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The Comparison of Electromyographic Activity of Selected Knee and Pelvic Muscles during Pair/Single-Leg Lunge and Squat Movements in Individuals with and without Genu Varum: A Quasi-Experimental Study

Ali Hatami-Yadegari[1], Ramin Baluchi[2], Farideh Babakhani[3]

Original Article

Abstract

Introduction: The lower limbs are a chain of columns and joints that tolerate the weight of the body. The aim of this study was to compare the electromyographic (EMG) activity of selected knee and pelvic muscles during pair/single-leg lunge and squat movements in individuals with and without genu varum.

Materials and Methods: 36 male students without regular exercise (19-25 years) were divided into two groups: healthy (n = 18) and genu varum (n = 18). EMG device was used to measure the electrical activity of muscles. Statistical analyzes were performed at a significance level of 0.05.

Results: There was a significant difference between two groups in EMG activity value of the gluteus medius (GM) in three movements (pair-leg squat, lunge, and single-leg squat) and in the tensor fasciae latae (TFL) in single-leg squat movement, but between EMG activity in three movements in vastus medialis, vastus lateralis, and crural biceps, no significant difference was observed between the two groups.

Conclusion: There is a significant difference between the EMG activity of GM in three movements (pair-leg squat, lunge, and single-leg squat) and in the TFL in one movement (single-leg squat) in the two groups, which shows the importance of mentioned muscles in the studied movements.

Keywords: Muscle electromyography; Lunge; Squat; Genu varum

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Introduction

Lower limb alignment is an important factor in height control. The human body's motor organs work together in a chain, and any disturbance in one part affects the others (1). This chain includes the thigh, knee, ankle, toes, and related joints, maintaining correct mechanics during sports performance (2). According to Janda's theory, a closed kinematic chain deformity in the knee genu varum can cause secondary pathomechanical and physiological complications in other organs (3). It has been reported that when the knee joint is misaligned, the quadriceps muscle becomes less effective due to the change in the muscle tendon's alignment and the patella's displacement (3). Additionally, a knee genu varum affects muscle activation, joint stiffness, force absorption and dispersion, and dynamic joint stability (4, 5).

A study observed that kinematic changes in the lower limb, specifically genu varum, can impact performance and knee joint loads during sports movements (6). Other researchers found that individuals with genu varum had higher maximum thigh abduction torque during weight transfer, increased internal rotation torque of the knee, and external rotation torque of the thigh in the transverse plane (4, 7). A study found that the angle of the genu varum affected the activity of the gluteus maximus

1- MSc Student, Department of Sport Injury and Corrective Exercises, School of Physical Education and Sports Sciences, Allameh Tabataba'i University, Tehran, Iran
2- Associate Professor, Department of Sport Injury and Corrective Exercises, School of Physical Education and Sports Sciences, Allameh Tabataba'i University, Tehran, Iran
3- Assistant Professor, Department of Sport Injury and Corrective Exercises, School of Physical Education and Sports Sciences, Allameh Tabataba'i University, Tehran, Iran
Corresponding Author: Ali Hatami-Yadegari, Email: alihatami6870@gmail.com

muscle during different activities, indicating that genu varum abnormalities can cause changes in muscle activity (8).

In this study, researchers found that people with genu varum had significantly different electromyographic (EMG) activity in their knee muscles compared to those with healthy knees when performing the squat movement (7). They also discovered that changing the distance between the legs during a leg press movement affected the activity ratio of the vastus medialis and vastus lateralis muscles in people with knee genu varum. At the same time, no such effect was observed in healthy people (9). Other researchers have noted EMG differences between agonist and agonist-antagonist contractions during single-leg and pair-leg squat movements. They have stated that when completing knee joint extension with only one leg, the quadriceps muscles can generate more force than when performing this movement simultaneously with both legs (7, 10).

In a study, researchers investigated muscle activity during three different squat exercises in athletes and non-athletes. They found significant differences in muscle activity for the semitendinosus, transversus abdominis, and multifidus muscles depending on the position of the squat (11). Another study examined the effects of four different leg positions on squat movement, with angles ranging from -10 degrees to 20 degrees outward. They found no significant difference in EMG activity between leg positions in squats for the vastus medialis, vastus lateralis, and rectus femoris muscles regarding activity duration and peak activity level (12). Given the limited research in this area and conflicting results, this study compared the EMG activity of selected knee and hip muscles during lunge and squat movements for individuals with and without genu varum.

Materials and Methods

This quasi-experimental study utilized a pretest-posttest design and two experimental groups. Thirty-six male students from clubs in Karaj, Iran, were selected using target and accessible population sampling methods. Participants voluntarily entered the study after meeting entry criteria and completing informed consent and general health forms. Inclusion criteria included being between 18 and 25 years old, having a body mass index (BMI) of 18 to 25 kg/m^2, and a 3 cm distance between the two inner condyles of the knee in the knee genu varum group (13). Exclusion criteria included a history of injury in the lower limbs, hip, knee, wrist, muscle injury, surgery in the lower back and lower limbs, and abnormalities such as flatfeet and pes cavus (13). To ensure proper execution of movements in the research, subjects received practical training and demonstrations, followed by performing three movements in actual conditions. Weight for squat was determined as 15% of the person's weight, and a barbell with different weights was used. Prior to the test, all subjects did stretching and general exercises for 10 minutes. A goniometer was used to adjust the squat movement up to a 90-degree angle, and a metal caliper (INSIZE model 1108-150, Japan) was used to measure the distance between the two inner condyles of the knee.

An EMG device (Desktop DTS Receiver Model, Noraxon, USA) was used to record the electrical activity of muscles before and after performing sports movements. EMG data were filtered using 500 high-pass and 10 low-pass filters. The root mean square estimates muscle activity, which must be divided by the maximum voluntary isometric contraction (MVIC) to normalize the data (14). Disposable surface electrodes (model F-RG, Skintact, Germany) were used to record the EMG signal.

Electrodes with a hypoallergenic conductive interface receive skin waves. They stick to and easily removed from the skin. Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIMA) protocol guides electrode placement on the dominant leg for vastus medialis oblique (VMO), vastus lateralis oblique (VLO), tensor fasciae latae (TFL), gluteus medius (GM), and biceps femoris (BF).

Before conducting the main study, the MVIC test was performed to standardize the comparison of EMG activity changes across different muscles and samples. This allowed the research data to be normalized as a percentage of MVIC (Figure 1).

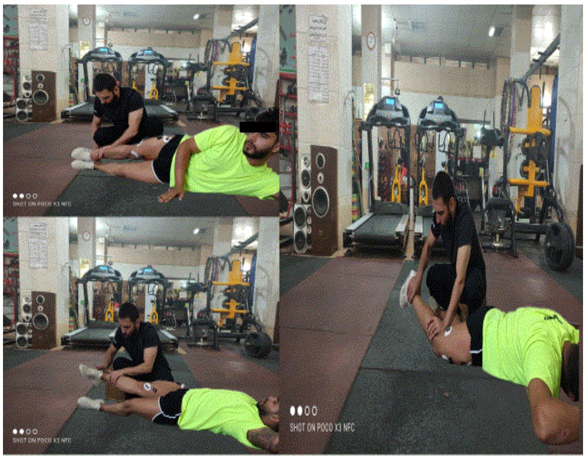

Figure 1. A view of maximum voluntary isometric contraction (MVIC)

The electrical activity of selected hip and knee muscles was investigated in two groups of people with and without genu varum. While subjects performed the squat in neutral hip positions, hip internal rotation at 15% angle, hip internal rotation at 30% angle, hip internal rotation at the end of the possible range where the toes touch, hip external rotation at 15% angle, hip external rotation at 30 degrees, and hip external rotation at 45 degrees were recorded. To determine the angle of rotation of the thigh, a plate was designed to adjust the angles of rotation of the thigh. In this way, two parallel lines with a distance of 30 cm from each other were placed on both sides of the screen as a guideline for the zero-degree range. Lines were drawn in two directions from these two parallel lines with angles of 15, 30, and 45 degrees. These lines were used to measure different ranges of hip rotation. The person stood on the screen in such a way that the center line (zero degrees) passed through the middle of the heel at the back and the second toe at the front. All subjects performed the movement three times with 30-second rest intervals between them (15), in which case, the effect of possible fatigue was eliminated (16). Between one position and the following position in the range of hip rotation change, a 4-minute rest interval was given to the sample, and to record the EMG activity at the next angle, the subjects were placed on the screen again (17).

Double-leg squat movement: In the starting position, the feet were shoulder-width apart, and a barbell was placed behind the neck and shoulders, right on the trapezius muscles. The start of the activity consisted of keeping the shoulder and back straight and the chest out (Figure 2).

Figure 2. Double-leg squat

In the single squat exercise, the barbell rests on the shoulder while one leg is positioned behind a bench. The movement involves lowering the thigh angle and front leg to 90 degrees before performing a squat.

At the start of the lunge movement, the halter positions the bar behind their neck, takes a big step forward with their left leg, bends their left knee to a 90-degree angle, and then repeats the movement with their right leg (Figure 3).

Figure 3. One-leg squat and lunge

We analyzed the data from the EMG device using LabVIEW software for muscle electrical activity. We used descriptive statistics to calculate central indices and dispersion of quantitative scales and created graphs and tables. We checked the data normality with the Shapiro-Wilk test and evaluated our hypotheses with independent t-test and repeated measures analysis of variance (ANOVA). Finally, we analyzed the data with SPSS software (version 24, IBM Corporation, Armonk, NY, USA) and set the significance level at $P \leq 0.05$.

Results

Table 1 displays descriptive indices and Shapiro-Wilk test results for age, height, weight, BMI, and knee condyle distance variables in the samples.

The Bonferroni post hoc test results on the VMO muscle activity in healthy subjects indicated a significant difference in EMG readings between the lunge, double squat, and single-leg movements. The pair-leg squat with lunge movements ($P = 0.023$) and the single-leg squat ($P = 0.001$) showed a significant difference. In contrast, the relationship between the lunge movement and the single-leg squat ($P = 0.222$) was insignificant.

During the study, researchers observed a significant difference in the squat movements of the VLO muscle for a pair of legs while performing a lunge ($P = 0.001$) and single-leg squat ($P = 0.001$). The relationship between lunge movement and single-leg squat ($P = 0.001$) was also significant.

Table 1. Subjects' individual characteristics and Shapiro-Wilk test results

Variable	Group	Mean ± SD	Shapiro-Wilk test	T statistics
Age (year)	Genu varum	25.36 ± 2.48	0.88	0.210
	Healthy	24.22 ± 2.34	0.16	
Weight (kg)	Genu varum	69.78 ± 4.41	0.38	0.450
	Healthy	71.43 ± 5.58	0.07	
Height (cm)	Genu varum	176.39 ± 5.45	0.15	0.130
	Healthy	177.19 ± 7.61	0.24	
BMI (kg/m^2)	Genu varum	21.33 ± 0.62	0.20	0.270
	Healthy	21.49 ± 1.14	0.35	
Distance between knee condyles (cm)	Genu varum	4.41 ± 0.77	0.33	0.001
	Healthy	1.91 ± 0.63	0.26	

BMI: Body mass index; SD: Standard deviation

The results indicated a significant difference in the squat movements of legs when performing a lunge (P = 0.001) and single-leg squat (P = 0.001). Furthermore, the relationship between lunge movement and single-leg squat (P = 0.045) was also significant (Table 2).

The investigations based on Table 3 showed that there was no significant difference in the squat movements of the pair of legs and the lunge (P = 0.733), but the difference between the squat of the pair of legs and the single leg (P = 0.001) and the single leg squat lunge (P = 0.001) was significant. Also, there was no significant difference in squat movements with one leg and lunge (P = 0.999), but the difference between squat with one leg (P = 0.001) and lunge with one leg squat (P = 0.001) was significant. A significant difference was observed in the movements of double leg squat with lunge (P = 0.001) and single leg squat (P = 0.001), but the relationship between lunge movement and single leg squat (P = 0.261) was not significant. Also, the results of the test did not show a significant difference in the amount of electromyographic activity of the BF muscle in three movements (double leg squat, lunge and single leg squat) in the knee genovarum group ($P \leq 0.050$).

The results of the test show a significant difference in the amount of electromyographic activity of the VMO muscle in the squat movements of the pair of legs (P = 0.180), the lunge (P = 0.720) and the single leg squat (P = 0.750), the VLO muscle in the movements of the pair of legs squat (P = 0.253), lunge (P = 0.463) and single leg squat (P = 0.098), BF muscle in double leg squat movements (P = 0.595), lunge (P = 0.814)) and single-leg squat (P = 0.136) and TFL muscle were not observed in the squat movements of the pair of legs (P = 0.225) and lunge (P = 0.183) between the two groups of healthy and braced knee, but in the squat movement One leg in the GM muscle (P = 0.033), in the squat movements of the pair of legs (P = 0.003), lunge (P = 0.004) and single leg squat (P = 0.001) significant difference in the amount of activity Electromyography was observed between two healthy groups and knee genovarum (Table 4).

Discussion

This study aimed to compare the EMG activity of specific knee and hip muscles during the execution of double/single-leg lunge and squat movements in two groups of male students, one with healthy legs and the other with knee genu varum. The study investigated and compared the neural effects of pair-leg squats, lunges, and single-leg squats on VMO, VLO, TFL, GM, and BF muscles. The study found a significant difference in the amount of EMG activity of the VMO muscle in three movements (pair-leg squat, lunge, and single-leg squat) in people with healthy legs.

Table 3. Bonferroni post hoc test results of muscles of healthy people

Muscle	Movement		Mean ± SD	P value
VLO	Pair-leg squat	Lunge	8.06 ± 1.64	0.001*
		One-leg squat	16.17 ± 2.30	0.001*
	Lunge	One-leg squat	8.11 ± 1.85	0.001*
VMO	Pair-leg squat	Lunge	11.02 ± 3.65	0.023*
		One-leg squat	19.79 ± 4.56	0.001*
	Lunge	One-leg squat	8.77 ± 4.60	0.222
GM	Pair-leg squat	Lunge	3.07 ± 0.43	0.001*
		One-leg squat	4.88 ± 0.54	0.001*
	Lunge	One-leg squat	1.81 ± 0.69	0.001*

*P < 0.05

VLO: Vastus lateralis oblique; VMO: Vastus medialis oblique; GM: Gluteus medius; SD: Standard deviation

Table 3. Bonferroni post hoc test results of muscles of people with genu varum

Muscle	Movement		Mean ± SD	P value
VLO	Pair-leg squat	Lunge	6.28 ± 5.21	0.733
		One-leg squat	23.92 ± 4.36	0.001*
	Lunge	One-leg squat	17.64 ± 3.30	0.001*
VMO	Pair-leg squat	Lunge	0.95 ± 3.39	0.999
		One-leg squat	21.84 ± 3.70	0.001*
	Lunge	One-leg squat	20.89 ± 3.79	0.001*
GM	Pair-leg squat	Lunge	8.58 ± 1.29	0.001*
		One-leg squat	4.88 ± 0.54	0.001*
	Lunge	One-leg squat	3.89 ± 2.13	0.261

*$P < 0.05$

VLO: Vastus lateralis oblique; VMO: Vastus medialis oblique; GM: Gluteus medius; SD: Standard deviation

The different execution of these movements is due to the change in the position of the muscle, the amount of torque, the resting length of the muscle, and the amount of tension and force applied to the muscle. Finally, the study found a significant difference between the amount of EMG activity of VMO and VLO muscles.

The difference in EMG activity between the VMO and VLO muscles may vary when performing squats with a free bar versus the Smith machine (17). One study found that doing a one-leg squat on a bench resulted in higher muscle activity in the hamstrings and quadriceps compared to the other two exercises (16). Another study reported that the activity of knee muscles increased with more significant load and weight (18).

This study's results suggest a difference in the EMG activity of the GM muscle in the healthy group. However, there was no difference in the activity of the TFL muscle during the three movements (double-leg squat, lunge, and single-leg squat) performed by the subjects. Studies have shown that the EMG activity of the GM, TFL, and VMO muscles varies between multi-joint and single-joint exercises (19). The non-change in TFL muscle EMG activity in three movements (double-leg squat, lunge, and single-leg squat) may be due to the change in GM muscle activity during these exercises (13). The measurement of EMG activity of the BF muscle in the three movements investigated in this study showed differences in healthy subjects. The reason for this could be related to the length-tension relationship and the changes caused by the difference in torque, resting length of the muscle, and the different amount of tension applied during the performance of pair-leg squats, lunges, and single-leg squats relative to each other. This is in line with the results of previous studies (8, 16). The monopodial squat has more activity than the forward lunge and lateral step exercises in all muscles except the right thigh (8).

Table 4. The mean and independent t-test results of selected knee muscles in two groups, healthy and knee genu varum

Variable	Movement	Genu varum group (mean ± SD)	Healthy group (mean ± SD)	T-statistics	Mean differences	F-statistics	P value
VMO	Pair-leg squat	56.96 ± 16.57	50.51 ± 11.18	1.369	6.450	2.255	0.180
	Lunge	63.24 ± 14.56	61.54 ± 13.76	0.361	1.706	0.296	0.720
	One-leg squat	80.89 ± 13.82	61.54 ± 13.76	1.838	10.580	2.602	0.075
VLO	Pair-leg squat	53.27 ± 8.20	49.14 ± 12.61	1.163	4.125	2.402	0.253
	Lunge	54.22 ± 12.92	57.21 ± 11.12	0.743	2.986	0.406	0.463
	One-leg squat	75.11 ± 18.33	65.32 ± 16.11	0.702	9.791	0.433	0.098
TFL	Pair-leg squat	8.30 ± 3.21	6.96 ± 3.31	1.236	1.345	0.001	0.225
	Lunge	9.28 ± 3.89	7.60 ± 3.49	1.359	1.676	0.002	0.183
	One-leg squat	6.93 ± 2.47	6.93 ± 2.47	2.218	2.593	0.888	0.033*
GM	Pair-leg squat	8.65 ± 5.26	4.38 ± 1.81	3.260	4.276	37.062	0.003*
	Lunge	17.23 ± 6.92	7.45 ± 1.80	5.799	9.780	16.494	0.004*
	One-leg squat	21.12 ± 7.21	9.27 ± 2.59	6.559	11.858	11.480	0.001*
BF	Pair-leg squat	23.42 ± 8.72	22.08 ± 6.08	0.537	1.347	1.940	0.595
	Lunge	25.32 ± 9.85	26.10 ± 9.93	0.237	0.782	0.516	0.814
	One-leg squat	27.01 ± 9.06	31.89 ± 10.06	1.529	4.880	0.120	0.136

*$P < 0.05$

VLO: Vastus lateralis oblique; VMO: Vastus medialis oblique; GM: Gluteus medius; TFL: Tensor fasciae latae; BF: Biceps femoris; SD: Standard deviation

The study examined the amount of muscle activity in the VMO and VLO muscles during three movements (double-leg squat, lunge, and single-leg squat) in individuals with knee genu varum. It was found that the muscle activity did not differ significantly compared to people with healthy knees.

Using the Smith machine for a forward lunge increased muscle activity in the VMO and VLO muscles. During a lunge in a downward position (sitting), the muscle activity in the right femoral and abdominal muscles increases. In the squat movement, the most muscle activity was observed in the internal and external broad muscles and the spine straighteners (20). No significant difference was observed in this group when measuring TFL EMG activity. However, the level of GM muscle EMG activity was significant. It seems that the deformity of the knee genu varum reduces the activity of the GM muscle in all movements. Instead, the GM muscle assumes a more significant role in the execution of these movements (21). Additionally, the findings did not show any substantial differences in the amount of EMG activity of the BF muscle in three movements, namely pair-leg squat, lunge, and single-leg squat, in the knee genu varum group. The absence of a significant difference in the EMG activity of the BF muscle in the three movements indicates that the abnormality of the knee genu varum affects the EMG activity of the muscles in such a way that the activity of this muscle (BF) in all three movements of the pair-leg squat, single-leg squat, and lunge follows a completely similar and abnormal trend compared to people with a healthy leg (22).

The VMO and VLO muscles are two important muscles that assist in knee extension. Research indicates that knee genu varum abnormalities can reduce the ability of the quadriceps muscle to create stability in the transverse and parabolic planes. However, compensatory alignments can also play a role in the strategies used by the plantar flexor muscles to create stability in the knee (23). Despite this, the results of the present study showed no difference in the amount of EMG activity of VMO and VLO muscles in three movements (double-leg squat, lunge, and single-leg squat) between the healthy and knee genu varum groups. This suggests that these two muscles work together as partners and are part of a muscle group called the quadriceps muscles. Therefore, the results of the study seem logical. Additionally, there is no difference in the start time of VMO and VLO muscle activity between the healthy and knee genu varum groups (24), which is consistent with the present study's findings.

The analysis of research data revealed that there was a significant difference in the amount of EMG activity of the GM muscle in three movements (pair-leg squat, lunge, and single-leg squat) between two groups - one with healthy knees and the other with knee genu varum. Comparing the average activity of the muscle, it was observed that there was a decrease in the activity of the GM muscle in people with knee genu varum compared to those with healthy knees. Meanwhile, the independent t-test results showed no significant difference between the EMG activity of the TFL muscle in the pair-leg squat and lunge movements between the two groups of healthy knees and knee genu varum. The difference was only significant in the single-leg squat exercise. However, no study has specifically compared the activity of these muscles in these skills. A previous study stated that the amount of activity of the GM and lumbar square muscles in the knee genu varum group was significantly lower than that of people without knee genu varum (22). This is because changes in the alignment of the lower limbs, the line of tension of the muscles, and the increase of the forces exerted on the ligamentous, capsular structures on the inside or outside of the knee in static and dynamic situations change the signals sent from the mechanical receptors to the central nervous system (CNS) (8).

The results obtained from the independent t-test also did not show a significant difference in the amount of EMG activity of the BF muscle in three movements (pair-leg squat, lunge, and single-leg squat) between the healthy and knee genu varum groups. This is because the BF muscle is a two-joint muscle, and changes in the natural alignment of the knee joint during the squat movement, either in a pair of legs or in a single-leg lunge movement, may change the length of this muscle. However, these changes seem insufficient to adjust the length of muscle rest (13).

Limitations

The present research had certain limitations that require attention. Firstly, due to the widespread outbreak of coronavirus disease 2019 (COVID-19), access to the statistical population was restricted. Additionally, timing and delay time in muscle activation were not measured. Lastly, as the study was conducted solely on men, it cannot be generalized to the broader population.

Recommendations

Investigating the impact of muscle activation timing and delay time is recommended. Conducting similar studies on women and a larger population with clubfoot deformity would be beneficial. Moreover, it is recommended that similar research be conducted on other sports skills.

Conclusion

The EMG activity of the GM muscle varies significantly between three movements (double-leg squat, lunge, and single-leg squat) and the TFL muscle in the movement of single-leg squat. This difference is observed in both healthy individuals and those with knee genu varum. These findings emphasize the significance of these muscles in the examined movements. Therefore, it is recommended that these changes in the EMG activity of the muscles be monitored and an exercise plan be developed aimed at correction and rehabilitation for people with genu varum deformity who perform the three movements of pair-leg squat, lunge, and single-leg squat.

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Authors' Contribution

Study design and ideation: Ali Hatami-Yadegari

Getting financial resources for the study: Ali Hatami-Yadegari

Scientific and executive support of the study: Ali Hatami-Yadegari

Data collection: Ali Hatami-Yadegari, Ramin Baluchi

Analysis and interpretation of the results: Ali Hatami-Yadegari, Ramin Baluchi, Farideh Babakhani

Specialized statistics services: Ramin Baluchi

Manuscript preparation: Ali Hatami-Yadegari, Ramin Baluchi, Farideh Babakhani

Specialized scientific evaluation of the manuscript: Ali Hatami-Yadegari, Ramin Baluchi, Farideh Babakhani

Confirming the final manuscript to be submitted to the journal website: Ali Hatami-Yadegari, Ramin Baluchi, Farideh Babakhani

Maintaining the integrity of the study process from the beginning to the publication, and responding to the referees' comments: Ali Hatami-Yadegari, Ramin Baluchi, Farideh Babakhani

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Conflict of Interest

The authors did not have a conflict of interest. This article is taken from the dissertation of Ali Hatami-Yadegari, a graduate of Allameh Tabataba'i University. Dr. Ramin Baluchi is an associate professor and Dr. Babakhani is an assistant professor and faculty member of Allameh Tabataba'i University.

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