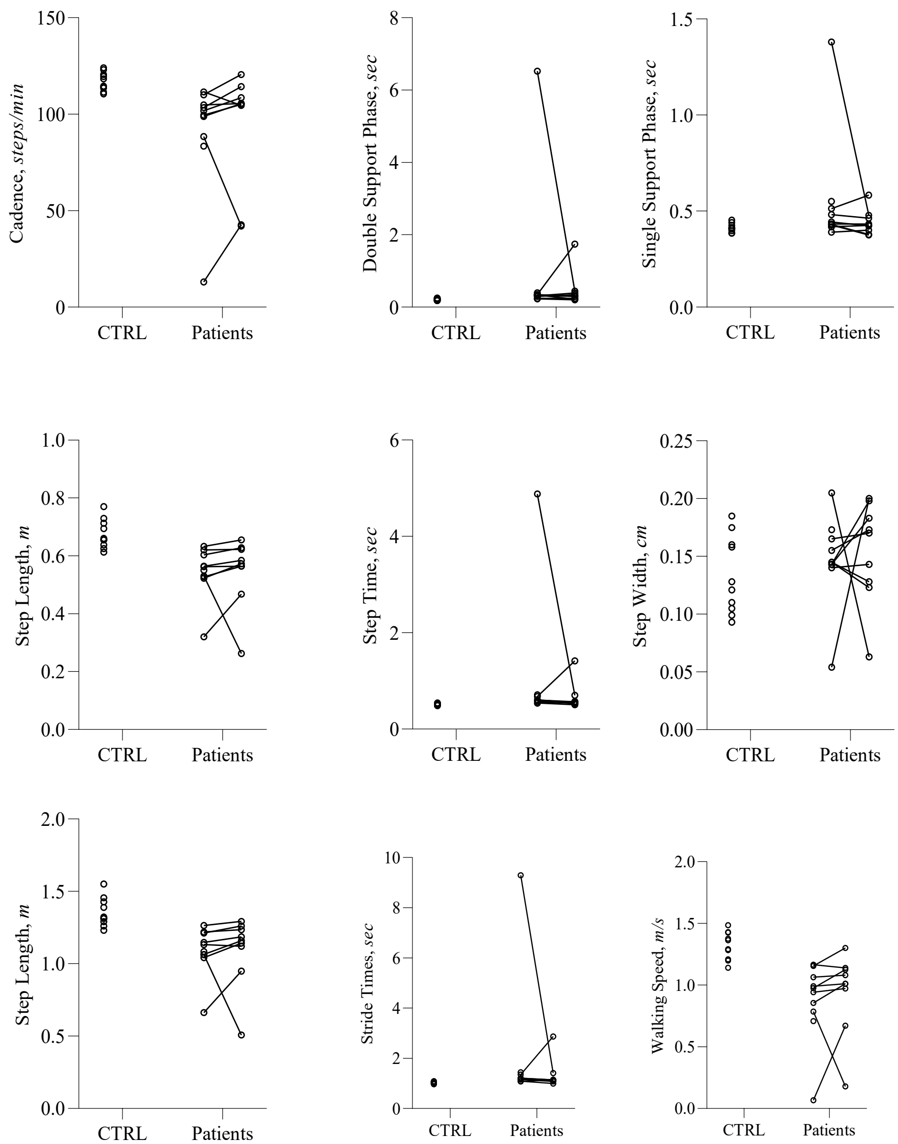
APPENDIX

Supplementary File 1: Individual parameter outcome of subjects during gait



CTRL: matched controls

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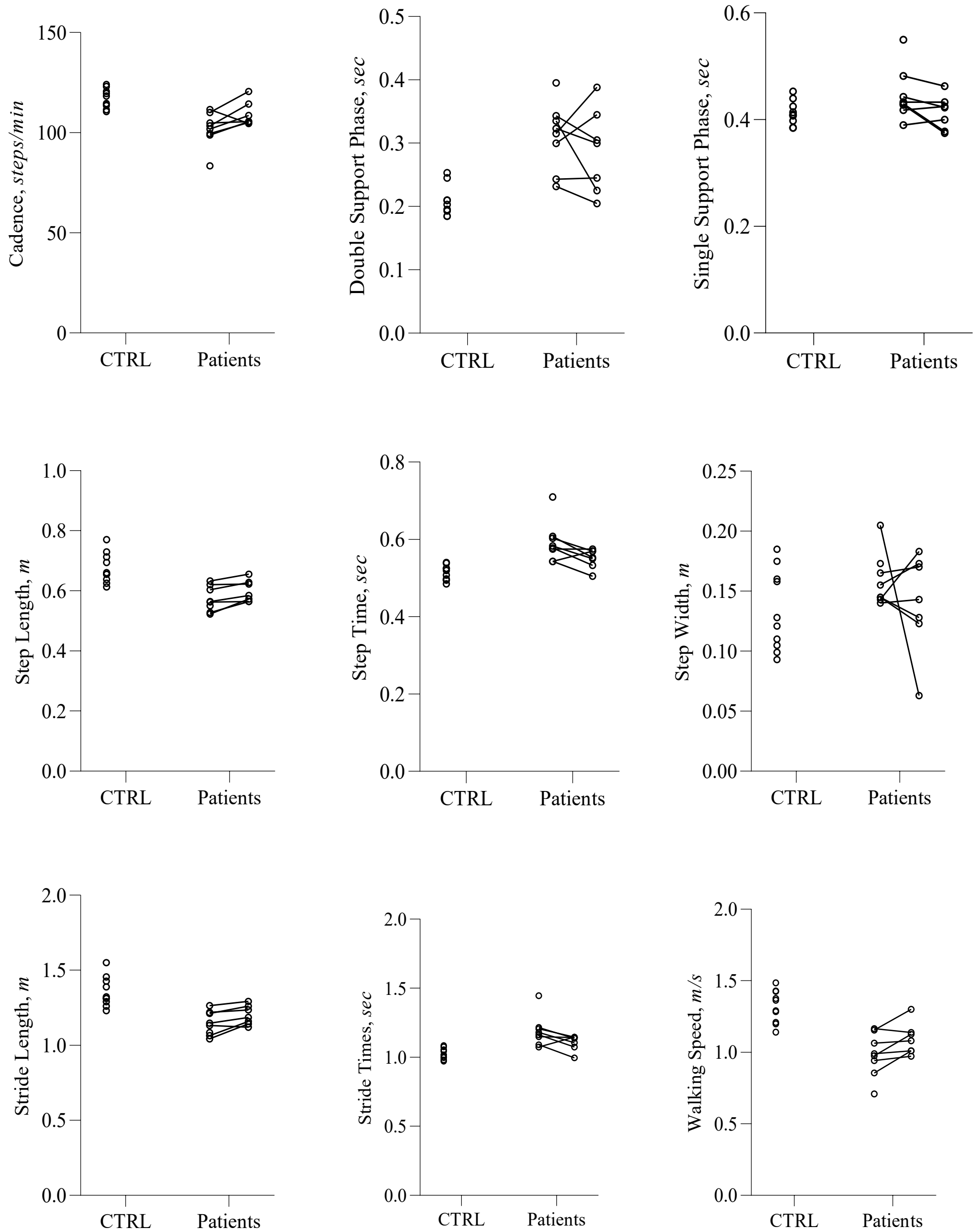
Supplementary file 2 Individual parameter outcome of subjects during gait, with exclusions of outliers (#8 and 9)



CTRL: matched controls