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Original Article

Assessment of isokinetic hip muscle strength and predictors in patients with lower limb amputation: A cross-sectional study

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ABSTRACT

Objectives: The purpose of the study was to determine isokinetic features and analyze significant predictors related to activity level of patients with lower limb amputation.

Patients and methods: Forty-three male patients (mean age: 32.9±8.8 years; range, 21 to 50 years) with lower limb amputation were recruited consecutively for this cross-sectional study between March 1, 2022, and June 30, 2022. The hip flexor and extensor peak torques and total work were evaluated by an isokinetic dynamometer. The secondary outcome measure was the Amputee Mobility Predictor. A linear regression analysis was used to determine factors independently affecting Amputee Mobility Predictor scores.

Results: All data of patients with unilateral amputation, except for flexor (p=0.285) and extensor (p=0.247) peak torques on the dominant side, were higher than those of patients with amputation. Dominant side extensor peak torque was statistically higher than nondominant side extensor peak torque (59.4±30.7 *vs.* 43.4±32.0) in patients with bilateral amputation. No difference was detected between amputated and intact sides of patients with unilateral amputation. Both flexor and extensor total work on the amputated side of the patients with below-knee amputation were higher than the patients with above-knee amputations (63.5±21.1 *vs.* 94.1±34.3 and 67.1±34.0 *vs.* 113.0±51.5, respectively). Unilateral amputation (odds ratio: 7.442) and nondominant side extensor total work (odds ratio: 0.615) were found to be significant predictors related with amputee mobility predictor scale.

Conclusion: It is possible to have an idea about the possible activity level of the patients with lower limb amputation with the help of the predictors obtained in the current study.

Keywords: Amputation, amputee mobility predictor, gait, isokinetic, mobility, strength.

The most important piece in the rehabilitation of patients with lower limb amputation (LLA), particularly for bilateral amputation, is to increase the gait quality and distance. Therefore, patients should have sufficient muscle strength to provide a more natural, symmetrical, and energy efficient gait. Exercise programs have been shown to be effective in improving gait performance of individuals with LLA.[1,2]

One of the most reliable methods for determining muscle strength is isokinetic dynamometers. The prominent advantages of these systems over other evaluation methods can be counted as making

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measurements across the total range of motion and being more objective and repeatable. In addition, changes in muscle strength at the end of the rehabilitation program or the differences with respect to the healthy extremity can be compared with isokinetic dynamometers.[3]

The most frequently used scale to estimate activity level of the patients with LLA is the Amputee Mobility Predictor (AMP).[4] Although the modified version is used in bilateral amputees, in the case without prostheses, the K-level of the patients may not be determined.[5] It is important to reveal clinical data that may be used instead of the AMP. Therefore, the aim of this study was to compare isokinetic measurements between subgroups in patients with LLA and determine predictive factors related to activity level.

PATIENTS AND METHODS

Patients with LLA who were admitted to the amputee rehabilitation unit of a Gaziler Physical Therapy and Rehabilitation Training and Research Hospital between March 1, 2022, and June 30, 2022, were consecutively enrolled for this cross-sectional study. The inclusion criteria for the patients were as follows: *(i)* being aged between 18 and 65 years; *(ii)* ≥3 months since amputation; *(iii)* unilateral or bilateral LLA above the ankle level. The age range of 18 to 65 years was determined to prevent bias since age may affect the age-related activity level and isokinetic measurements of the patients. Exclusion criteria were as follows: *(i)* <30 cm stump length for above-knee amputation; *(ii)* bilateral patients without prosthesis; *(iii)* accompanying upper extremity amputation; *(iv)* the presence of musculoskeletal diseases that could cause functional impairment other than amputation; *(v)* the presence of a neurological deficit; *(vi)* patients with hearing and vision loss. A total of 60 patients were assessed for eligibility, 10 patients were excluded for not meeting the inclusion criteria, and seven patients refused to participate. Finally, 43 male patients (mean age: 32.9±8.8 years; range, 21 to 50 years) with LLA were included.

Demographic and clinical data, including age, weight, height, time since amputation, side and level of amputation, and the dominant side of the lower extremity were recorded. The side that patients preferred to hit a ball was accepted as their dominant side.

Outcome measures

Isokinetic evaluation of the hip flexor and extensor muscles was performed using a computer-assisted isokinetic system (Cybex, Division of Lumex Inc., Ronkonkoma, NY, USA) in the isokinetic performance laboratory. Accessories appropriate for the extension and flexion of the hip joint were mounted on the device, and the calibration was renewed for every assessment. The body and the thigh were stabilized with stabilization straps. Measurements were performed with the patients in the supine position, with the dynamometer axis passing through the trochanter major and the dynamometer lever arm fixed to the most distal part of the thigh, as shown to minimize the intra and interrater observer bias. The participants completed five maximal repetitions in 60°/sec angular velocity. Peak torque (PT; highest torque achieved throughout the entire range of motion) and total work (TW; the sum of the work performed in all test repetitions) values were calculated for each set of isokinetic testing repetitions per body side and muscle group. Testing was performed at the morning to minimize confounding effect of fatigue. In light of previous literature, hip flexor and extensor muscles were selected for isokinetic assessment.[6] Several comparisons, including patients with unilateral amputation *vs.* patients with bilateral amputation, dominant side *vs.* nondominant side, flexor muscles vs. extensor muscles, amputated side *vs.* intact side, and above the knee level *vs.* below the knee level were performed.

The AMP is a commonly used tool for predicting the level of ambulation by assessing static and dynamic balance, transfers, and gait in patients with LLA. With this scale, patients with LLA can be evaluated with or without prosthesis. However, the activity level of patients with bilateral LLA can only be accurately predicted if they have prostheses. Bilateral patients without prosthesis were not included in the study to prevent bias and to determine homogeneity. All AMP evaluations were performed by a physiotherapist with 10 years of experience in amputee rehabilitation.

The walking distances were evaluated with the 2-min walking test (2-MWT). The 2-MWT was preferred due to its capacity to assess mobility and walking endurance in patients with LLA.[7] The patients were asked to walk with their prosthesis at normal speed as in daily life on a flat, level surface, and the number of meters walked in 2 min was recorded.

Statistical methods

Power analysis was performed using G*Power version 3.1 (Heinrich-Heine-Universität Düsseldorf,

Düsseldorf, Germany). It was calculated that 40 patients should be included in the study to achieve 80% power with an alpha level of 0.05 and an effect size of 1.25 based on the results of the study conducted by Alahmri et al.[8]

Data were analyzed using SPSS version 15.0 (SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to check the normality of data. The skewness value of the nonnormally distributed data was checked for the availability of parametric tests. The independent samples t-test or the paired samples t-test were applied to normally distributed data in the comparisons between and within the groups. The Spearman or Pearson tests were used to perform correlation analysis. Linear regression analysis was used to determine factors independently affecting AMP scores. Bivariate analysis was carried out between all possible risk factors (age, duration of amputation, and all isokinetic variables) and AMP scores. Variables with a p-value <0.10 in bivariate analysis were included in the multiple linear regression analysis. Afterward, regression analysis was repeated only for patients with bilateral LLA. The level of significance for all statistical analyses was set at p<0.05.

RESULTS

All of the patients had a traumatic etiology. Eleven patients had bilateral amputation, and 32 had unilateral amputation. Among those with unilateral LLA, 15 had left-sided and 17 had right-sided amputations. While 21 patients had knee disarticulation or a more proximal amputation level, the remaining 22 patients had below-knee amputations or more distal level amputation. The dominant side was the left side in two of 32 unilateral amputee patients; the others had right-side dominance. The two patients who were left-side dominant had amputations on their nondominant side. The characteristics of the cases are displayed in Table 1.

The mean AMP and 2-MWT scores were 43.7±4.6 and 152.6±19.3 for the patients with unilateral LLA and 31.3±9.3 and 103.1±28.5 for the patients with bilateral LLA, respectively. A statistically significant difference was found in terms of scores in favor of the patients with unilateral LLA (p<0.05).

Both hip flexor and extensor TWs on the dominant side were found to be statistically significantly higher in patients with unilateral

TABLE 1
Patients' characteristics

	Total		Unilateral		Bilateral		
	Mean±SD	Min-Max	Mean±SD	Min-Max	Mean±SD	Min-Max	*p*
Age (year)	32.9±8.8	21-50	33.5±8.7	23-50	31.1±9.4	21-46	0.328**
BMI (kg/m^2)	24.4±4.1	12.91-34.60	24.7±3.7	18.94-34.60	23.6±5.2	12.91-32.11	0.482*
Time since amputation (month)	72.8±98.7	3-312	72.81±104.2	3-312	73.0±85.2	6-240	0.401**
AMP score	40.5±8.1	15-46	43.7±4.6	20-46	31.3±9.3	15-43	0.001**
2-MWT distance (m)	139.9±30.7	60-180	152.6±19.3	90-180	103.1±28.5	60-167	0.001**

SD: Standard deviation; BMI: Body mass index; AMP: Amputee mobility predictor; 2-MWT: Two-minute walk test; * T test; ** Mann-Whitney U test.

TABLE 2
Dominant side isokinetic comparison between patients with unilateral *vs* bilateral amputations

	Total (n=43)	95% CI	Unilateral (n=32)	95% CI	Bilateral (n=11)	95% CI	
	Mean±SD	Lower-Upper	Mean±SD	Lower-Upper	Mean±SD	Lower-Upper	*p*
Hip flexor							
Peak torque	67.8±25.3	60.0-75.6	70.3±25.6	61.0-79.5	60.7±24.2	44.4-77.0	0.285
Total work	79.1±36.9	65.9-89.3	85.9±36.6	72.7-99.1	53.6±32.5	31.7-75.5	**0.013**[a]
Hip extensor							
Peak torque	69.5±33.2	59.3-79.8	73.0±33.8	60.8-85.2	59.4±30.7	38.7-80.1	0.247
Total work	95.3±50.4	79.7-111.5	103.4±51.0	84.5-121.6	72.0±42.3	43.1-102.6	**0.009**[a]

SD: Standard deviation; CI: Confidence interval; a Statistically significant difference between "Unilateral *vs* bilateral amputations" (Independent-Samples t-test).

TABLE 3
Non dominant side isokinetic comparison between patients with unilateral *vs.* bilateral amputations

	Total (n=43)	95% CI	Unilateral (n=32)	95% CI	Bilateral (n=11)	95% CI	
	Mean±SD	Lower-Upper	Mean±SD	Lower-Upper	Mean±SD	Lower-Upper	*p*
Hip flexor							
Peak torque	62.4±26.9	54.1-70.7	68.8±25.0	59.7-77.8	43.9±24.3	27.5-60.2	**0.007**[a]
Total work	75.1±35.9	64.1-86.1	83.2±32.8	71.3-95.1	51.5±35.2	27.8-75.2	**0.010**[a]
Hip extensor							
Peak torque	67.6±32.4	57.6-77.6	75.9±28.6	65.6-86.2	43.4±32.0	21.9-64.9	**0.003**[a]
Total work	95.6±43.0	82.4-108.9	106.6±43.6	90.9-122.3	63.8±19.2	50.9-76.7	**0.003**[a]

SD: Standard deviation; CI: Confidence interval; a Statistically significant difference between "Unilateral *vs* bilateral amputations" (Independent-Samples t-test).

LLA compared to patients with bilateral LLA (p=0.013 and p=0.009, respectively; Table 2). No significant difference was detected in dominant side flexor and extensor PTs (p=0.285 and p=0.247, respectively). Hip flexor PT, TW and hip extendor PT and TW at the nondominant side were higher in patients with unilateral LLA than in patients with bilateral LLA (p=0.007, p=0.010, p=0.003, p=0.003, respectively; Table 3).

Comparisons were also performed between isokinetic data measured at the dominant and nondominant side. Only dominant side hip extensor PT was statistically higher than nondominant side extensor PT in patients with bilateral LLA (59.4±30.7 *vs.* 43.4±32.0, p=0.007). There was no difference between the dominant and nondominant isokinetic values of the patients with unilateral LLA.

When flexor and extensor measurements were compared, both the dominant (103.4±51.0) and nondominant (106.6±43.6) hip extensor TW values were found to be higher than the flexor region (85.9±36.6 and 83.2±32.8, respectively) in analyses including only patients with unilateral LLA (p=0.009 and p=0.001, respectively). Dominant side

TABLE 4
Comparison of unilateral patients according to amputation level

		Amputated side	Intact side	
		Mean±SD	Mean±SD	*p*
All unilateral patients (n=32)				
Peak torque	Hip flexor	67.5±26.2	71.5±24.3	0.316
Total work	Hip flexor	84.5±33.7	84.6±35.9	0.985
Peak torque	Hip extensor	77.5±39.1	71.5±20.3	0.483
Total work	Hip extensor	98.6±51.0	101.1±43.2	0.251
Above knee (n=10)				
Peak torque	Hip flexor	56.1±24.5	67.3±25.7	0.189
Total work	Hip flexor	63.5±21.1	80.8±36.8	0.130
Peak torque	Hip extensor	61.0±31.7	69.3±17.5	0.479
Total work	Hip extensor	67.1±34.0	88.9±56.0	0.267
Below knee (n=2)				
Peak torque	Hip flexor	72.7±25.7	73.5±24.0	0.870
Total work	Hip flexor	94.1±34.3	86.4±36.3	0.354
Peak torque	Hip extensor	85.0±40.5	72.5±21.8	0.201
Total work	Hip extensor	113.0±51.5	121.1±32.7	0.189

SD: Standard deviation; Comparison of the amputated side *vs* intact side (Independent-Samples t-test).

extensor TW was statistically higher than the flexor TW in patients with bilateral LLA (53.6±32.5 *vs.* 72.0±42.3, p=0.005).

No significant difference was observed between amputated and intact sides of the patients with unilateral amputations (Table 4). There was no significant difference in the comparison of the extensor and flexor muscles of the patients with above-knee amputation. Extensor PT and TW on the amputated side and extensor TW on the intact side were found to be statistically significantly higher than the flexor muscles in patients with below-knee amputation. Both flexor and extensor TW on the amputated side of the patients with below-knee amputation were higher than patients with above-knee amputation (63.5±21.1 *vs.* 94.1±34.3 and 67.1±34.0 *vs.* 113.0±51.5, respectively).

Multiple linear regression analysis results showed that patients with unilateral LLA are prone to have an AMP score 7.4 times higher than patients with

TABLE 5
Linear regression analysis for factors associated with AMP score

			95% CI		
	B	*p*	Lower	Upper	
Flexor peak torque (ND)	0.014	0.780	-0.089	0.117	
Flexor total work (D)	-0.001	0.950	-0.046	0.044	
Flexor total work (ND)	-0.006	0.875	-0.081	0.070	
Extensor peak torque (D)	0.011	0.597	-0.030	0.051	
Extensor peak torque (ND)	0.027	0.274	-0.023	0.077	
Extensor total work (D)	0.005	0.782	-0.030	0.040	
Extensor total work (ND)	0.013	0.423	-0.020	0.047	
Unilateral *vs.* bilateral	7.442	**0.000**	4.792	10.092	
	Sum of squares	df	Mean square	F	*p*
Regression	681,084	8	85,135	9,225	0.0001
Residual	295,307	32	9,228		
Total	976,390	40			

AMP: Amputee mobility predictor; CI: Confidence interval; D: Dominant side; ND: Non-dominant side.

TABLE 6
Linear regression analysis for factors associated with AMP scores in patients with bilateral amputations

			95% CI		
	B	*p*	Lower	Upper	
Flexor peak torque (ND)	-0.199	0.097	-0.589	0.191	
Flexor total work (D)	-0.051	0.093	-0.148	0.045	
Flexor total work (ND)	0.185	0.078	-0.106	0.476	
Extensor peak torque (D)	0.098	0.096	-0.091	0.286	
Extensor peak torque (ND)	-0.128	0.076	-0.324	0.067	
Extensor total work (D)	0.002	0.857	-0.093	0.096	
Extensor total work (ND)	0.615	**0.024**	0.316	0.914	
	Sum of squares	df	Mean square	F	*p*
Regression	221,974	7	31,711	1213,741	0.022
Residual	0.026	1	0.026		
Total	222,000	8			

AMP: Amputee mobility predictor; CI: Confidence interval; D: Dominant side; ND: Non-dominant side.

bilateral LLA (Table 5). Another analysis including only patients with bilateral LLA was performed to determine significant variables to predict the AMP score. Results indicated that with every one-point increase in nondominant side extensor TW, the AMP score increased by 0.6 of a point in patients with bilateral LLA (Table 6).

DISCUSSION

The aim of this study was to reveal the isokinetic differences in individuals with LLA and to determine the predictors associated with the AMP scale used to estimate the activity level of the patients. In this study, isokinetic differences of amputee individuals with each other or their own extremities were revealed. Most importantly, unilateral amputation and nondominant extremity extensor TW were found to be significant predictors in relation to the AMP scale.

The muscle strength measurement is essential for patients who have a neurological, muscular, or skeletal illness. In scientific research related with LLA, various instruments are used to assess muscle strength, such as isokinetic systems[9,10] and handheld dynamometers.[11] Isokinetic systems are superior to other methods in muscle strength assessment despite their disadvantages, such as being expensive, needing experienced personnel, and taking a long time.[12] Isokinetic systems are capable of providing multiple muscle strength related data, such as PT, power, angle of maximal force, and TW. In the current study, PT and TW were selected as muscle strength parameters since they have been preferred in previous LLA-related studies.[6,10,13,14]

Isokinetic systems have a variety of assessments in the lower extremity in many different ways. In this study, patients with bilateral LLA and patients with unilateral LLA (those with below-knee amputation and those with above-knee amputation) were included together to combine the different populations. The hip joint was chosen as the most suitable joint for the evaluation of all patients included in the study. In their study, LaRoche et al.[15] found the intraclass correlation coefficient (ICC) ratio, which is an important indicator of reproducibility, of hip flexor and extensor isokinetic muscle strength to be 0.95 in two evaluations performed 48 h apart. Similarly, Cahalan et al.[16] obtained an ICC ratio of 0.96 in hip flexor and extensor measurements. Values in the range of 0.90 to 1.00 for ICC are considered very high in terms of reproducibility according to the literature.[17,18] In addition, in a systematic review, the angular velocity was selected as 60°/sec in studies with an ICC rate above 0.90.[6] It is known that individuals with a LLA compensate at the hip for the lack of a fully functioning knee or ankle joint during walking, running, and jumping. Thus, hip flexor and extensor measurements at an angular velocity of 60°/sec were performed in the current study.

Strength deficit has a central role in balance, mobility, and endurance in lower extremity prosthesis users. This loss may be more pronounced in patients with bilateral LLA.[19,20] In the current study, muscle strength indicators obtained by isokinetic measurement were higher in patients with unilateral LLA than in patients with bilateral LLA. This could be mostly explained by activity levels of the patients. In general, individuals with bilateral LLA may keep the prosthesis wearing time short for reasons such as comfort, pain, and fatigue. Studies indicate that patients with unilateral LLA were more active than patients with bilateral LLA.[21,22] Similarly, muscle torque values of active patients have been reported to be higher than inactive individuals.[9] Reduced muscle strength might lead to asymmetric gait with lower speed.[23-25]

In patients with LLA, the muscle strength around the hip is important for a natural, energy-efficient, and symmetrical gait. Kowal and Rutkowska-Kucharska,[9] as well as Nolan,[14] found that the hip joint flexors were stronger than the hip joint extensors among patients with LLA. In contrast to previous studies, the extensor TW was higher than the flexor in both dominant and nondominant hips in the current study. In addition, dominant hip extensor PT was significantly higher than the nondominant side in patients with bilateral LLA. The discrepancy might be explained by the population of the study. In the current study, patients with proximal and bilateral amputations were included more than the other studies. Patients with proximal and bilateral amputation need extensors as well as hip abductors during walking.[3] In addition, the superior strength of the hip joint extensors may be explained by the fact that these muscles function as antigravity muscles.[26] In the gait training of bilateral patients with LLA, sudden contraction of the hip extensors may be required. Unilateral patients can provide knee flexion with weight loading. Therefore, the extensor PT values of the dominant side may be higher than the nondominant side only in bilateral patients.

Comparisons of hip flexor and extensor muscle strengths between below-knee amputation and above-knee amputation patients can be a guide to determine the possible activity levels of the patients. Despite the growing literature on isokinetic evaluation in LLA, there has been no report that compares below-knee amputation and above-knee amputation. It can be commented that patients with a below-knee amputation are stronger than patients with above-knee amputation as they will have active quadriceps and hamstring muscle strength and are more active. Fontes Filho et al.[27] reported that the PT values of quadriceps (31.6 *vs.* 119.4) and hamstring (23.5 *vs.* 61.5) in the amputated side were lower than the nonamputee side in patients with below-knee amputation. In the current study, it was found that the amputated side's hip extensor and flexor TW was higher in patients with below-knee amputation compared to those with above-knee amputation. Intact muscle activation is the primary reason for these results. It has been previously shown that as stump length increases, muscle strengthening is also increasingly observed.[28]

Comparison of the muscle strength of the amputated and intact side is one of the features that guide the rehabilitation. However, there is conflicting evidence about the muscle strength differences between the amputated and the sound limb. Hip joint muscles' strength deficit has been reported in people with above-knee amputation of up to 35% compared to unimpaired limbs.[9,25,29] On the other hand, hip extensor, flexor, and abductor PTs were not significantly different between the residual and control legs.[30] The authors reported that there was no significant hip muscle strength difference between the amputated and nonamputated side. The most important reason for this was the inclusion of patients with high activity (K3 and K4 activity levels) in the current study. In patients with high activity, it can be predicted that the strength deficit would have been less on the amputated side. In addition, using the prosthesis for a longer period of time by active individuals also reduces the risk of loss of strength associated with inactivation.[9]

Predicted activity of the patient with LLA is probably the most important factor when prescribing prosthetics. A commonly preferred scale for this purpose in amputee rehabilitation is AMP. It is important to reveal more clinical data that could be preferred instead of this scale. When previous studies including regression analyses to predict the activity levels of amputee patients were analyzed, it was observed that the patients had either only unilateral below-knee amputations or only unilateral above-knee amputations. In the current study, unilateral or bilateral LLA was found to be a significant predictor of the AMP scale. It has been predicted that individuals with bilateral amputations may have an AMP score of approximately 7.4 points less than individuals with unilateral amputation. Slater et al.[31] showed that knee extensor muscle strength was significant in predicting the 6-min walk test. Similarly, it has been reported that hip adductor and extensor muscle strength may be used in estimating walking distance in patients with LLA.[3] However, it was seen that there was no study in which both below-knee amputation and above-knee amputation patients were included. It is not always easy to determine the activity level of patients with bilateral amputations. Thus, study populations with bilateral and unilateral patients are needed. In this study, bilateral or unilateral amputation was shown to be the most important predictive factor for activity level. In addition, nondominant hip extensor TW was found to be a significant predictor in patients with bilateral amputations. Even if the AMP scale could not be applied, an estimate can be made with these two data in terms of the possible activity levels of the patients.

There are some limitations to this study, the most important of which was that most of the patients in this center were at the K3 and K4 activity levels. More bilateral patients with low activity should be included in future studies. In addition, further large-scale studies including patients with nontraumatic etiology and a control group may strengthen the results. When all limitations are taken into account, doubts may arise about the generalization of the results. However, the strengths of the study outweigh the limitations. First, isokinetic tests, which can be the gold standard method among the methods used in the evaluation of muscle strength, were selected in this study. In addition, population heterogeneity was increased by including patients with both bilateral and unilateral LLA. Finally, predictors that can be useful in estimating the activity level of patients in cases where the AMP scale cannot be used have been obtained.

In conclusion, isokinetic measurements can be successfully applied at many levels of LLA, including patients with bilateral amputations. Unilateral amputation and nondominant extremity extensor TW were found to be significant predictors in relation with the AMP score. With the help of the predictors obtained in the current study, it is possible to have an idea about the possible activity level of the patients whose activity level cannot be determined with the AMP scale. By increasing the number of significant predictors, an alternative scale can be created instead of the AMP scale.

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Ethics Committee Approval: The study protocol was approved by the Ankara City Hospital Clinical Research Ethics Committee (date: 10.03.2021, no: E2-21-123). This study was registered to the ClinicalTrials.gov database with NCT05188599 ID. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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