ISSN: 2754-4745

Journal of Physical Medicine Rehabilitation Studies & Reports

SCIENTIFIC Research and Community

Case Report

Open Access

Multiple Sessions of One-Legged Recumbent Cycle Ergometer Exercise Improved Pedaling Rate and Knee Range of Motion in a Middle-Aged Man after Hip Disarticulation: A Clinical Case

Takuya Osada[1,2]*, Masahiro Ishiyama[1] and Ryuuichi Ueno[1]

[1]Rehabilitation Center, Tokyo Medical University Hospital, Tokyo, Japan

[2]Cardiac Rehabilitation Center, Tokyo Medical University Hospital, Tokyo, Japan

ABSTRACT

Background: This case evaluates the short-term training effects with alterations in pedaling rate (PR) and its relationship to knee range of motion (KROM) after multiple sessions of one-legged recumbent cycle ergometer exercise (1LREx) in a patient after hip disarticulation (HD).

Case: A 44-year-old male patient had left HD due to osteosarcoma. He performed unilateral right 1LREx at 10 W with a self-controlled freely chosen PR until exhaustion. Multiple 1LREx sessions (maximum 4-5 sessions/day) were performed over 6 consecutive days from day 15 post-HD. PR and right KROM in the downstroke (pushing) and upstroke (pulling) pedal phases were determined continuously using a goniometer placed between the thigh and lower leg. The PR time-course during 1LREx indicated differences among multiple daily sessions but tended to be higher and more stable at steady-state over the study period (average ± SD PR and its coefficients of variability, 33.2 ± 5.3 revolution per minute (rpm) and 28.0% on Day 1 versus 43.0 ± 3.0 rpm and 12.5% on Day 6). The time-course of KROM was similar among multiple sessions during each day; however, the average KROM over all sessions in a day tended to increase over the study period (51.0 ± 1.2° on Day 1 vs. 78.0 ± 2.3° on Day 6). Mean KROM in the downstroke or upstroke pedal phases during each session showed a significant positive linear correlation (total of 27 sessions, $p < 0.05$) with mean PR.

Conclusion: After HD, short-term one-legged trainability with multiple 1LREx resulted in increased KROM and PR with uniformly faster PR with whole leg exercising in the sagittal plane.

***Corresponding author**
Takuya Osada, Rehabilitation Center, Tokyo Medical University Hospital, 6-7-1, Nishi-shinjuku, Shinjuku-ku, Tokyo 160-0023, Japan.
E-mail: dentacmac@aol.com

Received: October 10, 2022; **Accepted:** October 17, 2022; **Published:** October 26, 2022

Keywords: Hip Disarticulation, Knee Range of Motion, One-Legged Recumbent Cycle Ergometer Exercise, Pedaling Ratio

Abbreviations:
Hip disarticulation (HD)
One-legged recumbent cycle ergometer exercise (1LREx)
Pedaling rate (PR)
Knee range of motion (KROM)
Downstroke (DwS)
Upstroke (UpS)
Blood pressure (BP)
Heart rate (HR)

Introduction

Hip disarticulation (HD) is a major ablative surgery with complete loss of limb functionality [1-4]. HD may be performed because of a malignant tumor in the bone and soft tissue, with a difference in classification between young and elderly populations [1,3,5]. Evaluating the basal and/or remaining physical activity in patients in the early phase after HD operation can provide important information for ordering exercise models or prescription of a rehabilitation program for further enhancement of daily and social living activity with or without a prosthesis [3].

Loss of one leg with hip joint ability may initially be necessary for further improvement of the locomotive function of the pelvis, trunk, as well as activity of the opposite leg. Therefore, HD amputees are generally recommended to increase their muscle strength in the non-amputated leg and to promote activity of the lower trunk after the hip joint stump reaches maturity in early post-operation phase.

Initially, patients need the ability to achieve one-legged standing motion and good body balance before fitting of a hip prosthesis [6] with compensation for the complete loss of activity of the major pelvic muscle group connected to the proximal femur [1]. Consecutively, recovery of both physical and mental states may prompt behavior modification towards physical fitness/activity and to prevent any phantom limb awareness with the acceptance of disability as well as the heavy emotional shock [7].

Limb exercise therapies such as walking using a crutch and/or upper arm/shoulder physical training including an arm cranking ergometer are well accepted for HD amputees [8,9]. Additionally, single leg ergometer activity may also provide an optimal exercise model for repeat leg cranking with working of the major thigh muscle mass, trunk, and buttocks for reduced muscle mass activity [10-14]. In particular, one-legged recumbent cycle ergometer exercise (1LREx) may be able to provide more stable pedaling rotation with upper body fixation using a backrest and safe environment for fall prevention compared with an upright exercise system because of hip instability due to loss of a unilateral leg.

On the other hand, these may have limitations for uniform rhythmical one-legged pedaling rotation with repeat thigh muscle contractions (alternate flexion and extension at the hip and knee joint) because of weakness of lower body strength (particularly loss of locomotor function related to the hip joint due to leg fixation), and additionally lack of pedaling assistance by the counter leg. Therefore, it may not be easy to carry out repeat rhythmical uniform single/one-legged pedaling rotations in the sagittal plane (limb axis through ankle, knee, and hip joint) because of potentially large fluctuation in knee joint blurring in both horizontal and frontal planes during leg exercise.

For exercise therapy in the early phase after HD, however, there are no clinical reports on the time-course of training effects, for instance short-term training via multiple sessions with healthy single-leg exercise on the loss of physiological/biomechanical function with two leg-activity. Kinesiological measurements in a few clinical cases of HD amputees may provide valuable information for exercise prescription and/or to procedures to select what type of exercise model and/or therapy remains as potential physical activity for an amputee [15].

In a middle-aged male HD amputee due to osteosarcoma, this clinical pilot study evaluated whether the leg pedaling rate (PR), knee range of motion (KROM), exercise time for both downstroke (DwS; pushing) and upstroke (UpS; pulling) phases in pedaling and objective leg work intensity, measured using blood pressure (BP) and heart rate (HR), in multiple 1LREx sessions were altered over 6 consecutive days in the early phase post-HD.

Case Presentation

The case was a male amputee (age: 44 years and 0 months, height: 164.1 cm, weight: 64.3 kg) with left HD due to osteosarcoma. HD without hemipelvectomy was performed due to metastasis of osteosarcoma to the femur with purulent arthritis around the thigh stump amputated 7 months before. Left knee artificial joint replacement had been performed because of primary osteosarcoma in the knee diagnosed at 32 years old. He was treated for diabetes mellitus (diagnosed at age 38 years) with a hypoglycemic agent and a hypertensive state without medication. There were some occurrences of left phantom limb with itch and pain with shaping of the separation section post-HD.

The length between the greater trochanter and the knee joint space was 39.0 cm. The lower leg length was 38.5 cm between the knee joint space and lateral malleolus in the non-amputated leg. The circumference of the thigh was 51.5 cm at maximum, 43.2 cm at 10 cm above the patella, and 40.5 cm at 5 cm above the patella in the non-amputated leg, and that of the lower leg was 34.9 cm at maximum.

He has been training his leg using a 500 g weight attached to the right ankle in the daytime or using a right unilateral exercise ergometer (simplified ergometer instrument, TERASU Ergo III, SHOWA DENKI, Co., Ltd.) at lower workload (10 min/set, 4 sets/day) with an assist for pushing the crank rotation using a reach extender to the left pedal from the left hand daily after the left thigh amputation before HD at home. Consecutively post-HD in hospital he was able to perform physical exercise and therapy with 1LREx to return to his social activities.

The present clinical case was conducted in accordance with the principles of the Declaration of Helsinki (1964) and with approval of the Institutional Ethics Committee of the authors' institution. The participant gave written consent and was informed of the nature and purpose of the clinical case trial and publication, as well as potential risks and discomfort. The patient was informed that withdrawal from the exercise sessions included the general physical therapy in rehabilitation was possible at any time without consequences.

Exercise Model and Protocol

It may be expected that the basic action (postural change and standing, etc.) through a unilateral leg in an HD amputee will be relatively weak because of insufficiency in pelvic-spinal support. The complete loss of hip acetabulum function in major ablative surgery may represent non-voluntary contraction of unilateral muscle groups around the pelvis including iliopsoas, rectus femoris, and hamstring attached to the femur [1]. 1LREx can be utilized for stable pedal rotation with upper body fixation to examine the trainability of a unilateral right leg with previous findings demonstrating that one- legged interval training improved aerobic power and/or measurement of exercise tolerance [11,16-18].

A 1LREx (Cordless bike V67Ri, Senoh Corporation, Japan) at 10 W was tested with a self-controlled freely chosen PR until exhaustion corresponding to difficulty in making continuous cranking rotations owing to fatigue. The present amputee performed 1LREx with his hips at a 100° angle, with the thigh positioned horizontally and the knee joint bent before starting leg exercise. The position in the seat to achieve the optimal pedaling rotation was fixed throughout multiple sessions over all days.

The 1LREx was also safe in term of fall prevention rather than an upright exercise system, because hip instability due to loss of a unilateral leg (absence of lower limb function linked to the trunk) make increase fall risk in an early phase post-HD. However, biomechanical limitations with widely used leg ergometer instruments may exist due to difficulty with rhythmical one-legged cranking balanced between Up's and DwS of the pedal rotation because of the lack of assistance in the turning the pedal by the counter leg [19]. The right foot-ankle was fixed in the pedal for the motion of both pulling pedaling rotation of UpS phase and pushing pedaling rotation of DwS phase for the uniform rhythmical one-legged cranking with repeat thigh muscle contractions.

In addition, it was speculated that the 1LREx model may indirectly evaluate the activity of the major thigh muscle mass and buttocks from the time difference between pushing (bringing the pedal top to the bottom of the cycle; corresponding to DwS) and pulling (bringing the pedal back to the top of the cycle; corresponding to UpS) pedaling rotation [20]. The anterior thigh muscle mass mainly works during pushing pedaling rotation, and the posterior thigh muscle mass mainly works during pulling pedaling rotation [21].

Multiple 1LREx sessions (maximum number of sessions depending on exercise performance) in a day were begun with a test at 3 pm following regular exercise therapy performed at 10 am (trunk and leg muscle strengthening exercise for 30 min) over 6 consecutive days from day 15 post-HD. The interval between sessions comprised precisely 3 min of rest. The present intervention involved repeat 1LREx as an early rehabilitation program from day 15 post-HD corresponding to Day 1, and then day 16 (Day 2), day 17 (Day 3), day 19 (Day 4), day 20 (Day 5), and day 22 (Day 6).

PR, KROM and Time Duration for DwS and UpS Pedal Rotation

Changes in knee joint angle between the thigh and lower leg during 1LREx were monitored continuously using a goniometer (FA-DL-262 S&ME. Inc. Japan) placed between the lateral lower leg and the vastus lateral muscle and recorded on a PowerLab data acquisition system (Chart v.4.2.3 software; AD Instruments, Sydney, Australia). Measurements were performed throughout whole sessions, including both PR for every pedal rotation and time for DwS (pushing)/UpS (pulling) pedal phase via the time-course of recorded KROM signals. Using the profile in the KROM signal wave, KROM was precisely determined as the knee joint angle between the knee in the flexed position and the knee in the extended position (KROM during pushing the pedal in the DwS phase) and between the knee in the extended position and the knee in the flexed position (KROM during pulling pedal in the UpS phase) in accordance with previously validated measurements [15]. It was examined whether the KROM was similar between the DwS and UpS during 1LREx throughout the multiple sessions.

The time interval for pushing pedal in the DwS phase was defined as the time between end of the knee being in a flexed position and end of the knee being in an extended position. The time interval for pulling the pedal in the UpS phase was defined as the time between end of the knee being in an extended position and the end of the knee being in a flexed position. The PR during 1LREx was defined using the formula: 60 divided by the time interval for each cycle pedal rotation (sum of DwS time and UpS time), in units of "revolutions per min (rpm)". The mean value in the above-mentioned parameters was determined as the average of all "data estimated for every pedal rotation" in each session. The average value was defined as the average of the mean values for all sessions in a day.

BP and HR for 1LREx Work-intensity, Electrocardiogram, and Day-to-day Variability

BP and HR representing parameters for exercise work-intensity were also monitored simultaneously using an auricular plethysmography device with oscillometric calibration, through a cuff tourniquet placed on the upper right arm (RadiaPress RBP-100, KANDS, Aichi, Japan), single-lead electrocardiogram and data were recorded on a PowerLab data acquisition system. Both BP and HR were evaluated for every pedal rotation. Mean values for BP and HR were determined as the average of all "data estimated for every pedal rotation" in each session. The average values for BP and HR were defined as the average of mean values for all sessions in a day. Prior to exercise, both BP and HR measured by beat-by-beat for 1 min was defined as basal value at pre-exercise.

In a previous study, the cardiovascular responses during 4-min of one-legged upright cycling at 40, 80, and 120 W showed significant increases in BP and HR in a non-counterweighted single-leg compared with a counterweighted single- leg in healthy subjects [19]. In the present case, 1LREx in a HD amputee (corresponding to non-counterweighted single-leg cycling) potentially induced greater peripheral stress when performed at 10 W until exhaustion, corresponding to difficulty with continuous pedaling rotations because of fatigue; therefore, both BP (including peak BP) and HR values may also be objective parameters for the ensuring a safe exercise intensity (overload) with cardiovascular stressor potentially resulting in arrhythmia during non-physiologic (such as loss of a single leg) unilateral one-legged exercise compared with two healthy legs.

Statistical Evaluations

The mean values and standard deviations for PR, KROM, both DwS (pushing) and UpS (pulling) pedal phases, BP, and HR were evaluated in each session. Consecutively averaged values for the above-mentioned parameters were expressed as mean values for all sessions in a day. In addition, coefficients of variation calculated using the formula: "standard deviation/mean × 100%" for PR and KROM both pushing and pulling pedal phases were measured.

Statistical comparisons with a linear fitting regression correlation coefficient (r), and p-values were conducted between the mean PR and mean KROM evaluated for DwS (pushing) as well as UpS (pulling) pedal rotation phases (Microsoft 365 Excel). A P-value < 0.05 was considered significant. All data were indicated as mean ± standard deviations.

Results

The PR corresponding to a self-controlled free rhythm in the non-amputated leg stabilized with an increase in multiple 1LREx sessions over 6 days (Table 1 and Figure 1). There were large fluctuations in PR expressed by coefficients of variations in Day 1 (range: 16.2-47.2%) and Day 2 (range: 15.2-37.9%) compared with Day 5 (range: 10.2-13.5%) and Day 6 (range: 10.4-15.1%) (Table 1). The exercise time was prolonged with an increase in sessions (average 40-59 sec on Day 1 and Day 2 vs. 73-81 sec in Day 5 and Day 6). Furthermore, the mean PR tended to increase with the increase in days (range: 26.0-38.4 rpm on Day 1 vs. 39.3-45.8 rpm on Day 6). The range in KROM was similar among multiple sessions within each day but altered between days.

Mean KROM tended to increase over the 6-day study period (range: 49.2-52.9° on Day 1 vs. 75.4-81.0° on Day 6) in Table 1 and Figure 2. Additionally, the exercise time at each session was prolonged in Day 5 and Day 6 (range: 73-81 sec) compared with Day 1 and Day 2 (range: 40-59 sec).

Mean KROM had a significantly positive linear correlation with mean PR in the DwS (pushing) ($n=27$, $r=0.382$, $p<0.05$) and UpS (pulling) ($n=27$, $r=0.387$, $p<0.05$) pedal phases in Figure 3. The time duration was described in terms of DwS (pushing) and UpS (pulling) pedal phases in Figure 4 (partially expanded from Figure 1 except data of time duration at the onset and end of exercise for emphasis of the difference between pushing and pulling pedal times). The time duration may be longer in the DwS (pushing) pedal phase than the UpS (pulling) pedal phase, in particular on Day 1 and Day 2.

Mean/peak BP showed a slight increase with an increase in pedaling rotations, which was in agreement with the cardiovascular stressor depending on the exercise duration and/or multiple exercise sessions (Table 1 and Figure 5). The time-course of HR showed an increase with an increase in the number of pedal rotations, or J-curve-like pattern representing an increase with a transient decline around the 10-20th pedal rotations. A premature beat or cardiac conduction disturbance with a sudden decline in HR occurred immediately before the end of exercise in some sessions (see A-H in the Figure 6).

Citation: Takuya Osada, Masahiro Ishiyama, Ryuuichi Ueno (2022) Multiple Sessions of One-Legged Recumbent Cycle Ergometer Exercise Improved Pedaling Rate and Knee Range of Motion in a Middle-Aged Man after Hip Disarticulation: A Clinical Case. Journal of Physical Medicine Rehabilitation Studies & Reports. SRC/JPMRS/180. DOI: doi.org/10.47363/JPMRS/2022(4)162

Table 1: Changes in self-controlled freely chosen PR, KROM, exercise time, and other parameters

Day	Measurement		Pre-exercise	One-legged recumbent ergometer exercise					
				1st session	2nd	3rd	4th	5th	Average
1	Exercise time (sec)		-	75	39	30	16		40.0±25.2
	PR (rpm)		-	38.4±6.2 (16.2)	35.3±7.4 (20.9)	32.9±9.0 (27.5)	26.0±12.2 (47.2)	-	33.2±5.3 (28.0)
	KROM (degree)	DwS	-	51.6±1.9 (2.5)	52.1±1.9 (4.6)	49.7±4.0 (1.8)	52.9±1.9 (2.9)	-	51.6±1.4 (3.0)
		UpS	-	51.4±1.8 (3.2)	51.6±1.6 (3.9)	49.2±3.2 (4.6)	51.6±1.8 (3.4)	-	51.0±1.2 (3.8)
	BP (mmHg)		61.1±2.1 (3.5)	63.0±2.5 (4.0)	72.0±5.3 (7.4)	77.1±5.3 (6.8)	72.7±3.0 (4.1)	-	71.2±5.9 (5.6)
	Peak BP (mmHg)		-	70.8	87.5	83.6	77.5	-	79.8±7.3
	HR (beats/min)		91.8±3.5 (3.8)	97.6±3.3 (3.4)	96.3±3.3 (3.4)	99.2±14.2 (14.3)	95.3±1.4 (1.5)	-	97.1±1.7 (5.7)
2	Exercise time		-	67	58	72	39	-	59.0±14.5
	PR		-	48.0±7.3 (15.2)	40.8±8.0 (19.6)	31.4±6.6 (21.0)	28.4±10.8 (37.9)	-	37.2±9.0 (23.4)
	KROM	DwS	-	65.2±1.3 (2.8)	64.2±1.3 (3.3)	61.5±2.0 (2.1)	58.9±4.6 (2.4)	-	62.5±2.8 (2.7)
		UpS	-	65.2±1.4 (3.1)	64.3±1.3 (3.4)	61.5±2.3 (2.2)	58.6±4.2 (2.6)	-	62.4±3.0 (2.8)
	BP		92.5±1.6 (1.7)	92.3±1.9 (2.1)	96.7±3.9 (4.0)	98.7±3.4 (3.4)	98.3±5.4 (5.5)	-	96.5±2.9 (3.8)
	Peak BP		-	95.7	109.2	106.1	115.4	-	106.6±8.2
	HR		86.1±3.2 (3.7)	94.6±3.6 (3.8)	92.4±11.7 (12.6)	97.4±4.8 (4.9)	98.0±3.8 (3.9)	-	95.6±2.6 (6.3)
3	Exercise time		-	90	89	53	51		70.8±21.7
	PR		-	38.1±6.5 (17.2)	34.4±4.2 (12.3)	31.5±5.0 (15.8)	53.1±9.9 (18.7)	-	39.3±9.6 (16.0)
	KROM	DwS	-	77.8±1.9 (2.7)	75.2±3.5 (2.0)	71.9±1.3 (2.3)	72.1±2.1 (3.5)	-	74.3±2.8 (2.6)
		UpS	-	77.7±2.5 (2.6)	75.4±3.0 (2.0)	71.4±3.3 (2.2)	71.7±2.4 (3.1)	-	74.1±3.0 (2.5)
	BP		85.0±0.8 (1.0)	83.4±1.9 (2.3)	89.5±2.7 (3.1)	92.0±1.9 (2.1)	95.8±3.2 (3.4)	-	90.2±5.2 (2.7)
	Peak BP		-	87.7	99.0	96.5	101.9	-	96.3±6.1
	HR		94.5±2.5 (2.6)	102.2±3.7 (3.6)	99.9±5.6 (5.6)	98.2±2.0 (2.0)	100.9±3.9 (3.9)	-	100.3±1.7 (3.8)
4	Exercise time		-	84	54	53	67	58	63.2±12.9
	PR		-	45.8±9.3 (20.4)	60.7±9.8 (16.1)	42.9±7.0 (16.3)	40.7±6.3(15.5)	44.5±4.9 (10.9)	46.9±7.9 (15.8)
	KROM	DwS	-	65.4±1.8 (2.9)	66.3±2.0 (3.1)	62.6±1.3 (1.4)	63.4±1.5 (1.7)	62.9±2.3 (2.8)	64.1±1.6 (2.4)
		UpS	-	65.4±2.1 (3.1)	65.9±2.1 (3.2)	62.4±1.4 (1.4)	63.1±1.6 (2.4)	62.6±1.9 (3.3)	63.9±1.6 (2.7)
	BP		93.7±1.7 (1.8)	94.1±2.0 (2.1)	98.6±2.7 (2.8)	99.9±1.8 (1.8)	103.3±3.3 (3.2)	103.9±2.1 (2.0)	99.9±3.9 (2.4)
	Peak BP		-	98.9	103.5	103.9	114.2	108.1	105.7±5.8
	HR		90.5±3.5 (3.9)	99.8±3.9 (4.0)	100.8±5.5 (5.4)	97.9±2.2 (2.3)	99.2±4.2 (4.2)	98.9±2.1 (2.1)	99.3±1.1 (3.6)
5	Exercise time		-	101	74	69	80	81	81.0±12.2
	PR		-	42.8±4.4 (10.4)	45.1±5.4 (12.0)	47.1±6.4 (13.5)	43.7±4.4 (10.2)	45.9±5.1 (11.2)	44.9±1.7 (11.5)
	KROM	DwS	-	71.5±2.0 (2.7)	69.8±1.4 (2.0)	72.1±1.6 (2.3)	69.2±2.4 (3.5)	69.4±2.0 (2.9)	70.4±1.3 (2.7)
		UpS	-	71.5±1.9 (2.6)	69.8±1.4 (2.0)	71.9±1.6 (2.2)	69.2±2.1 (3.1)	69.5±2.4 (3.5)	70.4±1.2 (2.7)
	BP		88.2±0.7 (0.8)	89.0±1.9 (2.1)	90.7±2.3 (2.5)	93.0±2.0 (2.1)	95.2±2.4 (2.5)	100.9±3.1 (3.0)	93.8±4.6 (2.4)
	Peak BP		-	93.0	95.8	97.8	101.5	111.8	100.0±7.3
	HR		103.3±2.9 (2.8)	110.2±5.0 (4.5)	107.4±4.4 (4.1)	107.1±3.2 (3.0)	108.2±2.9 (2.7)	105.1±3.2 (3.0)	107.6±1.8 (3.5)
6	Exercise time		-	86	62	55	91	71	73.0±15.3
	PR		-	45.8±4.8 (10.4)	45.6±6.9 (15.1)	40.5±5.4 (13.3)	39.3±3.8 (9.8)	43.7±6.0 (13.8)	43.0±3.0 (12.5)
	KROM	DwS	-	75.7±2.2 (2.9)	75.4±2.8 (3.7)	79.3±1.1 (1.4)	78.8±1.4 (1.7)	81.0±2.2 (2.8)	78.0±2.4 (2.5)
		UpS	-	75.8±2.3 (3.1)	75.4±2.8 (3.7)	79.3±1.1 (1.4)	78.7±1.9 (2.4)	80.8±2.7 (3.3)	78.0±2.3 (2.8)
	BP		90.4±1.2 (1.3)	92.0±1.9 (2.1)	95.7±1.6 (1.7)	98.6±2.4 (2.4)	98.0±2.5 (2.5)	100.8±3.1 (3.1)	97.0±3.3 (2.4)
	Peak BP		-	97.4	99.4	104.7	104.3	112.3	103.6±5.8
	HR		97.0±2.4 (2.5)	102.5±3.3 (3.3)	100.0±3.3 (3.3)	98.2±2.5 (2.5)	103.1±4.0 (3.8)	102.1±4.2 (4.1)	101.2±2.0 (3.4)

The data are expressed as mean ± standard deviation (coefficients of variation) over 6 consecutive days. PR, pedaling rate; KROM, knee range of motion; DwS, downstroke (pulling) of the pedal rotation; UpS, upstroke (pushing) of the pedal rotation; BP, blood pressure; HR, heart rate.

Discussion

This clinical case may provide insights for optimal single leg exercise by HD amputees in rehabilitation programs that potentially exploit exercise trainability for increasing PR, increasing KROM, and prolonging exercise duration with the achievement of a sense of accomplishment. We employed a widely used recumbent bicycle ergometer in the early post-operative phase after major loss of a unilateral leg. Furthermore, this work continues the findings of our previous case series, which involved estimation of the physiological and kinematic features for amputated lower legs with a leg exercise model focused on dynamic knee extensors [22,23].

The findings in the present case showed that enlargement of KROM with an increase in PR over 6 days with 1LREx sessions may represent exercise trainability for physical and exercise therapy. There are still few clinical acknowledgements for HD amputees regarding the evaluation of dynamics (kinematic and biomechanical analyses) for unilateral leg exercising. This may be the reason why the process for the initial approach in physiotherapy in the early postoperative phase has potentially large variations owing to the subject background. This may include predicting walking ability, remaining physical fitness, muscle mass/strength in the unilateral healthy leg, instability in sitting due to postural control, phantom limb, anxious mental state related the change in body image, and comorbidities [24].

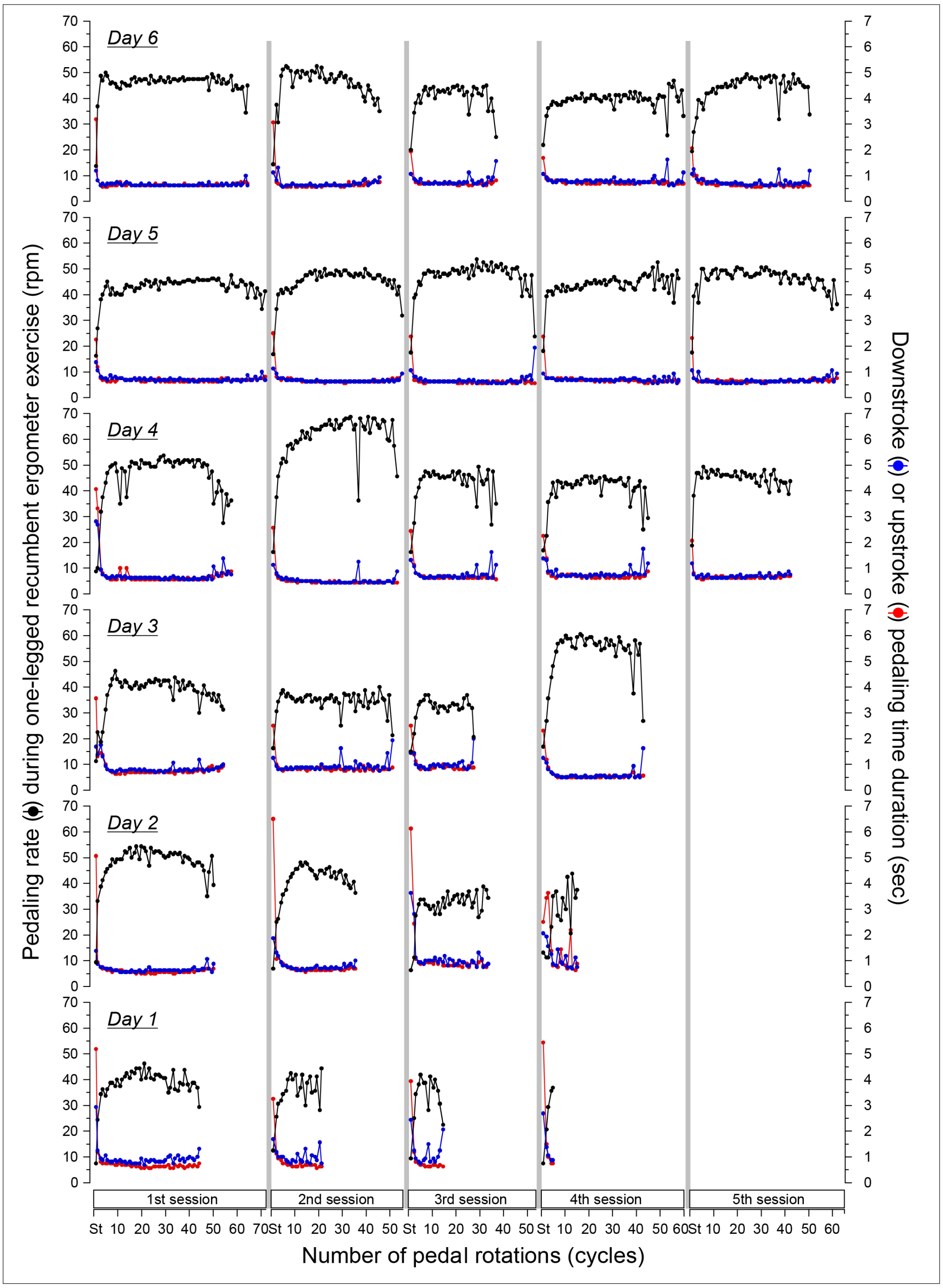

Figure 1: Time-course of self-controlled freely chosen PR and time duration of pedal rotation with one-legged recumbent ergometer exercise

The self-controlled freely chosen pedaling rate (PR) (●) showed an exponential increase (upward curve) from onset of exercise to exhaustion. Therefore, PR may increase rapidly to achieve a steady state after the 6-7th pedaling rotations from the onset of exercise. Exercise time in a session was prolonged on Day 5 and Day 6 compared with Day 1 and Day 2. Because the time duration of one pedal rotation precisely corresponded to the sum of the downstroke pushing (●) and upstroke pulling pedaling times (●), there were reciprocal changes between PR and time duration of both the downstroke pushing and upstroke pulling pedaling phases. Over whole days, at the beginning of exercise lower PR was seen due to taking more time for the 1st to approximately 4th pedal rotation from the onset of exercise. St, start of exercise; rpm, revolutions per min.

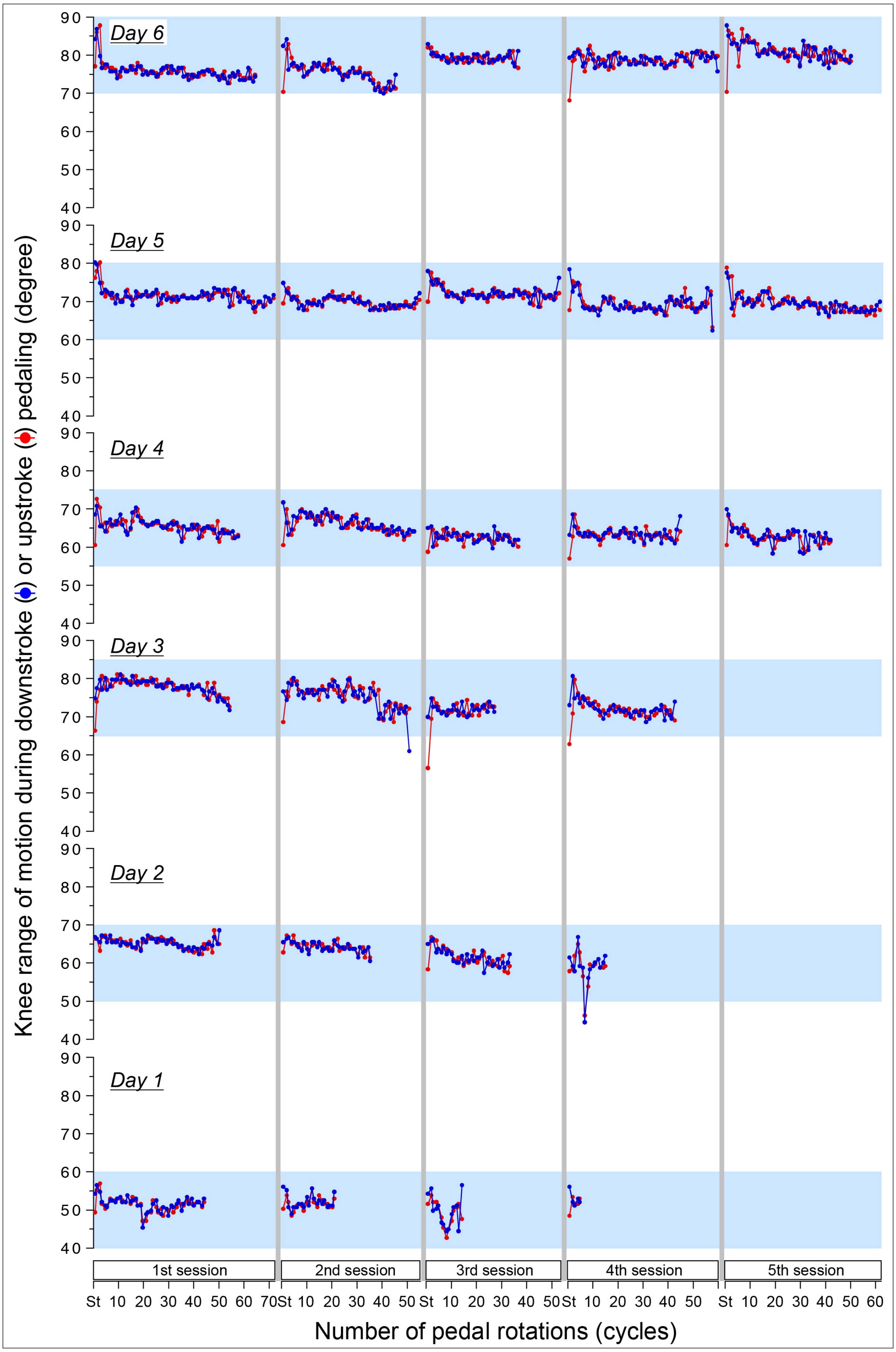

Figure 2: Magnitude of KROM during 1LREx between multiple sessions over 6 consecutive days
The knee range of motion (KROM) during one-legged recumbent ergometer exercise (1LREx) was clearly different between Day 1 to Day 2 and Day 5 to Day 6, although the present amputee tried to repeat uniform pedal rotation among sessions over 6 consecutive days. KROM may be more variable over multiple sessions on Day 1 but with fewer fluctuations on Day 4 and Day 5.

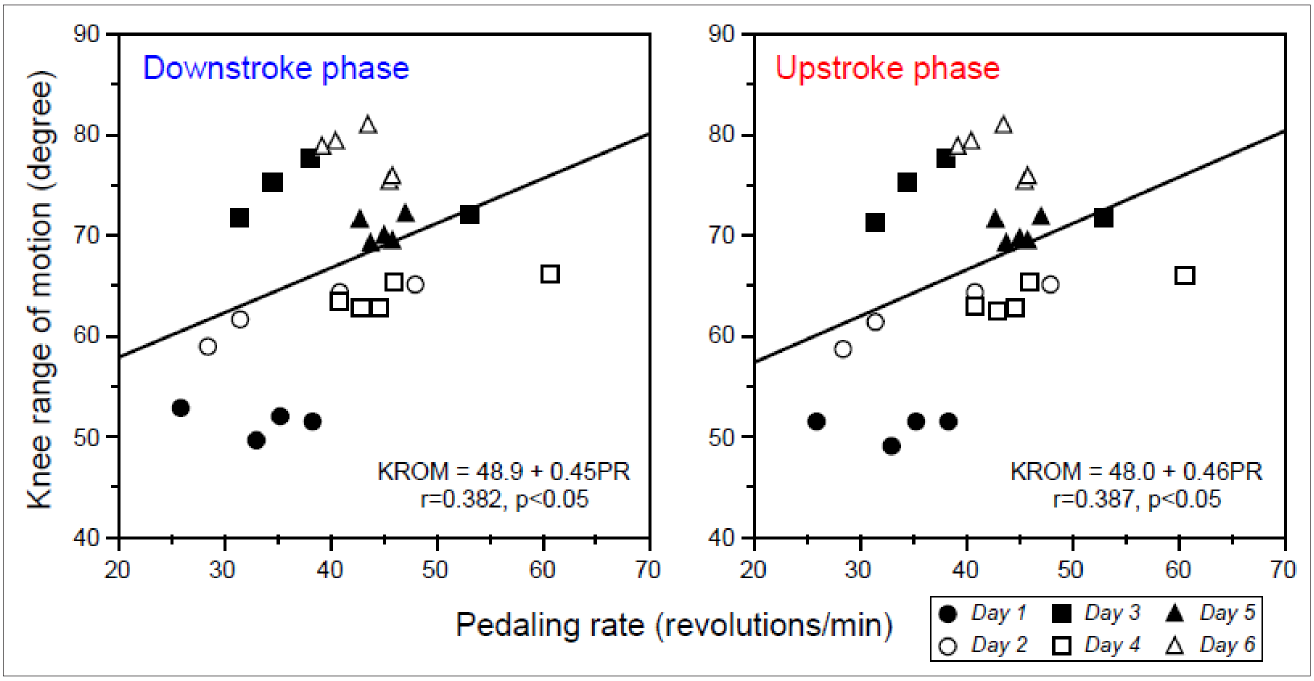

Figure 3: Relationship between self-controlled freely chosen PR and KROM in downstroke and upstroke phases
There is significant close relationship between pedaling rate (PR) and knee range of motion (KROM) in the downstroke pushing pedal phase ($r=0.382$, $p<0.05$) as well as the upstroke pulling pedaling phase ($r=0.387$, $p<0.05$).

In addition, gait with a prosthetic limb leads to a higher energy consumption compared with gait with crutches [25-28], and energy expenditure for such a gait increases by 82%, which may potentially lead to patients being confined to a wheelchair or bedridden [29,30]. In previous case reports there are some significant successes with regaining gait with a fixed walker using a hip prosthesis during the early postoperative period [8,9]. Moreover, it might be considered that there are only small group of HD amputees with few comorbidities or high physical fitness/activity who can walk with a hip prosthesis [31,32]. However, it is still important to estimate the initial muscle strength/power, articular movement, and one-legged standing for potential gait ability for such patients.

The present HD amputee was well-trained through habitual physical exercise (daily limb muscle strength training and ergometer exercise at home) as a thigh stump amputee before HD. Thus, the present trial was a significant opportunity to exploit the motivation for exercise performance following unilateral leg loss even with a short duration of 1LREx can influence unilateral leg trainability corresponding to PR, KROM and exercise time in multiple sessions over 6 days. These findings are discussed in the following section.

Alterations in self-controlled free PR induced KROM
In the previous study, the voluntary rhythmic movement behavior and control of PR during cycling has been investigated [33]. The PR during cycling may be influenced by the biomechanical, physiological, and psychophysiological variables with performance in relation to energy turnover and maximum oxygen uptake. Particularly, alterations in freely chosen PR versus an energetically optimal PR was focused on following strength training in trained and untrained subjects.

Recreationally active individuals chose a PR on average 11 rpm lower after 4 weeks of strength training, but well-trained cyclists did not change their freely chosen PR [34]. Freely chosen cadence only changed in response to heavy strength training, occurring already after 1 week of training [35]. PR is also affected by the altered crank torque profile following strength training as well as gross efficiency [36]. Daily active exercise with leg muscle strength related to cycling may induce an alteration in freely chosen PR, but PR may also be characterized as a highly individual choice [34]. The exercise model in the present case was 1LREx at low intensity, which is not similar to the upright cycling in the above-mentioned study. In addition, the manner of the pedaling rotation is biomechanically different between an HD amputee and non-leg amputees because of the complete absence of assistance by the counter leg influencing the PR during unilateral cycling, with exhaustive leg fatigue being reached within approximately 100 sec.

Figure 1 shows that the fluctuation in PR measured for every pedal rotation was larger in the 2nd to 4th sessions on Day 1, and in the 3rd and 4th sessions on Day 2, which was while the subject was not familiar with the pedaling rotation. The range for the coefficient of variation of the fluctuation in PR was below 48% (average 28.0% in all sessions) on Day 1 but was below 16% (average 11.5-12.5%) on Day 5 and Day 6, which may indicate uniformity in one-legged cycling increased over the course of the 1LREx sessions (Table 1). Moreover, the prolongation of the 1LREx time was observed by approximately 2-fold on Day 5 and Day 6 (average 73-81 s) compared with Day 1 and Day 2 (40-59 s) (Table 1).

One of the reasons why the present HD amputee was promptly able to achieve familiarity with 1LREx may be due to the manner of the pedaling rotation between DwS and UpS. In Figure 4 showing a partially expanded part of Figure 1, the slight differences in time between DwS (pushing) and UpS (pulling) pedaling phases as clearly shown from Day 1 to Day 3. It can be speculated that this may be a positive effect because of the equivalent time ratio between “pushing the pedal in the DwS phase” and “pulling the pedal in the UpS phase” on Day 5 compared with Day 1 and Day 2 with a longer time spent in pushing phase rather than the pulling pedaling phase.

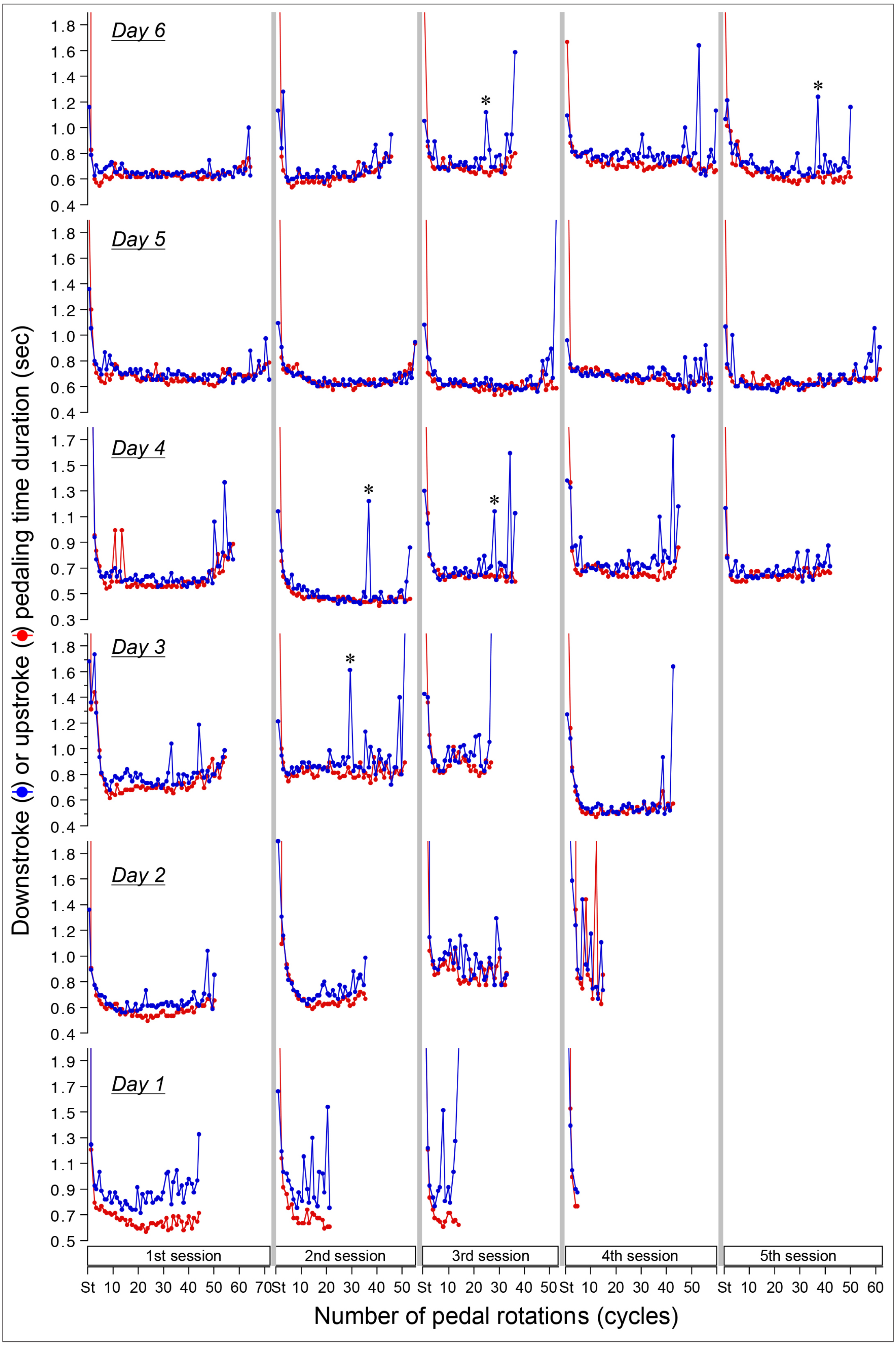

Figure 4: Difference in time between downstroke (pushing) and upstroke (pulling) pedal phases (except onset of exercise)
This figure shows an expanded time-course of pedaling time shown in Figure 1 except for the onset and immediately prior to the end of exercise. Difference in time between downstroke pushing (●) and upstroke pulling pedaling time (●) was clearly described with a range of below 0.2 sec except for the onset of exercise on Day 1. The difficulty with continuous rhythmical pedal rotation in the downstroke pushing phase (* in Figure) for a moment was suspected because of the time extension with the pushing phase [for example, Day 3: 2nd session (29th pedal rotation); Day 4: 2nd session (36th pedal rotation) and 3rd session (28th pedal rotation); Day 6: 3rd session (25th pedal rotation), 5th session (37th pedal rotation)] during the intermediate exercise phases. The variations in pedaling rhythm corresponded to the cranking rate may be less with the increase in test days. St, start of exercise.

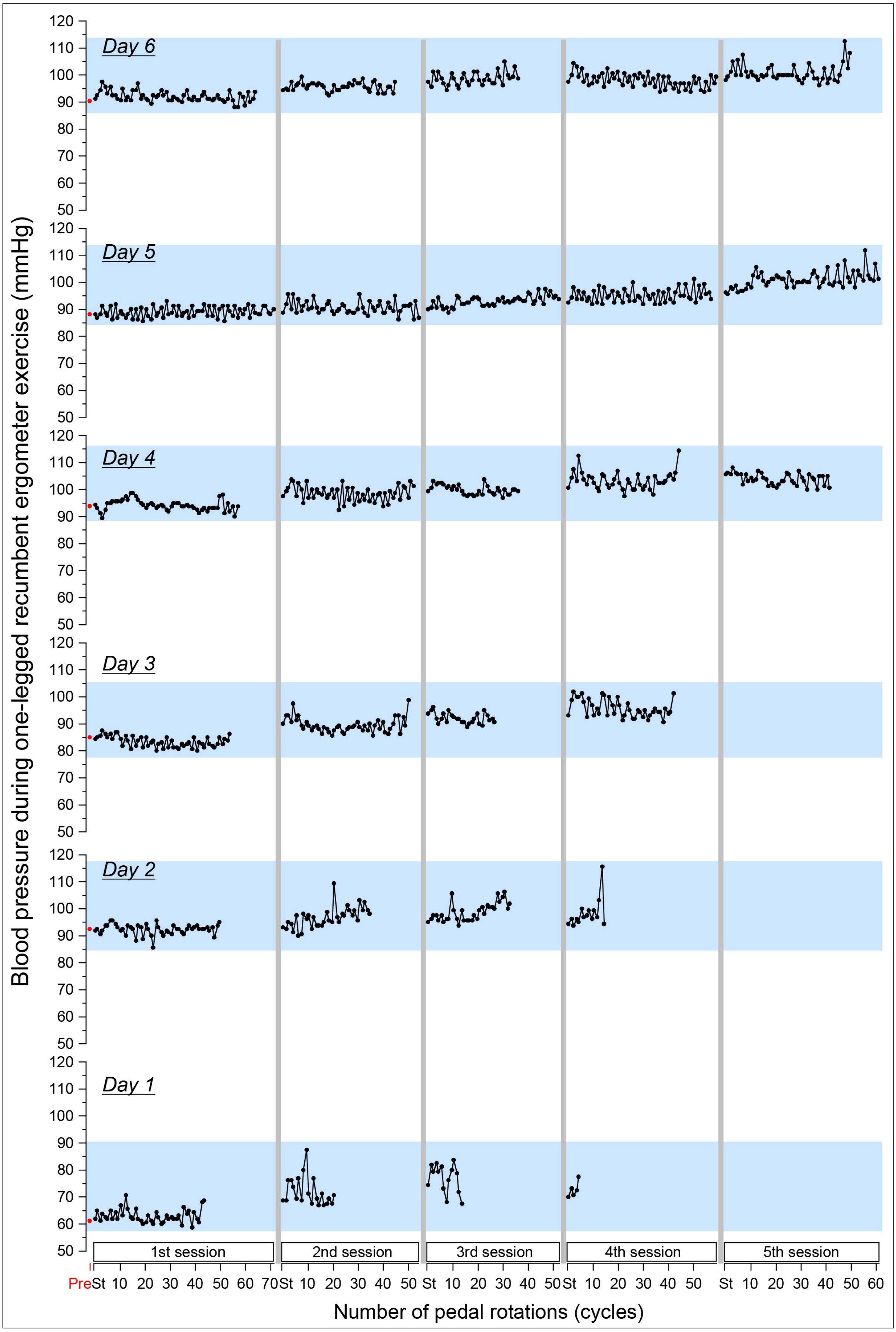

Figure 5: Time-course of BP during 1LREx between multiple sessions over 6 consecutive days
The time-course of blood pressure (BP) showed a slight increase with an increase in the number of pedaling rotations in a session as well as over consecutive sessions in whole. Pre, mean beat-by-beat basal pre-exercise BP; St, start of exercise.

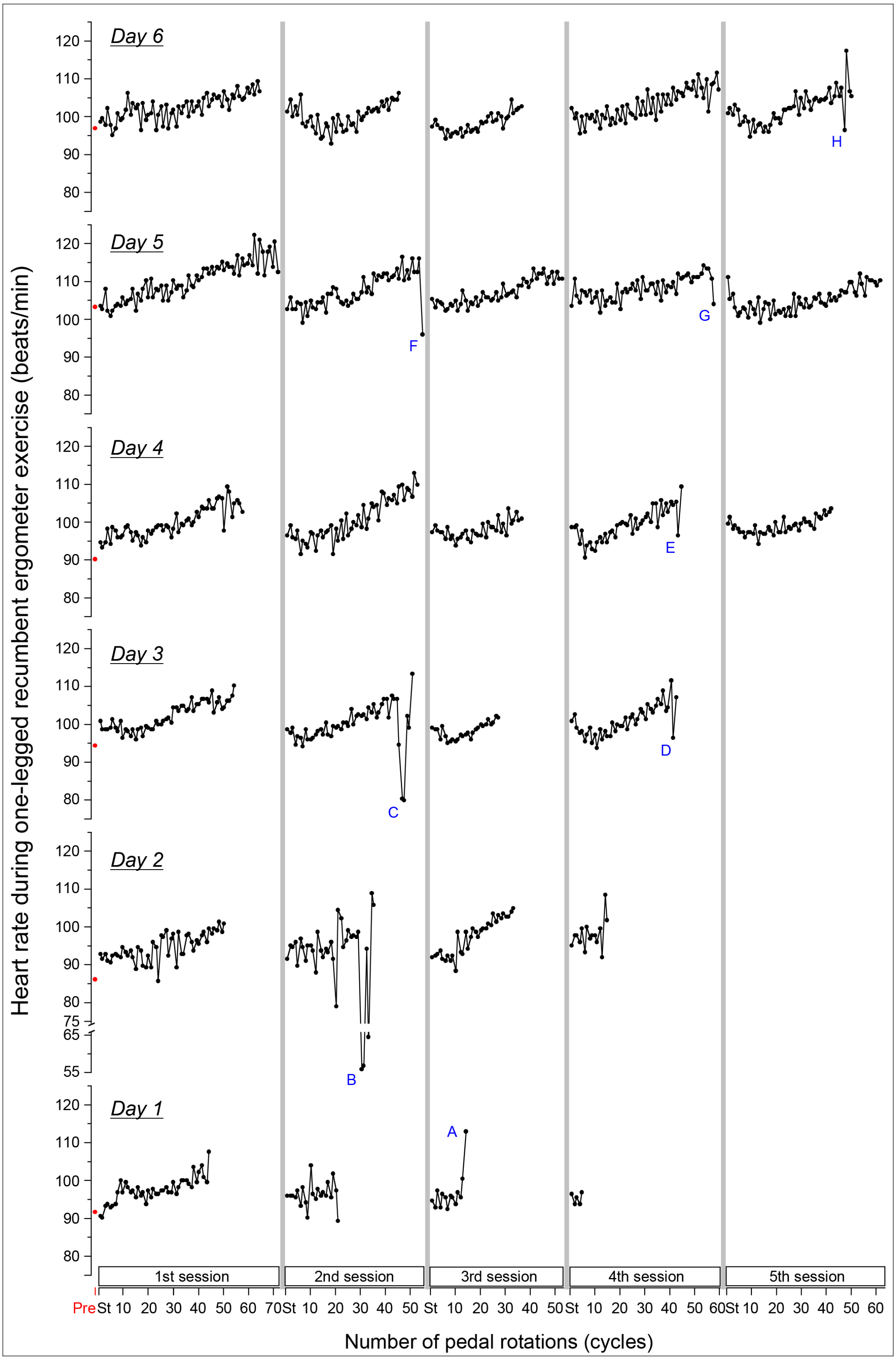

Figure 6: Time-course for HR during 1LREx between multiple sessions over 6 consecutive days
Time-course of heart rate (HR) with a linear increase and/or J curve-like increase with increased exercise duration over each session and day-to-day variability. The HR was determined as the mean value of the phase between the downstroke pushing and upstroke pulling pedaling phases (one rotation of the pedals) but not beat-by-beat value. The mean beat-by-beat basal pre-exercise HR (Pre) was measured before exercise. Sudden increases in HR were caused by triplet premature atrial contraction (A). Sinus block appeared consecutively with missed beats (B and F) before the end of exercise induced the reduction in the mean HR value. The transient reduced mean value of HR represents a single premature atrial contraction (C) with a compensatory pause, and a single premature ventricular contraction (D, E, G and H). St, start of exercise.

Time difference between DwS (pushing) and UpS (pulling) pedaling phase during 1LREx

The slightly longer time in DwS (pushing) compared with UpS (pulling) pedaling rotation seen in Days 1, 2, and 3 indicated that the subject did not get used to pedaling rotation at the beginning of 1LREx in the first sessions (Figure 4). Furthermore, an approximately 0.1-0.2 sec longer DwS phase suggested difficulty with the "leg press in a semicircle trajectory of the crank" in the pushing pedaling rotation following the end of the pulling pedaling rotation phase in Day 1 and Day 2. Unexpectedly, the pushing pedaling rotation phase took substantially more time (approximately 0.8 sec) to for the leg press as well as knee extension power for the initial reaction from the peak hip flexed position (for example, Day 3: 29 cycles and Day 4: 36 cycles in the 2nd session, see * in Figure 4). This was caused by the difference between muscle mechanical energy during pushing and pulling pedaling rotations, which demonstrated that the uniarticular hip and knee extensors generated 65% of the total mechanical work in the recumbent pedaling motion [37].

The gastrocnemius, hamstring muscles, and vastus medialis systematically increased muscle activity as PR increased. The gluteus maximus and soleus also showed significant changes in relation to PR. Furthermore, the soleus was active as the crank extensor-bottom transition muscle, whereas the rectus femoris functioned as the crank top transition-extensor muscle [38]. The targeted muscle groups in the hip extension-flexion exercise included the gluteus maximus and the iliopsoas muscles, respectively, which had an important role in the generation of pedaling motion [39,40] Moreover, the hamstring activity increased at higher PR more than that of the quadriceps [20]. Naturally, the targets in working muscles may be different from the patterns of muscular activity during DwS and UpS in pedal rotation.

In the present HD amputee, the effort of the initial leg power during DwS pedaling on Day 1 and Day 2 may be influenced by the lack of counter leg support from the peak flexed knee-hip position to the peak extended knee-hip joint, with partial agreement with previous findings suggesting the role of a counterweight to the leg for the recruitment of hip flexors in the active leg during one-legged cycling [19].

Correlation between self-controlled freely chosen PR and KROM during 1LREx in multiple sessions over 6 days

The time-course of PR expressed as a self-controlled freely chosen rhythm was mostly described as "exponential increase like" on Day 5 and Day 6 compared with Day 1. Notably, the PR 10 cycles after onset of 1LREx was stabilized with an increase of approximately 10 rpm on Day 5 and Day 6 (average 43.0-44.9 rpm) compared with Day 1 (average 33.2 rpm) (Table 1 and Figure 1). Finally, the KROM achieved was on average 78° on Day 6 from an average of 51° on Day 1. Mean KROM tended to increase over the 6-day study period, although unaltered circumduction with pedal rotation theoretically indicated an identical KROM (from the orbit of the knee joint) in the sagittal plane without a relation to PR. The range of KROM (75-81°) on Day 6 measured in the recumbent position was within an acceptable range reported in previous data as ranging from 46° to 112° degrees knee flexion on an upright bicycle ergometer [41]. The difference in KROM between Day 1 and Day 6 may show the acquisition of an optimal manner for cycling using a 1LREx (Table 1).

The overall result of the data showed a good positive linear relationship between PR and KROM, as seen in Figure 3. In particular, the sessions on Day 1 and Day 2 demonstrated large oscillation at lower PR values with a lower KROM value represent a lack of familiarity with 1LREx. However, that on Day 5 and Day 6 showed higher PR values with higher KROM values. This can be speculated as being caused by the uniform faster PR with coordinated leg joint motion (ankle, knee, and hip) in the sagittal plane increasing KROM with an increase in 1LREx sessions associated with short-term trainability.

BP, HR, and arrhythmia during 1LREx at 10 W

Consideration of the stressors for hemodynamics with multiple 1LREx sessions may be valuable information for safe exercise prescription including overload (exercise work-intensity). Cardiovascular stress during exercise is altered with changes in cardiac output and peripheral vascular resistance related to pathophysiological functions, including the state of any cardiovascular disease.

According to Figure 5 and 6, both BP and HR slightly increased during 1LREx, even if the minimum workload setting recumbent ergometer used here was set to a low intensity of 10 W. Burns (2014) reported statistically significant increases in BP, HR, and oxygen uptake during single-leg non-counterweight cycling compared with single-leg counterweight (only grounded foot) cycling for 4 min at 40 and 120 W, because the recruited hip flexors in the active leg during the upstroke to bring the pedal back to the top of the cycle resulted in greater effort, metabolic, and cardiovascular demand because of the lack of action by the counterweight of leg. Therefore, BP and HR during 1LREx with the absence of counter leg in the present case (but not equal to single-leg non-counterweight cycling) may be the source of the relatively higher values presented in Figure 5 although it would be impossible to determine them for two-legged cycling. In the present case, it was considered that the time-course of BP measured on Day 5 typically showed a slight increase with the increase in the number of pedaling rotations in a session as well as the 5 consecutive sessions as a whole (Figure 5). Thus, BP reached a peak value before the end of 1LREx with insufficient pedaling cycles achieved in sessions potentially indicating the accumulation of fatigue with cardiac stress.

In addition, premature cardiac contraction with or without compensatory pause and/or sinus block with sporadic missed beats was seen immediately before the end of the exercise session (representing a decline in HR because the average values including prolonged beat-by-beat intervals following arrhythmia in a cycle of pedaling rotation, as indicated in Figure 6A- H). In the present case, the above-mentioned occasional arrhythmias appeared before the end of the exercise session, with leg fatigue suggested that 1LREx with multiple sessions was associated with the accumulation of cardiovascular stressors even in the absence of cardiac disease.

This may be caused by transient isometrical exercise-induced myocardial stress increasing mainly cardiac output, which in turn is due primarily to the increase in HR. This was particularly the case during strenuous static exercise sessions when intrathoracic pressure increase associated with the exercise effort, most likely with a Valsalva maneuver and/or exercise pressor response to central commands [42].

The slightly prolonged pushing pedaling time in DwS compared with pulling pedaling time in UpS immediately before the end of exercise may indicate transient strenuous isometric exercise likely with the initial action (onset) of the leg press, which potentially induced arrhythmia (Figure 1, 4 and 6). However, there is insufficient enough data in HD amputees to confirm single leg exercise-induced BP and HR responses in comparison with that in pre-HD individuals. In addition, the intensity of dynamic or static one-legged exercise should be further evaluated as regards cardiovascular responses with likely increases in BP with arrhythmia and/or latent myocardial/vascular disease.

Summary

The present single clinical case with a middle-aged HD amputee with good physical condition helped to examine how exercise trainability through short-term multiple 1LREx sessions induced alterations in PR and KROM during voluntary one-legged pedaling rotation over 6 days via the acquisition how to rotate the unilateral leg during cycling for motivation with dynamic exercise.

In the early/acute phase at day 15 post-HD amputation consecutive exercise therapy generated improved familiarity with pedaling and a potential improvement in performance/ability with 1LREx even with a physical state involving an unbalanced limb. Moreover, the present HD amputee readily accepted the purpose of exercise therapy using 1LREx and showed strong motivation to return to his occupation and social life using a new Canadian prosthesis. The motivation to return to social activity with improved remaining physical fitness may also influence exercise ability with short-term training. Finally, a finding from the present case may potentially include considerations to provide an exercise program with achievement of a sense of accomplishment in various activities through 1LREx.

Conflicts of Interest

The authors declare that there are no conflicts of interest associated with this work.

Acknowledgments

The first author acknowledges the long-term support of the late professor emeritus Bengt Saltin of The Denmark Copenhagen Muscle Research Centre as well as the late professor emeritus Hisao Iwane formerly of The Tokyo Medical College for contributions leading to environmental exercise physiology and rehabilitation. The present case was supported by a Scientific Research (C) general grant (No. 22K11431) from MEXT and JSPS (to T. Osada).

References

1. Sugarbaker PH, Chretien PB (1981) A surgical technique for hip disarticulation. Surgery 90: 546-553.
2. Moura DL, Garruço A (2017) Hip disarticulation-case series analysis and literature review. Revista Brasileira de Ortopedia 52: 154-158.
3. Dénes Z, Till A. (1997) Rehabilitation of patients after hip disarticulation. Archives of Orthopaedic and Trauma Surgery 116: 498-499.
4. Dillingham TR, Pezzin LE, MacKenzie EJ (2002) Limb amputation and limb deficiency: epidemiology and recent trends in the United States. Southern Medical Journal 95: 875-883.
5. Wakelin SJ, Oliver CW, Kaufman MH (2004) Hip disarticulation-the evolution of a surgical technique. Injury 35: 299-308.
6. Eijk MS, van der Linde H, Buijck BI, Zuidema SU, Koopmans RT (2012) Geriatric rehabilitation of lower limb amputees: a multicenter study. Disability and Rehabilitation 34: 145-150.
7. Yiğiter K, Şener G, Erbahçeci F, Bayar K, Ülger ÖG, et al. (2002) A comparison of traditional prosthetic training versus proprioceptive neuromuscular facilitation resistive gait training with trans-femoral amputees. Prosthetics and Orthotics International 26: 213-217.
8. Iwasa S, Uchiyama Y, Kodama N, Koyama T, Domen K (2021) Regaining gait using an early postoperative hip prosthesis: A case report of an elderly women. Progress in Rehabilitation Medicine 6: 20210011.
9. Yoshikawa K, Mutsuzaki H, Sano A, Kiguchi N, Shimizu Y, et al. (2019) A case of an elderly hip disarticulation amputee with rheumatoid arthritis who regained the ability to walk using a hip prosthesis. Journal of Physical Therapy Science 31: 366-370.
10. Ericson MO, Nisell R, Arborelius UP, Ekholm J (1985) Muscular activity during ergometer cycling. Scandinavian Journal of Rehabilitation Medicine 17: 53-61.
11. Chin T, Sawamura S, Fujita H, Nakajima S, Ojima I, et al. (1997) The efficacy of the one-leg cycling test for determining the anaerobic threshold (AT) of lower limb amputees. Prosthetics and Orthotics International 21:141-146.
12. Abbiss CR, Karagounis LG, Laursen PB, Peiffer JJ, Martin DT, et al. (2011) Single-leg cycle training is superior to double-leg cycling in improving the oxidative potential and metabolic profile of trained skeletal muscle. Journal of Applied Physiology 110: 1248-1255.
13. Wezenberg D, de Haan A, van der Woude LH, Houdijk H (2012) Feasibility and validity of a graded one-legged cycle exercise test to determine peak aerobic capacity in older people with a lower-limb amputation. Physical Therapy 92: 329-338.
14. Dolmage TE, Goldstein RS (2006) Response to one-legged cycling in patients with COPD. Chest 129: 325-332.
15. Osada T, Ishiyama M, Ueno R (2021) Variations in knee range of motion during repeat knee extension with an amputated lower leg at different contraction rhythms over 8 consecutive days in a patient with severe diabetic neuropathy: A clinical study. International Journal of Sports Medicine and Rehabilitation 4: 23.
16. Bell G, Neary P, Wenger HA (1988) The influence of one-legged training on cardiorespiratory fitness. Journal of Orthopaedic and Sports Physical Therapy 10: 1-11.
17. Mikami Y, Fukuhara K, Kawae T, Sakamitsu T, Kamijo Y, et al. (2018) Exercise loading for cardiopulmonary assessment and evaluation of endurance in amputee football players. Journal of Physical Therapy Science 30: 960-965.
18. Saitoh M, Matsunaga A, Kamiya K, Ogura MN, Sakamoto J, et al. (2005) Comparison of cardiovascular responses between upright and recumbent cycle ergometers in healthy young volunteers performing low-intensity exercise: assessment of reliability of the oxygen uptake calculated by using the ACSM metabolic equation. Archives of Physical Medicine and Rehabilitation 86: 1024-1029.
19. Burns KJ, Pollock BS, LaScola P, McDaniel J (2014) Cardiovascular responses to counterweighted single-leg cycling: implications for rehabilitation. European Journal of Applied Physiology 114: 961-968.
20. Katona P, Pilissy T, Tihanyi A, Laczko J (2014) The combined effect of cycling cadence and crank resistance on hamstrings and quadriceps muscle activities during cycling. Acta Physiologica Hungarica 101: 505-516.
21. Ericson MO, Bratt A, Nisell R, Arborelius UP, Ekholm J (1986) Power output and work in different muscle groups during ergometer cycling. European Journal of Applied Physiology and Occupational Physiology 55: 229-235.
22. Osada T, Ishiyama M, Ueno R (2018) Time-course of thigh muscle contraction-induced blood flow magnitude in amputated lower limb with prosthesis during dynamic knee

extensions: A case study. Physical Therapy and Rehabilitation 5: 21.

23. Osada T, Ishiyama M, Ueno R (2019) Voluntary thigh muscle strength with resection stump-dependent blood flow and vasodilation in an amputated lower leg with total surface bearing prosthesis during dynamic knee extensor: A case trial. Open Journal of Therapy and Rehabilitation 7: 151-169.
24. Kahle JT, Highsmith MJ, Schaepper H, Johannesson A, Orendurff MS, et al. (2016) Predicting walking ability following lower limb amputation: an updated systematic literature review. Technology and Innovation 18: 125-137.
25. Nowroozi F, Salvanelli ML, Gerber LH (1983) Energy expenditure in hip disarticulation and hemipelvectomy amputees. Archives of Physical Medicine and Rehabilitation 64: 300-303.
26. Shurr DG, Cook TM, Buckwalter JA, Cooper RR (1984) Hip disarticulation. a prosthetic follow-up. Orthot Prosthet 37: 50-57.
27. McAnelly RD, Refaeian M, O'Connell DG, Powell GD, Walsh NE (1998) Successful prosthetic fitting of a 73-year-old hip disarticulation amputee patient with cardiopulmonary disease. Archives of Physical Medicine and Rehabilitation 79: 585-588.
28. Chin T, Kuroda R, Akisue T, Iguchi T, Kurosaka M (2012) Energy consumption during prosthetic walking and physical fitness in older hip disarticulation amputees. Journal of Rehabilitation Research and Development 49: 1255-1260.
29. Zalavras CG, Rigopoulos N, Ahlmann E, Patzakis MJ (2009) Hip disarticulation for severe lower extremity infections. Clinical Orthopaedics and Related Research 467: 1721-1726.
30. Unruh T, Fisher DF Jr, Unruh TA, Gottschalk F, Fry RE, et al. (1990) Hip disarticulation. (1990) An 11-year experience. Archives of Surgery 125: 791-793.
31. Fernández A, Formigo J (2005) Are Canadian prostheses used? A long-term experience. Prosthetics and Orthotics International 29: 177-181.
32. Jain R, Grimer RJ, Carter SR, Tillman RM, Abudu AA (2005) Outcome after disarticulation of the hip for sarcomas. European Journal of Surgical Oncology 31: 1025-1028.
33. Hansen EA (2015) On voluntary rhythmic leg movement behaviour and control during pedalling. Acta Physiologica 214: 1-8.
34. Hansen EA (2012) Cyclists' improvement of pedaling efficacy and performance after heavy strength training. International Journal of Sports Physiology and Performance 7: 313-321.
35. Sardroodian M, Madeleine P, Voigt M, Hansen EA (2014) Frequency and pattern of voluntary pedalling is influenced after one week of heavy strength training. Human Movement Science 36: 58-69.
36. Hansen EA, Jørgensen LV, Jensen K, Fregly BJ, Sjøgaard G (2002) Crank inertial load affects freely chosen pedal rate during cycling. Journal of Biomechanics 35: 277-285.
37. Hakansson NA, Hull ML (2007) Influence of pedaling rate on muscle mechanical energy in low power recumbent pedaling using forward dynamic simulations. IEEE Transactions on Neural System and Rehabilitation Engineering 15: 509-516.
38. Neptune RR, Kautz SA, Hull ML (1997) The effect of pedaling rate on coordination in cycling. Journal of Biomechanics 30: 1051-1058.
39. So RCH, Ng JK-F, Ng GYF (2005) Muscle recruitment pattern in cycling: a review. Physical Therapy in Sport 6: 89-96.
40. Gondoh Y, Tashiro M, Itoh M, Masud MM, Sensui H, et al. (2009) Evaluation of individual skeletal muscle activity by glucose uptake during pedaling exercise at different workloads using positron emission tomography. Journal of Applied Physiology 107: 599-604.
41. Ercison MO, Nisell R, Nemeth G (1988) Joint motions of the lower limb during ergometer cycling. Journal of Orthopaedic and Sports Physical Therapy 9: 273-278.
42. Smith JJ, Kampine JP (1990) Circulatory Physiology the essentials Third Edition. Chapter 12 Physiology of exercise and the effect of aging. Williams & Wilkins. A Waverly Company. Baltimore, Maryland USA 223-251.