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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

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ABSTRACT

Background: This clinical study sought to understand the knee range of motion (KROM) in an amputated stump during repeat voluntary knee extension with or without a 0.5 kg weight in the acute/early phase after amputation can vary between different target knee extension rhythm frequency (KER) levels in the amputated lower leg of a patient with severe diabetic sensory disorder and leg ischemia.

Case Presentation: A 51-year-old male patient with severe diabetic neuropathy had a right lower leg amputation due to necrosis and ulcer lesion following a burn injury to the first toes and severe ischemic peripheral vascular disease. In a sitting position with the base of the foot of the non-amputated left leg on the ground, he performed repeat knee extension of the resected stump (knee active extension and passive flexion without a target KROM) for 1 min with both self-controlled free KER and different target KERs (30, 40, 50, 60, and 80 contractions per minute [cpm] using a metronome), with or without a 0.5 kg weight placed on the resected stump over 8 consecutive days. The KROM was measured using a goniometer placed between the resected stump and the thigh muscle with a continuous data acquisition system. The mean values achieved for KER, KROM, and angle rate during a 1 min session was determined during each daily session, and consecutively average values over sessions on 8 consecutive days was also evaluated. The achieved mean KER

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at all target KERs corresponded closely with the target KER. The average KROM was approximately 60 degrees over a range of targets between 30 and 60 cpm, but the value was lower at approximately 50 degrees at 80 cpm. The angle rate increased consistently with the increase from a target of 30 to 60 cpm, but it was reduced at 80 cpm. The mean KROM was inversely related ($r=-0.390$, $P<0.01$, $n=40$) to the mean KER without the weight, but not significantly ($r=-0.256$, P=ns, $n=40$) with the 0.5 kg weight. The achieved KER in the self-controlled free trial with or without the 0.5 kg weight might increase with an increase in sessions over 8 days with a range between approximately 30 and 60 cpm.

Conclusion: The present case study showed that a higher contraction frequency may limit KROM determined below 60 cpm because of the reduced angle rate in an amputated lower leg. A low and moderate KER below 60 cpm may be appropriate to maintain KROM with a stable angle rate. Furthermore, voluntary KER with free self-controlled rhythm may increase over the course of multiple sessions as familiarity improves with kicking the amputated limb and generating a potential improvement in performance/ability effect with consecutive leg exercise with no use of a prothesis such as in the early/acute phase post-amputation using audible biofeedback.

Keywords: Knee extension rhythm (frequency), below knee amputation, knee joint range of motion, diabetic sensory disorder

Introduction

Recently, an increase in the number of the patients with amputated limbs may potentially be associated with severe diabetic mellitus with lower exercise tolerance and/or inactivity [1-3]; therefore, adaptation for self-exercise performance for them should be encouraged to increase daily physical activity after amputation [4]. In addition, severe diabetic dysesthesia and/or coexisting severe limb ischemia with potential necrosis in the legs may limit the continuous repeat muscle contractions typically required for uniform repetitive leg exercise against an increase in resistance due to a reduction in endurance and/or proprioception.

In physical therapy, below-knee amputees are recommended to maintain the knee and hip angle motion for the prevention of joint contraction to support activities of daily living as well as the usage of a prothesis [5]. Thus, for patients with lower leg amputation, repeated leg motion such as passive and/or active knee/hip extension-flexion with shrinkage of the stump is an important form of exercise therapy for standing and walking ability in the acute and early phase in rehabilitation [6,7].

There is, however, only limited information regarding the optimal muscle contraction intensity, frequency, and/or duration for thigh stump exercise as knee extension-flexion exercise after lower leg amputation, even though it may be influenced by the weakness of the resected stump muscle, including thigh strength and/or reduced basal physical activity, associated with potential disorders due to comorbidities in older age groups [8,9].

Therefore, clinical studies to better to understand how the knee range of motion (KROM) in an amputated lower leg can be altered through voluntary knee extension exercise at different knee extension rhythm frequency (KER) levels with no target KROM. Furthermore, the unilateral knee extension model in amputated lower legs may be biomechanically different compared with non-amputated healthy legs [10]. Consequently, the lack of the lower leg may be kinematically supposed to influence kicking performance due to the shorter length (so called resistance/lever arm) of the remaining lower leg between the knee joint (fulcrum point) and the end of resection-stump gravity/weight (load point) in a third-class lever. The issue in the present amputee was the potentially reduced ability for repetitive muscle contractions due to severe diabetic sensory disorder and leg ischemia may increase with a time-course of variations in voluntary KROM, and its relationship to KER may differ at a range of target KER levels.

Thus, the present case was a preliminary clinical study of a below-knee amputee with severe diabetic neuropathy in an attempt to measure the KROM at different target KER levels with and without a weight load using a metronome for auditory biofeedback.

Case presentation

A male (age: 51 years and 3 months, height: 170.0 cm, weight: 74.3 kg) with trans-tibial amputation of the right lower leg due to toe necrosis caused by burns resulting in pain and numbness in the foot. The patient also exhibited severe diabetic neuropathy (diabetes mellitus diagnosed at age 43 years) after self-interruption of insulin treatment, and an old cerebrovascular infarction without motor paralysis (diagnosis at age 49 years) participated in the present trial. He also had an old myocardial infarction (onset time unknown) with potential ischemia due to heart failure (peak brain natriuretic peptide value, 1348 pg/ml) and low cardiac ejection fraction (30%) with anterior wall hypokinesia as well as severe aortic stenosis associated with a long-term heavy smoking history for 29 years. The day before amputation, angiography detected an ischemic region in the highly calcified coronary artery (left anterior descending artery; 90-99% stenosis) and in the right coronary artery (complete obstruction) in the heart. At the same time obstructions were found in the left common iliac artery (complete obstruction), right anterior-posterior tibial artery (complete obstruction), and right peroneal artery (99% stenosis) in the legs caused by severe peripheral arterial disease with a low ankle-brachial index of 0.76 in the right leg and unmeasurable due to a region in the common iliac artery in the left leg that exhibited critical limb ischemia. Moreover, the ultrasonography found a filled thrombosis in the left posterior tibial, peroneal, and soleal veins. Below-knee amputation of the right lower leg was performed due to critical ischemia below the knee. The day after amputation, a percutaneous cardiac intervention was performed for the region in the left anterior descending coronary artery. There was no phantom limb or pain with shaping of the stump by soft dressing/bandaging post-amputation; however, hypoesthesia due to diabetic sensory disorder was seen in the resection stump.

The length of the resected stump was 19.0 cm from the knee joint space to the stump-end with a 38.0 cm maximum circumference. The circumference of the thigh was 46.3 cm at maximum, 40.2 cm at 10 cm above the patella, and 38.0 cm at 5 cm above the patella in the non-amputated leg, and 42.1 cm at maximum, 38.5 cm at 10 cm above the patella, and 37.5 cm at 5 cm above the patella in the amputated leg. The length between the greater trochanter and the knee joint space was 41 cm in both legs. The lower leg length was 36.5 cm in the non-amputated leg.

The present intervention involved repeat voluntary knee extension exercise from day 13 post-amputation as an early rehabilitation program (corresponding to *Day 1* for intervention), and then day 14 (*Day 2*), day 16 (*Day 3*), day 17 (*Day 4*), day 20 (*Day 5*), day 21 (*Day 6*), day 24 (*Day 7*), and day 25 (*Day 8*). In addition, endovascular treatment was performed in the left common iliac artery (completely obstruction) for improvements of critical limb ischemia at day 15 post amputation.

The present clinical study 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 (approval No. 2016-080). The participant gave written consent and was informed for the nature and purpose of the study and for further publication, as well as potential risks and discomfort. The participant was informed that withdrawal from the study was possible at any time without consequences.

Exercise model and protocol

The patient performed voluntary dynamic/repeat knee extension exercise of the amputated leg in a sitting position [11,12]. The patient performed the exercise with his hips at a 100 degree angle, thigh positioned horizontally with the knee joint bent, and resected stump drooped (Figure 1) [11,12].

In a sitting position with the base of the foot on the ground for the non-amputated left leg, he performed repeated knee extension of the resected stump (knee active extension and passive flexion) for 1 min both with a self-controlled free rhythm and target KER levels (30, 40, 50, 60, and 80 contraction per minute [cpm]) using the pace of an audible metronome (Quartz Metronome SQ 70, SEIKO, Tokyo Japan), with or without 0.5 kg weight placed on the resected stump over 8 consecutive days. The target value for KROM was not provided during knee extension exercise; therefore, the KROM achieved depended on the self-controlled performance with less effort for all the interventions. Before the study, it was tested how much weight may be suitable for 1 min of knee extension exercise. The overload that presents with which patient was able to stably continue 1 min of knee extension exercise was around 0.5 kg in weight.

The initial intervention was set as a self-controlled free rhythm; however, intervention with 5 levels of target KER was randomly performed over 8 consecutive days. The recovery time was sufficient for the basal condition at each intervention.

Knee range of motion, knee extension rhythm, and angle rate

The KROM signal wave was monitored continuously using a goniometer (FA-DL-262 S&ME. Inc. Japan) placed between the resected stump and the thigh muscle and recorded on a PowerLab data acquisition system (Chart v.4.2.3 software; AD Instruments, Sydney, Australia) [11,12]. The KROM was evaluated precisely as the angle between the peak extension point of the resected stump and the knee flexed position using the profile in the signal wave. The rate of angle change was also calculated using the KROM divided by the time interval between the peak extension point of the resected stump and peak knee flexed position using degrees/sec. The KER (frequency) was determined using the cycle of knee active extension and passive flexion, which was estimated using the time interval between the peak knee flexed position and next one.

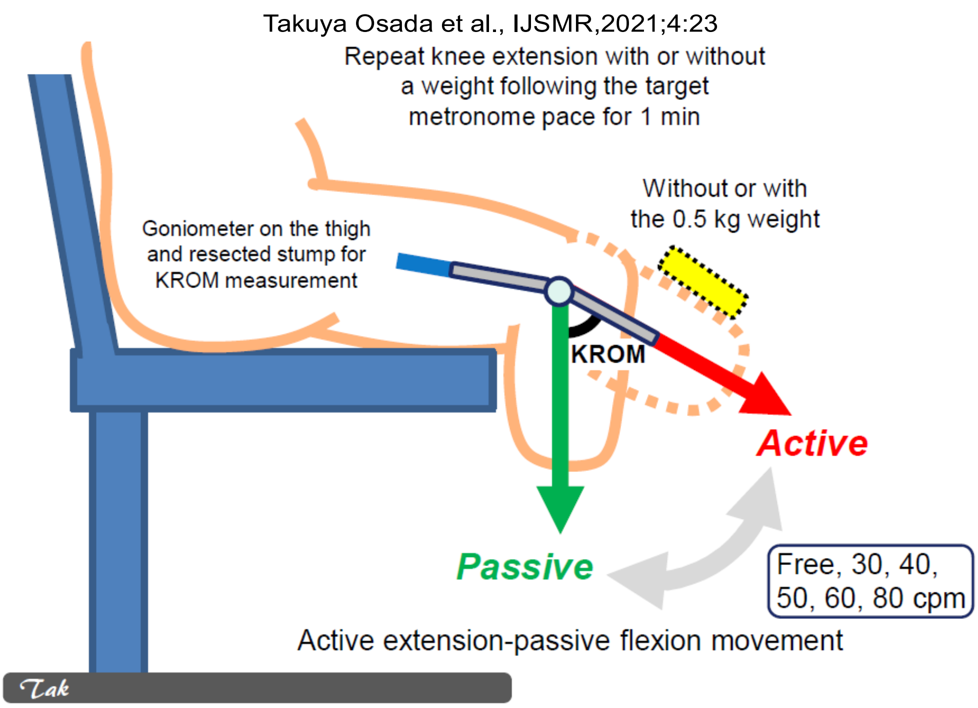

Figure 1. Repeat dynamic knee extension of the right amputated lower leg

In a sitting position, repeated thigh exercise of the resected stump after right lower leg amputation was performed as voluntary muscle contraction (active knee extension phase) and paused muscle relaxation (passive knee flexion phase) for 1 min at a self-controlled free rhythm and with a target contraction frequency (30, 40, 50, 60, and 80 contractions per minute [cpm]). The knee extension contraction rhythm was maintained using the pace of an audible metronome set at the target rhythm except for the self-controlled free session. There were a couple of intensities with or without 0.5 kg weight placed in the upper side of the resected stump. The right knee range of motion (KROM) of the amputated leg was monitored using a goniometer attached laterally on the thigh and laterally on the resected stump. The goniometer was connected to a data acquisition system for determination of the precise KROM as well as the knee extension frequency. The sole of the left foot was placed flat on the ground (omitted from the figure).

Data collection and evaluation

We collected data for each knee active extension-passive flexion rhythm for the determination of each time interval (60/time interval, cpm), KROM, and angle rate for each 1 min session. Additionally, the mean value and standard deviation in KER, KROM, and angle rate were also evaluated for each whole 1 min session. The average values of KER (frequency), KROM, and angle rate was expressed as the mean value for the sessions over 8 consecutive days. Coefficients of variation for KER and KROM were defined as the standard deviation/mean × 100%. The variations above mentioned were evaluated as i) variability during each 1 min session and ii) day-to-day variability for sessions over 8 consecutive days.

Statistical comparisons with a linear fitting regression correlation coefficient (r), and P-value were conducted between the KER levels, and mean KROM was examined with or without the self-controlled free rate (Microsoft 365 Excel). Moreover, the correlation between KER and angle rate was also evaluated between 30 and 60 cpm without 80 cpm. A P-value < 0.05 was considered significant.

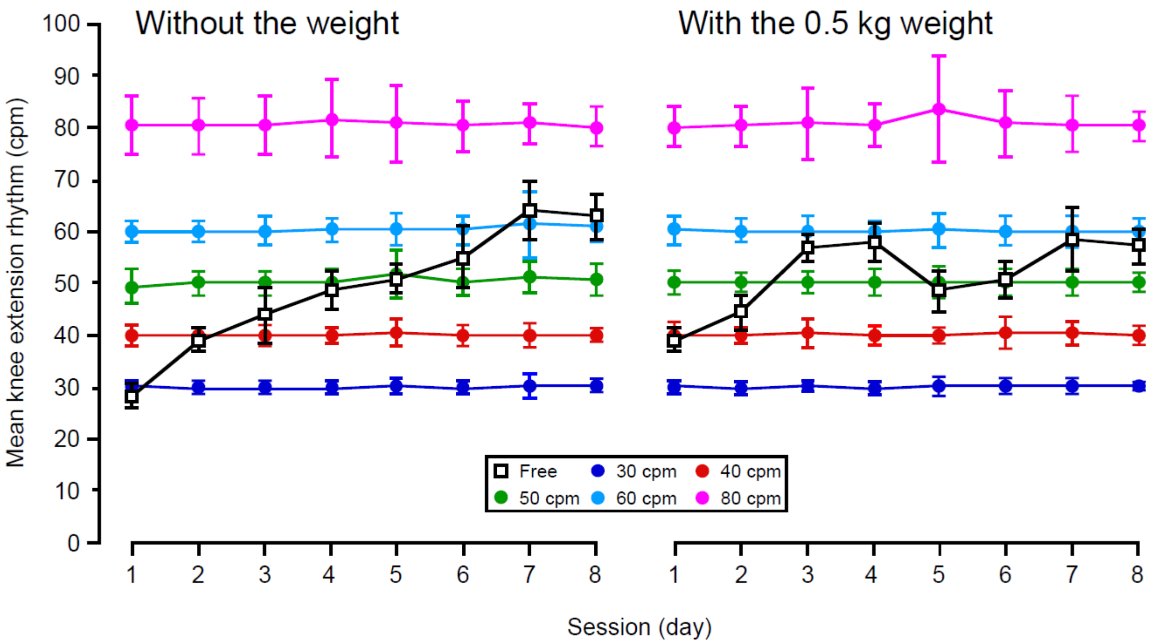

Figure 2. Variations in knee extension rhythm over sessions on 8 consecutive days

The voluntary achieved knee extension rhythm was corresponded well with target contraction frequencies at 30, 40, 50, 60, and 80 contractions per minute (cpm), respectively over sessions on 8 consecutive days, which was validated with data from the performance in the present patient. The variations in knee extension rhythm for 1 min was larger with the high (80 cpm) rather than the low contraction frequency (30 cpm) because the difference in standard deviations. The knee extension rhythm (frequency) may tend to increase with more sessions of exercise intervention, as seen with an increase at approximately 30 cpm without the weight and at approximately 20 cpm with the 0.5 kg weight by the 8th day compared with the 1st day. The day 1 session was equal to day 13 in post-amputation with the rehabilitation program in the early phase. The data are expressed as mean ± standard deviations.

Results

The achieved voluntary KER was almost equal to the target contraction frequency both without a weight and with the 0.5 kg weight; however, that in the self-controlled free performance may improve over time within a range of approximately 30 to 60 cpm (Figure 2). There were large in coefficients of variation in the self-controlled free sessions with (6.9%) or without a weight (8.3%) compared with another session with a similar extension rhythm (frequency) and 80 cpm, which may indicate a large number of fluctuations (Table 1). Figure 3 shows the variations in KROM for the self-controlled free and target KER for sessions over 8 consecutive days. Day-to-day variability over 8 consecutive days was relatively low at 50 and 60 cpm without the weight (below 14%) and with the 0.5 kg weight (below 20%), but higher at 30, 40, and 80 cpm without the weight (above 18%) and with the 0.5 kg weight (above 24%) (Table 2). There was a close relationship ($r=-0.390$, $P<0.01$ without self-controlled free, $r=-0.343$, $P<0.05$ with self-controlled free) between mean KER and mean KROM without the weight, but not significantly with the 0.5 kg weight (Figure 4A). Average KROM during sessions over 8 consecutive days may be lower at 80 cpm than at 30-60 cpm with or without the weight (Figure 4B and Figure 5A). There was a strong relationship (r=1.0) between the KER and angle rate in the range 30-60 cpm without 80 cpm without the weight and with the 0.5 kg weight (Figure 5B).

Table 1. Variations in the knee extension rhythm. The data are expressed as mean ± standard deviation (coefficients of variation, CV) over 8 consecutive days. The mean knee extension rhythm over 8 days is represented as “8 days Ave”. The day-to-day variability (DDV) was defined as the variability in mean KER level evaluated per day over 8 days. The average CV over 8 days is represented as “8 days Ave CV”.

Session	Achieved knee extension rhythm without the weight, cpm						Achieved knee extension rhythm with the 0.5 kg weight, cpm					
Day	Free	Target contraction frequency					Free	Target contraction frequency				
		30	40	50	60	80		30	40	50	60	80
1	28.3 ± 2.3 (8.0)	30.1 ± 1.4 (4.6)	40.1 ± 1.8 (4.4)	49.4 ± 3.3 (6.6)	60.1 ± 2.0 (3.3)	80.5 ± 5.7 (7.1)	39.1 ± 2.3 (5.8)	30.1 ± 1.2 (4.0)	40.1 ± 2.3 (5.6)	50.1 ± 2.3 (4.6)	60.3 ± 2.9 (4.9)	80.1 ± 3.8 (4.8)
2	39.2 ± 2.3 (6.0)	30.0 ± 1.1 (3.8)	40.1 ± 1.5 (3.8)	50.2 ± 2.3 (4.6)	60.0 ± 2.1 (3.5)	80.3 ± 5.2 (6.5)	44.4 ± 3.2 (7.1)	29.9 ± 1.2 (3.9)	40.0 ± 1.6 (4.0)	50.2 ± 1.8 (3.5)	60.1 ± 2.3 (3.8)	80.4 ± 3.9 (4.9)
3	43.9 ± 5.5 (12.6)	30.0 ± 1.3 (4.2)	40.2 ± 2.0 (4.9)	50.1 ± 2.4 (4.8)	60.2 ± 2.9 (4.9)	80.7 ± 5.6 (7.0)	57.0± 2.6 (4.6)	30.1 ± 1.1 (3.7)	40.3 ± 2.9 (7.2)	50.2 ± 2.2 (4.4)	60.1 ± 2.8 (4.6)	80.8 ± 6.7 (8.3)
4	48.7 ± 3.5 (7.1)	30.0 ± 1.3 (4.5)	40.0 ± 1.6 (4.1)	50.2 ± 2.5 (5.0)	60.3 ± 2.3 (3.8)	81.7 ± 7.5 (9.2)	57.9 ± 3.7 (6.4)	30.0 ± 1.2 (4.0)	40.2 ± 1.9 (4.6)	50.2 ± 2.4 (4.8)	60.1 ± 1.9 (3.2)	80.4 ± 4.2 (5.2)
5	51.0 ± 3.0 (5.9)	30.2 ± 1.6 (5.3)	40.4 ± 2.6 (6.5)	51.8 ± 4.7 (9.0)	60.3 ± 3.1 (5.1)	80.9 ± 7.4 (9.1)	48.5 ± 3.7 (7.6)	30.1 ± 1.7 (5.7)	40.1 ± 1.4 (3.6)	50.3 ± 3.2 (6.3)	60.3 ± 3.4 (5.6)	83.4 ± 10.3 (12.4)
6	55.1 ± 6.0 (11.0)	30.0 ± 1.3 (4.4)	40.2 ± 2.0 (5.1)	50.2 ± 2.4 (4.8)	60.3 ± 3.0 (5.0)	80.3 ± 4.9 (6.1)	50.8 ± 3.6 (7.1)	30.2 ± 1.4 (4.5)	40.5 ± 2.9 (7.2)	50.2 ± 2.6 (5.3)	60.2 ± 2.9 (4.8)	80.8 ± 6.5 (8.0)
7	64.1 ± 5.7 (8.8)	30.5 ± 2.5 (8.3)	40.2 ± 2.3 (5.7)	51.2 ± 3.1 (6.0)	61.4± 6.4 (10.4)	80.8 ± 4.0 (4.9)	58.5 ± 6.1 (10.4)	30.3 ± 1.4 (4.7)	40.3 ± 2.1 (5.3)	50.3 ± 2.7 (5.3)	60.1 ± 3.0 (4.9)	80.6 ± 5.3 (6.5)
8	62.9 ± 4.5 (7.2)	30.3 ± 1.3 (4.1)	40.2 ± 1.2 (2.9)	50.8 ± 2.9 (5.6)	60.8 ± 3.0 (4.9)	80.1 ± 3.9 (4.9)	57.3 ± 3.4 (6.0)	30.2 ± 0.8 (2.7)	40.2 ± 1.8 (4.5)	50.2 ± 1.8 (3.6)	60.2 ± 2.2 (3.6)	80.4 ± 2.8 (3.4)
8 days Ave (DDV, %)	49.1 ± 12.0 (24.4)	30.2 ± 0.2 (0.7)	40.2 ± 0.1 (0.2)	50.5 ± 0.8 (1.6)	60.4 ± 0.4 (0.7)	80.7 ± 0.5 (0.6)	51.7 ± 7.2 (13.9)	30.1 ± 0.1 (0.3)	40.2 ± 0.1 (0.2)	50.2 ± 0.1 (0.2)	60.2 ± 0.1 (0.0)	80.9 ± 1.0 (1.2)
8 days Ave CV, %	8.3 ± 2.4	4.9 ± 1.4	4.7 ± 1.1	5.8 ± 1.5	5.1 ± 2.3	6.9 ± 1.6	6.9 ± 1.7	4.2 ± 0.9	5.2 ± 1.4	4.7 ± 0.9	4.4 ± 0.8	6.7 ± 2.8

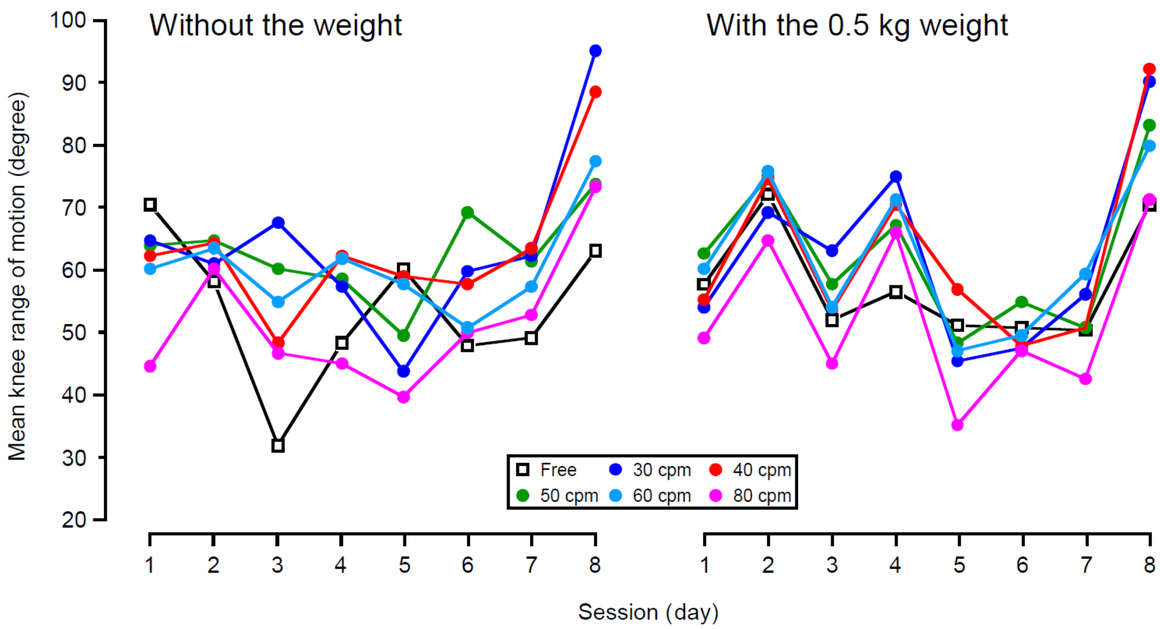

Figure 3. Variations in mean knee range of motion at 8 days secession

The day-to-day variability in knee range of motion (KROM; large fluctuations in KROM) might be relatively high with the 0.5 kg weight compared with without the weight (see also Table 2). However, the difference in KROM between the target contraction frequencies at each session was smaller with the 0.5 kg weight compared with without the weight. The KROM was increased rapidly both without the weight and with the 0.5 kg weight by the last session. The mean KROM was defined as the mean value from samplings for 1 min. The standard deviation for KROM over the 1 min session was omitted.

Discussion

This clinical study may provide insights for optimal repeat leg exercise in patients with an amputated lower leg (below knee amputation) with diabetes mellitus and/or cardiovascular disease in the acute phase of their rehabilitation program post-amputation. This work continues the findings of our previous case, which involved determination of the physiological and kinesiological features for exercising a thigh-resection stump after lower leg amputation using a dynamic knee extension model [13-20].

In the early/acute phase post-amputation, it is necessary to estimate the initial motor function such as muscle strength, joint movement, one-legged standing motion, etc., for further rehabilitation pre/post-amputation [8,9]. It was clearly established that guidelines for physiotherapy including walking ability using a prosthesis, stretching pre/post-amputation were required for amputees [21]; however, the optimal exercise frequency was not fully discussed.

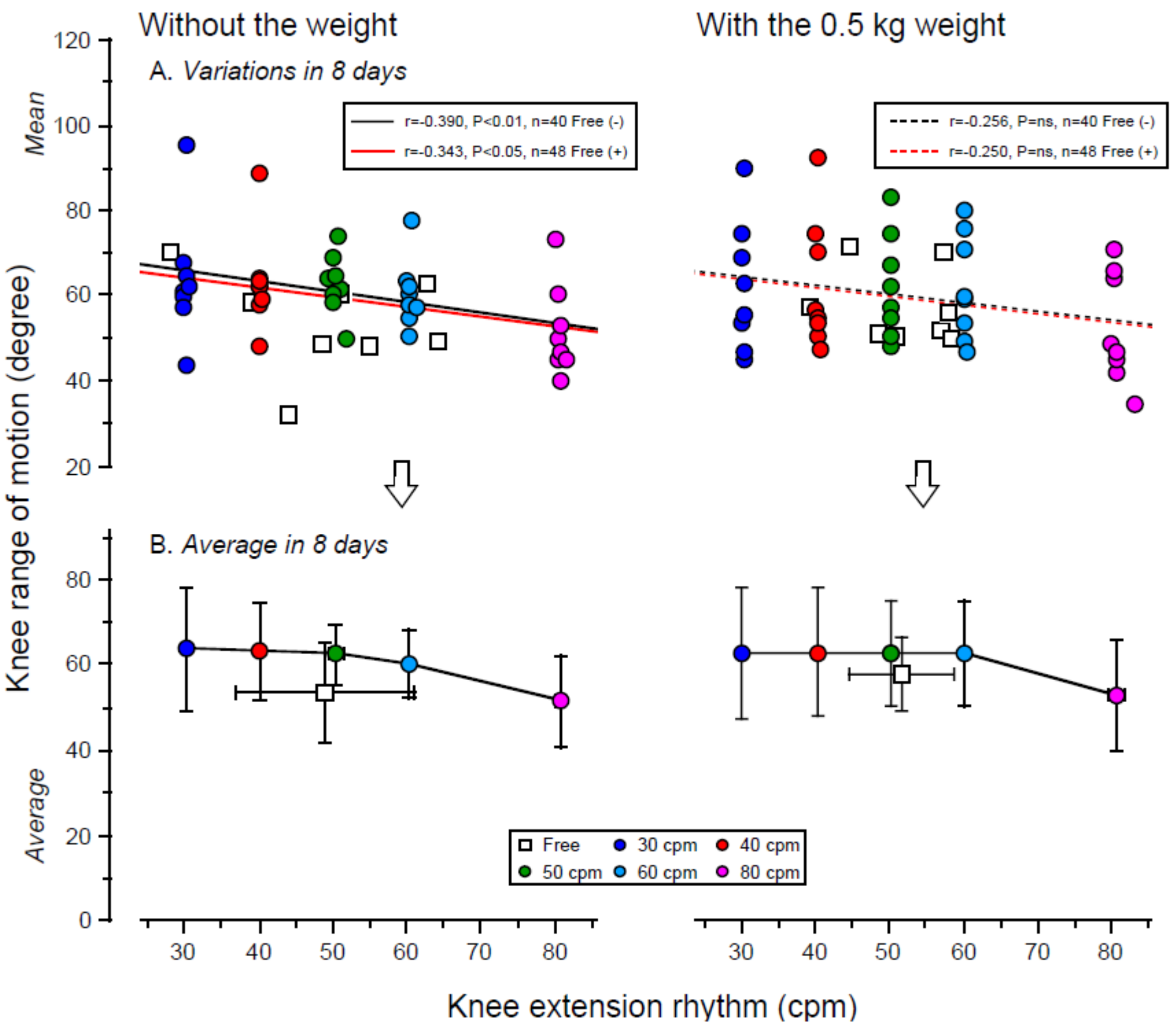

Figure 4. Relationship between KER and KROM in over sessions on 8 consecutive days

A: The variations in knee range of motion (KROM) with all interventions over sessions on 8 consecutive days. The KROM was significant inversely related to the knee extension rhythm (KER) without the weight, but not significance with the 0.5 kg weight. Without the weight, a statistically significant relationship was high with all target KER interventions with and without self-controlled free intervention (P<0.05, r=-0.343, n=48 vs. P<0.01, r=-0.390, n=40). In 0.5 kg-weight, there was no linear relationship between the KROM and KER (P=ns: r=-0.250, n=48 and r=-0.256, n=40). The data represented as mean value from a 1 min session. B: Average data for KROM over sessions on 8 consecutive days for each intervention. With the 0.5 kg weight, the rate of reduction in KROM was clearly higher at 80 cpm compared with other target contraction levels, with speculation on the absence of a linear correlation between KROM and KER. The data was expressed as mean ± standard deviation.

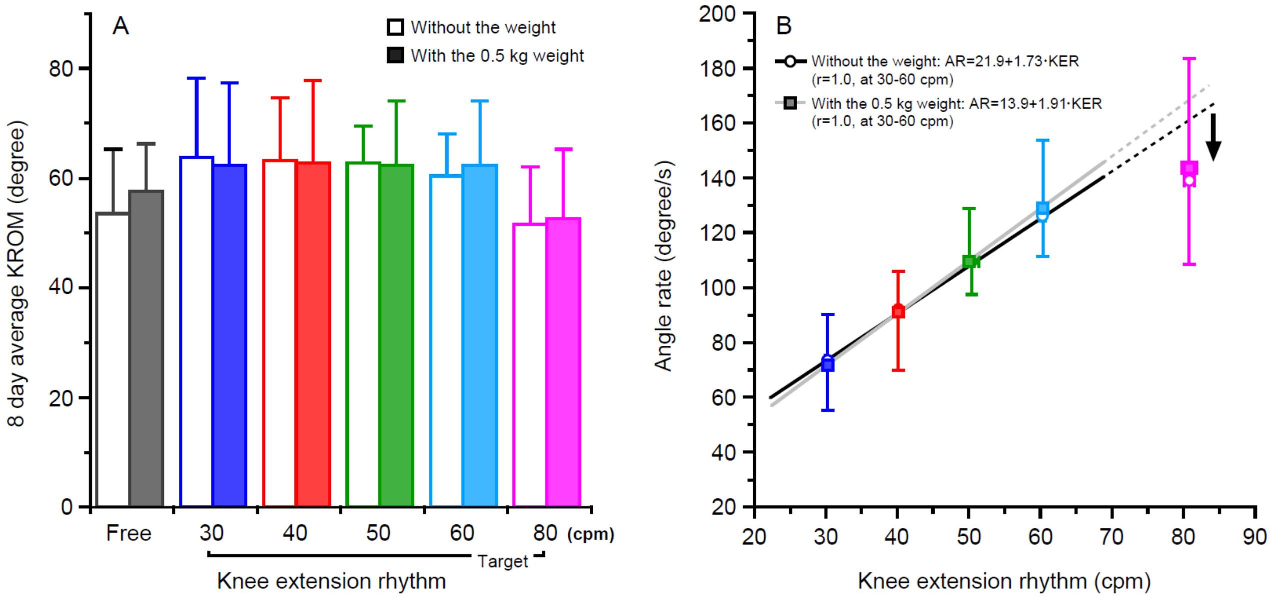

Figure 5. The knee range of motion (A) and angle rate (B) for the knee extension rhythm

A: The comparison in average knee range of motion (KROM) over sessions on 8 consecutive days between without and with a 0.5 kg weight. The KROM may be similar between without the weight and with the 0.5 kg weight except for the self-controlled free intervention. The KROM was clearly lower at 80 cpm compared with other target intervention levels. B: Relationship between knee extension rhythm (KER) and angle rate. There is strong positive linear relationship (r=1.0, n=4 except for the 80 cpm intervention) KER from 30 cpm to 60 cpm and angle rate both without the weight (black line) and with the 0.5 kg weight (gray line). Achieved angle rate at 80 cpm may be reduced (↓) from the point (dotted line) of the ideal angle rate for obtaining a range of KROM at 30-60 cpm, due to difficulty in the rapid repetition of voluntary knee extension.

Table 2. Variations in the knee range of motion. The data are expressed as mean ± standard deviation (coefficients of variation, CV) over 8 consecutive days. The mean knee range of motion (KROM) over 8 days is represented as "8 days Ave". The day-to-day variability (DDV) was defined as the variability in mean KROM evaluated per day over 8 days. The average CV over 8 days is represented as "8 days Ave CV".

Session	Knee range of motion without the weight, degree						Knee range of motion with the 0.5 kg weight, degree					
Day	Free	Target contraction frequency					Free	Target contraction frequency				
		30	40	50	60	80		30	40	50	60	80
1	70.3 ± 4.5 (6.4)	64.6 ± 2.3 (3.5)	62.1 ± 2.7 (4.4)	64.0 ± 5.3 (8.3)	60.1 ± 3.0 (4.9)	44.7 ± 6.2 (14.0)	57.8 ± 3.0 (5.1)	53.9 ± 1.9 (3.6)	55.1 ± 2.7 (4.9)	62.5 ± 2.8 (4.5)	60.1 ± 3.6 (6.0)	49.2 ± 4.0 (8.1)
2	58.2 ± 5.6 (9.7)	61.1 ± 3.9 (6.4)	64.3 ± 3.4 (5.3)	64.7 ± 4.3 (6.7)	63.4 ± 3.4 (5.4)	60.1 ± 6.2 (10.2)	71.9 ± 3.2 (4.5)	69.1 ± 3.0 (4.3)	74.6 ± 3.6 (4.9)	75.0 ± 4.1 (5.5)	76.0 ± 4.1 (5.4)	64.6 ± 5.3 (8.2)
3	32.0 ± 6.6 (20.6)	67.5 ± 5.5 (8.2)	48.2 ± 6.8 (14.1)	60.0 ± 4.4 (7.4)	54.9 ± 8.2 (15.0)	46.5 ± 7.5 (16.1)	52.0 ± 5.1 (9.8)	62.9 ± 5.7 (9.0)	53.6 ± 9.7 (18.0)	57.7 ± 5.5 (9.6)	54.2 ± 5.2 (9.6)	45.0 ± 6.4 (14.1)
4	48.5 ± 5.7 (11.7)	57.5 ± 9.8 (17.1)	62.3 ± 8.3 (13.3)	58.5 ± 6.4 (10.9)	62.0 ± 5.1 (8.2)	45.0 ± 7.6 (17.0)	56.4 ± 6.1 (10.8)	75.0 ± 4.8 (6.4)	70.5 ± 3.9 (5.5)	67.2 ± 5.5 (8.1)	71.1 ± 4.1 (5.7)	65.9 ± 5.1 (7.8)
5	60.1 ± 3.7 (6.1)	43.6 ± 5.8 (13.3)	59.0 ± 6.2 (10.5)	49.7 ± 6.4 (12.8)	57.8 ± 6.3 (10.8)	39.8 ± 5.8 (14.5)	51.2 ± 3.2 (6.2)	45.4 ± 7.9 (17.3)	56.8 ± 6.8 (11.9)	48.4 ± 5.3 (11.0)	46.9 ± 4.9 (10.5)	35.2 ± 7.0 (20.0)
6	48.0 ± 10.4 (21.7)	59.8 ± 6.5 (10.9)	57.6 ± 8.0 (13.9)	69.1 ± 5.8 (8.4)	50.7 ± 5.9 (11.7)	50.0 ± 5.9 (11.9)	50.6 ± 4.5 (9.0)	47.4 ± 9.3 (19.5)	47.8 ± 11.7 (24.5)	55.0 ± 4.2 (7.7)	49.5 ± 4.5 (9.0)	46.9 ± 5.9 (12.5)
7	49.0 ± 6.0 (12.4)	62.3 ± 11.4 (18.3)	63.6 ± 7.8 (12.2)	61.3 ± 5.5 (8.9)	57.5 ± 7.2 (12.5)	52.7 ± 6.4 (12.2)	50.2 ± 12.0 (23.8)	56.0 ± 5.5 (9.8)	50.6 ± 6.3 (12.5)	50.9 ± 7.2 (14.1)	59.5 ± 4.6 (7.8)	42.4 ± 6.4 (15.2)
8	63.0 ± 5.8 (9.1)	95.2 ± 2.4 (2.5)	88.5 ± 4.0 (4.5)	73.7 ± 4.8 (6.5)	77.4 ± 5.7 (7.4)	73.2 ± 4.5 (6.1)	70.3 ± 5.2 (7.3)	90.2 ± 3.3 (3.7)	92.2 ± 3.8 (4.2)	83.0 ± 2.9 (3.5)	79.9 ± 5.0 (6.3)	71.3 ± 3.2 (4.5)
8 days Ave (DDV, %)	53.6 ± 11.8 (22.0)	63.9 ± 14.5 (22.7)	63.2 ± 11.4 (18.0)	62.6 ± 7.2 (11.5)	60.5± 7.9 (13.1)	51.5 ± 10.7 (20.8)	57.6 ± 8.8 (15.3)	62.5 ± 15.1 (24.2)	62.7 ± 15.2 (24.2)	62.5 ± 12.0 (19.2)	62.2 ± 12.3 (19.8)	52.5 ± 13.0 (24.8)
8 days Ave CV, %	12.2 ± 6.0	10.0 ± 5.9	9.8 ± 4.3	8.7 ± 2.2	9.5 ± 3.6	12.8 ± 3.5	9.6 ± 6.2	9.2 ± 6.2	10.8 ± 7.4	8.0 ± 3.5	7.6 ± 2.0	11.3 ± 5.1

Recently, there has been an increase in patients with amputated limbs with severe diabetic mellitus and coexisting severe vascular disease who may have lower exercise tolerance and/or inactivity (reduced physical activity and fitness); therefore, adaptation of self-exercise performance should be encouraged for daily physical active in the early/acute phase post-amputation [22]. It was reported previously for amputees (40-80 years old) with a lower leg amputation due to vascular or traumatic disease may experience light-touch and vibration sensations [23]. In addition, limitation in the joint range of motion was clearly found in an amputee with diabetes mellitus [24].

Therefore, the issue in the present amputee with severe diabetic sensory disorder can provide insights on the time-course (day-to-day) of variations in KROM and its relationship to KER might be altered at different target KER levels with/without a weight using audiometry biofeedback. Moreover, knee extension exercise with a self-controlled free rhythm was also examined without audiometry biofeedback

Variations in both KER and KROM in a day or day-to-day with/without weight

In first, any limitation in exercise including the uniformity of rhythmic movement of a resected stump may potentially be supposed in the present amputee with diabetic neuropathy and coexisting severe leg ischemia due to the reduced exercise performance and sensory disorder. However, the achieved voluntary KER was almost equal to the target contraction frequency, which supported exercise being precisely performed using audiometric metronome (pace) biofeedback even if the sensory disorder was present in the resected stump (Figure 2).

Overview in the knee extension rhythm at 80 cpm, which was the higher target KER, indicated that the achieved mean KER with a range 80.1 to 81.7 cpm without the weight, and with a range of 80.1 to 83.4 cpm with the 0.5 kg weight, which was an acceptable range for precise repeat leg exercise. However, the slightly larger value of coefficients of variation (6.9% without the weight and 6.7% with the 0.5 kg weight) at 80 cpm compared with other target interventions (below 5.8% without the weight and below 5.2% with the 0.5 kg weight) indicated the fluctuation in time for the knee extension cycle due to high kicking frequency (Table 1 and Figure 2). Notably, the self-controlled free knee extension induced an increase in KER over sessions with or without the weight although the KER altered over a range of approximately 30-60 cpm without a weight, and a range of approximately 40-60 cpm with the 0.5 kg weight, but not with a higher contraction rhythm above 70 cpm. It was suggested that performing knee extension comfortably and stably at a higher contraction frequency may be biomechanically limited by the amputated leg with no limitation for the target KROM. Moreover, there were wide ranges in the coefficients of variation (8.3% without a weight and 6.9% with the 0.5 kg weight) in self-controlled free extension with or without the weight compared with another session with a similar KER (Table 1 and Figure 2), which may indicate a larger number of fluctuations in the time interval of a cycle of knee extension. The present data may be useful for physical therapy post-amputation in determining the most effective target muscle contraction rhythm, strength, and time duration for exercise prescription and/or procedures for individual patients.

Figure 3 shows the day-to-day variability in achieved KROM over sessions on 8 consecutive days. It seemed that fluctuations in KROM at target KER levels among 8 consecutive days was higher with the 0.5 kg weight (19.2-24.8%) versus without the weight (11.5-22.7%) (Table 2). However, better uniformity in KROM between different target KER levels may be observed with the 0.5 kg weight rather than that without the weight (Figure 3). There are few previous reports regarding the features of resected stumps and the thigh related to KROM versus KER.

The acknowledgement of day-to-day variability in KROM in an amputated lower leg may be useful information for the training prescription for physical therapy and/or for sampling in kinematics research.

Relationship between KROM and KER over different target contraction frequencies

The angle rate must theoretically be elevated to maintain the KROM during knee extension when the target KER level increases. A knee extension model most likely involving the action of a third-class lever has an advantage for dynamic leg movement with rapid muscle contraction velocity; however, there is a disadvantage that the model might require the muscle power strength [25]. This can produce a large range of movement with relatively low effort.

In an amputated lower leg, the distance of the resistance arm (lever arm) between the fulcrum point (knee joint) and load point (resected stump weight) was shorter due to loss of the lower leg, although the distance in the force arm between the fulcrum and effort (mainly from the attached rectus femoris muscle) was not changed. This means that the distance for the resistance arm may be close to that for the force arm with below-knee amputation.

Therefore, it may be hypothesized that resected stump knee extension model at higher contraction frequency around 80 cpm can be performed easily with a wide KROM in the present patient. According to Figure 4, however, KROM decreased significantly ($P<0.01$) with an increase in target KER level without a weight, but not less so with the 0.5 kg weight. This means that the KROM was mainly not enough to maintain 80 cpm (reduced by approximately 10 degrees) compared with 30, 40, 50, and 60 cpm (Figure 4B), because of the reduced angle rate with the effort to reach the target 80 cpm (see ↓ in Figure 5B).

Notably, the mean KROM was similar at the range between 30 and 60 cpm with the 0.5 kg weight but was slightly decreased at 50-60 cpm compared with 30-40 cpm without the weight. It was speculated that an additional slight overload on the resected stump may improve the repetitive and rapid contraction stability via the action of a third-class lever. However, the data showed a reduction in KROM by approximately 10 degrees at 80 cpm compared with 30-60 cpm.

It is still unknown whether above mentioned finding is unique to amputated lower legs because there are no data for the non-amputated lower leg in the present patient. However, a possible reason for the reduced angle rate around 80 cpm may be biomechanical limitations for the lower amputated limb in this patient with severe diabetic neuropathy related to reduced kinesthesis and/or proprioception.

Self-controlled free

The study with self-controlled free exercise showed large average coefficients of variations for the KER level 8 consecutive days was 8.3% without a weight and 6.9% with the 0.5 kg weight (Table 1). This value was high compared with another target KER level. Maintaining a uniform KER level was difficult for the present patient, even though he was able to comfortably repeat knee extension between approximately 30 and 60 cpm (Figure 2). Moreover, the KER level with the free self-controlled rhythm may increase with more sessions, with improving familiarity in kicking the amputated limb potentially improving performance via the consecutive leg exercise intervention with no use of a prothesis in the early/acute phase post-amputation using audible biofeedback.

Conclusion

In the present interventional case as a preliminary trial, we examined an amputee with trans-tibial amputation to determine whether KER level may be related to KROM (resected stump and thigh) during 1 min of knee extension exercise, using audiometry pacing as biofeedback. Data from a single case is insufficient for providing conclusive evidence regarding the relationship between KER level and KROM for an amputated lower leg, thus further research will require additional data sets of kinesiologic features with various conditions, including from patients with low exercise tolerance. This preliminary trial may provide new insights into procedures for the determination of optimal exercise prescription

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Conflicts of Interest

The author declares that there is no conflict of interest associated with this work.

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