Journal of Sport Rehabilitation, 2011, 20, 174-186

Gluteus Medius Muscle Activation During Isometric Muscle Contractions

Catriona O'Dwyer, David Sainsbury, and Kieran O'Sullivan

Context: Functional subdivisions are proposed to exist in the gluteus medius (GM) muscle. Dysfunction of the GM, in particular its functional subdivisions, is commonly implicated in lower limb pathologies. However, there is a lack of empirical evidence examining the role of the subdivisions of the GM. ***Objectives:*** To compare the activation of the functional subdivisions of the GM (anterior, middle, and posterior) during isometric hip contractions. ***Design:*** Single-session, repeated-measures observational study. ***Setting:*** University research laboratory. ***Participants:*** Convenience sample of 15 healthy, pain-free subjects. ***Intervention:*** Subjects performed 3 maximal voluntary isometric contractions for hip abduction and internal and external rotation on an isokinetic dynamometer with simultaneous recording of surface electromyography (sEMG) activity of the GM subdivisions. ***Main Outcome Measures:*** sEMG muscle activity for each functional subdivision of the GM during each hip movement was analyzed using a 1-way repeated-measures ANOVA (post hoc Bonferroni). ***Results:*** The response of GM subdivisions during the 3 different isometric contractions was significantly different (interaction effect; $P = .003$). The anterior GM displayed significantly higher activation across all 3 isometric contractions than the middle and posterior subdivisions (main effect; both $P < .001$). The middle GM also demonstrated significantly higher activation than the posterior GM across all 3 isometric contractions (main effect; $P = .027$). There was also significantly higher activation of all 3 subdivisions during both abduction and internal rotation than during external rotation (main effect; both $P < .001$). ***Conclusions:*** The existence of functional subdivisions in the GM appears to be supported by the findings. Muscle activation was not homogeneous throughout the entire muscle. The highest GM activation was found in the anterior GM subdivision and during abduction and internal rotation. Future studies should examine the role of GM functional subdivisions in subjects with lower limb pathologies.

Keywords: hip, abductor, functional subdivisions, electromyography

The gluteus medius (GM) plays an important role in maintaining normal movement patterns of the pelvis and lower limb and is considered one of the primary stabilizers in the pelvic region.[1–3] Dysfunction of hip muscles such as the GM has been associated with many lower limb pathologies including patellofemoral pain

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O'Dwyer and O'Sullivan are with the Dept of Physiotherapy, University of Limerick, Limerick, Ireland. Sainsbury is with the School of Physiotherapy, Curtin University of Technology, Perth, Australia.

syndrome, iliotibial band syndrome, and hip osteoarthritis.[2,4–10] This is based on the premise that GM dysfunction may result in poor control of hip adduction and internal-rotation forces during weight bearing.[11–14] Furthermore, exercise programs aimed at rehabilitating the GM appear to have some effectiveness in the management of these disorders.[5,15–18] However, uncertainty remains regarding the best method of activating the GM muscle because its precise action is still debated in the literature.[3,19,20]

The primary action of the GM at the hip is commonly described as abduction,[21–23] but a previous study described little or no GM activation during hip abduction.[24] Weakness of the GM is often hypothesized in the presence of reduced hip external-rotation strength,[20] yet other research has shown that hip internal rotation results in higher activation of the GM than hip external rotation.[19] Furthermore, simply considering the role of the GM as a homogeneous muscle does not reflect findings on anatomical dissection.[22,25,26] These anatomical studies suggest that the GM consists of distinct functional subdivisions (anterior, middle, and posterior), similar to other muscle groups—for example, the trapezius and gluteus maximus.[27,28] Consequently, many rehabilitation programs for the GM are based on the presence of these functional subdivisions.[5,29] The exact role of the functional subdivisions of the GM remains poorly understood. Most previous studies examining GM activation used only 1 or 2 electrodes and therefore did not evaluate all proposed functional subdivisions of the GM muscle.[2,10,19,23,30–33] Only 1 previous study examined the activation of the 3 individual functional subdivisions of the GM[34] and found that the subdivisions are activated differently during functional tasks. As a precursor to determining whether there are differences in GM functional subdivisions in injured subjects, it is important to initially establish the activation of the functional subdivisions of the GM in pain-free subjects. In addition, the direction of hip movement that results in greatest muscle activation is of interest because of its potential significance for exercise prescription.

Therefore, the primary aim of this study was to compare the activation of the proposed functional subdivisions (anterior, middle, and posterior) of the GM during isometric contractions of the hip in normal subjects using surface electromyography (sEMG). The secondary aim was to determine which isometric hip contraction (abduction, internal rotation, or external rotation) causes the greatest activity of the GM. We hypothesized that there would be a significant difference in the activation pattern of the GM subdivisions, with the anterior and middle subdivisions contributing more to abduction and internal rotation of the thigh because of their almost vertical anatomical alignment.[22,25,26] Conversely, we hypothesized that the posterior aspect of the GM would contribute more to external rotation of the thigh because of its more horizontal alignment.[22,25]

Methods

Design

Subjects attended a single 1-hour testing session in the university research laboratory. Isometric-contraction direction (abduction, internal rotation, external rotation) and muscle subdivision (anterior, middle, posterior) were the independent variables, and sEMG activity was the dependent variable.

Participants

Approval for this study was granted by the local university research ethics committee. A convenience sample of 15 healthy subjects (7 male, 8 female) was recruited from the university campus via e-mail. The participants' mean (± SD) age was 22 (± 4) years, height was 170 (± 12) cm, body mass was 68 (± 12) kg, and body-mass index was 23 (± 3) kg/m^2. Written informed consent was obtained from all subjects before testing. Subjects were included if they were 18–30 years old and had had no back or lower limb injury requiring treatment in the past 6 months.

Procedures

Subjects completed the Modified Physical Activity Readiness Questionnaire in advance of testing.[35] They then completed a 5-minute aerobic warm-up at a self-selected pace on a treadmill, as well as gentle lower limb stretches to minimize the risk of muscle soreness and muscle fatigue.[36] A multichannel EMG system (MA-300, Motion Laboratory Systems, Baton Rouge, LA, USA) was used to acquire sEMG data using bipolar, preamplified, circular electrodes that were 144 mm^2 in size, with a fixed interelectrode distance of 18 mm. The sample rate was 1250 Hz per channel, with a bandwidth of 5 to 500 Hz. The gain setting was 2000, and the common-mode rejection ratio was >100 dB at 65 Hz. Each subject's right leg was tested. The skin was prepared for electrode placement by abrading it with fine sandpaper, shaving any hair, and cleansing the skin with isopropyl alcohol solution to reduce skin impedance.[37] Before testing, the optimal electrode location and orientation for the anterior, middle, and posterior GM subdivisions were determined. SENIAM guidelines describe only 1 surface electrode position for the GM,[38] so electrode-placement positions for each subdivision were modified based on previous sEMG[19,23] and anatomical[22,25,26] studies. In addition, a preliminary pilot study using real-time ultrasound confirmed that the GM was the muscle immediately beneath the chosen electrode placements. The anterior GM electrode was placed 50% of the distance between the anterosuperior iliac spine and the greater trochanter. The middle GM electrode was placed 50% of the distance between the greater trochanter and the iliac crest. The posterior GM electrode was placed 33% of the distance between a mark on the posterior ilium and the greater trochanter (Figure 1). The posterior ilium landmark used was 20% of the distance between the iliac crest and the L4–L5 interspace. Anatomical landmarks were marked on subjects and confirmed by a second tester in an attempt to improve reliability. One preamplified bipolar electrode was then placed on each muscle subdivision (anterior, middle, and posterior) oriented parallel to the muscle-fiber direction of the individual muscle subdivision.[37,39] A reference electrode was placed on the ulnar styloid process.[37] Correct location of the electrodes was visually confirmed by examining the sEMG output while applying manual resistance to hip abduction.[38] Electrodes were checked for good contact before all contractions.[40]

The Biodex System 3 isokinetic dynamometer, which provides reliable and valid measures of torque,[41] was used for the isometric hip contractions. Hip abduction was tested in standing with the hip in 30° abduction (Figure 2). Subjects were instructed to maintain an upright trunk position and to push their leg directly laterally during testing. Internal and external rotation were tested in prone with the hip in neutral rotation and the knee flexed to 90° (Figure 3).

Figure 1 — Electrode placements for the posterior, middle, and anterior subdivisions of the gluteus medius. X's mark the landmarks used to locate the electrodes: anterosuperior iliac spine, iliac crest, greater trochanter, and posterior ilium.

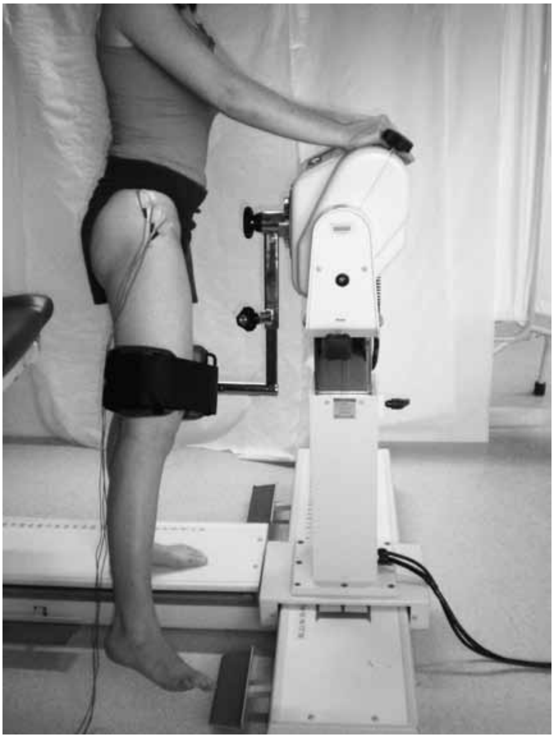

Figure 2 — Subject position for performing isometric abduction while standing.

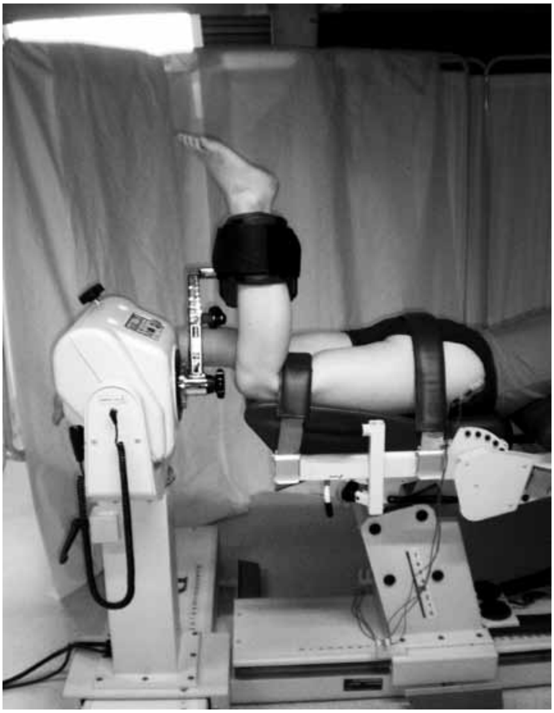

Figure 3 — Subject position for performing isometric internal and external rotation in prone.

The hip was in neutral flexion/extension for all contractions. The dynamometer resistance pad was placed 2 cm superior to the superior pole of the patella during abduction and 2 cm superior to the lateral malleolus for internal/external rotation. Before testing in each position, 3 submaximal and 1 maximal contraction were performed for familiarization purposes and to ensure correct performance.[42] The isometric hip contractions were then consistently tested in the order of abduction, external rotation, and internal rotation. Subjects completed 3 maximal voluntary isometric contraction (MVIC) trials, each of 5 seconds duration, in each position.[39] Before and during each trial, subjects received standardized verbal instructions and encouragement.[43] They were given a 1-minute break after familiarization, in addition to a 30-second rest between MVIC repetitions and a 3-minute rest between positions to minimize muscle fatigue.[32] After testing, the electrodes were removed and the skin was cleansed.

EMG signals were processed with customized WinDaq software. The EMG data were then full-wave rectified and processed using a root-mean-square (RMS) algorithm over 150 milliseconds.[39,44] The RMS amplitude was then calculated from the middle 3 seconds of each trial to minimize any effects associated with beginning or ending performance effort or changes in skin–electrode interface characteristics.[31,39] RMS amplitudes for the 3 trials of each isometric contraction were then averaged and used for statistical analysis.[45]

Statistical Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences, version 15.0. A 1-way ANOVA for muscle subdivision with repeated measures on isometric-contraction direction (with post hoc Bonferroni) was performed to determine whether there were any significant differences with respect to muscle-subdivision × isometric-contraction-direction interaction, muscle subdivision, and isometric-contraction direction. Assumptions for such statistical analysis (normality of distribution and sphericity) were considered. For all statistical tests the alpha level was set at $P < .05$ in accordance with previous research.[19,30]

Results

All 15 subjects completed the test protocol. The muscle activity of the 3 subdivisions of the GM during the 3 isometric hip contractions is displayed in Table 1.

Interaction Effect

There was a significant interaction between muscle subdivision and isometric contractions ($P = .003$), indicating that the activation of the 3 subdivisions of the GM were different depending on which isometric contraction was performed. Figure 4 illustrates that the overall activation of the subdivisions differs but also that there are significant differences between isometric-contraction directions. For example, the activation during abduction is significantly greater than during internal rotation in the posterior subdivision ($P < .01$) but not in the other 2 subdivisions (both $P > .05$).

Main Effect: Muscle Subdivision

There was a significant main effect for muscle subdivision ($P < .001$). The anterior GM had a significantly higher activation across all 3 isometric contractions than either the middle or posterior GM (both $P < .001$). The middle GM also demonstrated a significantly higher activation than the posterior GM across all 3 isometric contractions ($P = .027$; Figure 4).

Table 1 Muscle Activity for Individual Gluteus Medius Muscle Subdivisions During Isometric Hip Contractions, Mean ± SD

Muscle subdivision	Contraction direction	Root-mean-square muscle activity (mV)
Anterior	Abduction	0.47 ± 0.24
	Internal rotation	0.47 ± 0.33
	External rotation	0.09 ± 0.07
Middle	Abduction	0.24 ± 0.15
	Internal rotation	0.25 ± 0.14
	External rotation	0.02 ± 0.01
Posterior	Abduction	0.12 ± 0.05
	Internal rotation	0.07 ± 0.03
	External rotation	0.02 ± 0.01

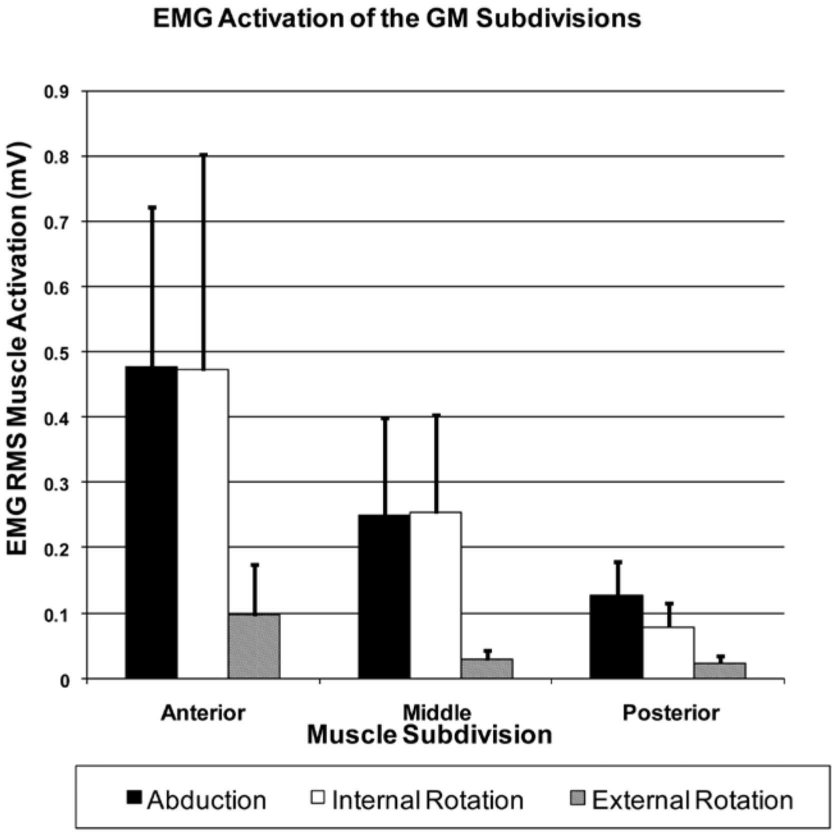

Figure 4 — Mean root-mean-square (RMS) muscle activity for each gluteus medius subdivision during the three hip contractions: abduction, internal rotation, and external rotation.

Main Effect: Isometric-Contraction Direction

There was also a significant main effect of isometric-contraction direction (*P* < .001). There was significantly lower activation of the muscle subdivisions during external rotation than during either internal rotation or abduction (both *P* < .001). No significant difference in muscle activation was found when comparing the activation of the muscle subdivisions during abduction and internal rotation (*P* = 1.000; Figure 4).

Discussion

The results of this study demonstrate that the muscle activation of the individual subdivisions of the GM during isometric hip contractions is not homogeneous. There were significant differences in sEMG activation between the functional subdivisions of the GM. The anterior GM demonstrated the highest level of activation, followed by the middle GM, and the posterior GM had the lowest activation. It is clear that the activation of the GM was not uniform throughout the muscle. It is difficult to compare the activation of the 3 different functional subdivisions of the GM in this study with other work, because there is limited literature available. However, the current findings are consistent with those of Soderberg and Dostal,[34] who also reported differences in muscle activity between these 3 subdivisions. Unfortunately, Soderberg and Dostal[34] quantified muscle activation simply on an ordinal scale and used fine-wire electrodes, making it difficult to compare their results with those of the current study. In addition, they assessed functional tasks rather than the isometric hip movements performed in the current study. Despite this, their assertion that there are significant differences between GM subdivisions is supported by the findings of the current study.

The direction of hip contraction had a significant effect on the activation of GM subdivisions. Abduction and internal rotation both resulted in significantly higher activation across all 3 functional subdivisions of the GM than external rotation. The important role of the GM as an abductor in this study is consistent with the findings of some previous EMG evaluations of the GM.[19,23,30,46] It is also in line with suggestions that abduction and internal rotation are the main roles of the GM,[19] because the alignment of the muscle fibers, in particular those of the anterior and middle subdivisions, supports their role in abduction and internal rotation.[22] However, in contrast to these findings, Wilson et al[24] reported that the GM was relatively inactive during abduction in many subjects. The current study helps shed some light on these conflicting findings. EMG studies showing significant activation of the GM during abduction analyzed the anterior and middle subdivisions,[19,30,46] which showed high levels of activation during abduction in the current study, whereas those that concluded that the GM was relatively inactive during abduction[24] used a single EMG electrode for the posterior GM. The current study also found that the posterior GM demonstrates consistently lower levels of activity during abduction than the anterior and middle GM. Hence, the reduced activity described by Wilson et al[24] may reflect the reduced activity of the posterior GM similar to that observed in the current study, as opposed to the functional role of the entire GM muscle during abduction. This helps explain the difference between these previous studies and highlights the risks of only assessing 1 GM subdivision and extrapolating the results to the muscle as a whole.

Regarding hip rotation, the results of the current study are in agreement with previous research by Earl[19] that demonstrated that the anterior and middle GM are significantly more active during combined abduction and internal rotation than during simple abduction or a combined abduction/external-rotation task. Earl,[19] however, did not evaluate the posterior GM subdivision. Schmitz et al[30] also demonstrated that GM activity increases when external hip-rotation forces are increased, again suggesting that the GM plays an important role in internal rotation. Schmitz et al[30] appear to have placed their GM electrode over the middle GM, so their findings are consistent with the current study. The hypothesis that the posterior GM would be more active during external rotation because of the more horizontal alignment of its fibers[3,5,18,29] is contradicted by the results of the current study, because the posterior GM actually demonstrates lower activation during external rotation than during either abduction or internal rotation. This indicates that the posterior GM does not necessarily activate as per anatomically based hypotheses.[22,47] If the GM is not very active during external rotation, this questions the unique importance placed on its role in numerous lower limb injuries, because weakness of abduction and external rotation appears to be more significant in the development of lower limb injuries than weakness of internal rotation.[9,20,48–51] Similarly, the fact that excessive hip adduction and internal-rotation motion have been implicated in these lower limb injuries[11,12] also brings into question the unique importance of the GM if it has a greater role in hip internal rotation than in hip external rotation. Thus it is possible that greater consideration should be given to other hip muscles such as the gluteus maximus and the deep hip lateral rotators in the development of these injuries.[3,28]

Although there is evidence that rehabilitation programs aimed at increasing the strength and activation of hip muscles including the GM are moderately effective in reducing pain and disability in many lower limb disorders,[5,15–18] the mechanism by which these programs have their effect remains unclear.[15,33,51] The dysfunction may not be isolated to only 1 muscle subdivision[3,10] or hip movement.[48] Future research examining the role and activation of the GM and its functional subdivisions in a symptomatic population may facilitate a clearer understanding of the mechanisms involved and enable clinicians to provide targeted rehabilitation.

Limitations of this study include the small sample (N = 15) of young asymptomatic subjects. Although this is comparable to previous EMG studies,[19,33] a power calculation was not performed and larger studies in clinical populations are required. Using sEMG has inherent limitations, for example, a risk that “cross-talk” from nearby muscles or even adjacent muscle subdivisions could affect the results.[40] This limitation applies to all sEMG studies and was minimized by the use of a small interelectrode distance as recommended.[37] sEMG data could have been normalized to MVIC or another reference standard,[52] but this is not necessary when within-day, within-subject comparisons are made if the electrodes remain in place throughout testing,[39] and this approach is similar to previous sEMG research on the GM.[19,30] Furthermore, the optimal electrode-placement locations for sEMG recording of the GM subdivisions are unknown and were simply chosen based on preliminary ultrasound findings and previous dissection studies.[22,25,26] Ultrasound was performed in advance to confirm that the electrode placements were appropriate and overlying the GM muscle, but this ultrasound confirmation was not repeated for each subject at the time of testing. Furthermore, the reliability of palpating anatomical landmarks was not examined before testing. Of particular concern is the fact that part of the posterior GM lies deep to the gluteus maximus,[25] Therefore, the posterior GM subdivision measured and described here reflects the superior, and not the deep inferior, part of the posterior GM. We acknowledge the possibility that the activation of the deep, inferior fibers of the posterior GM may be different, possibly by having a greater role in external rotation, but there is a lack of data in this area to compare with, and we hope to examine this in further research using fine-wire EMG. The order of isometric-contraction direction was not randomized, but any learning effect was minimized by familiarization in advance,[42] and the risk of fatigue was minimized by providing subjects with adequate rest periods.[32] We examined only isometric non-weight-bearing contractions, not functional weight-bearing tasks. Similarly, all hip movements were tested in neutral hip flexion/extension. Given that the action of the hip muscles appears to be influenced by the degree of hip flexion,[47] functional weight-bearing activities in positions of varying hip-joint angles should be examined in future studies. This study examined only the magnitude of GM activation during maximal activities, not the timing of muscle activation during submaximal functional tasks, which may be an even more important factor to consider in future studies.[2,10,15] This is important because previous research has demonstrated timing differences between GM subdivisions during functional tasks,[34] and there is confusion regarding the presence or absence of GM activation timing differences in patellofemoral pain syndrome.[2,10,15] Future research is needed to concurrently assess numerous parameters in several key hip muscles involved in movement and stability of the hip, including assessment of EMG timing and amplitude, lower limb kinematics, muscle size, and muscle strength. Despite these limitations, this study remains the first to look at each subdivision of the GM during isometric hip movements and has demonstrated that there are subdivisions in the GM, as previously hypothesized based on anatomical studies[25,26] and in line with observations of other skeletal muscles such as the trapezius,[27] quadriceps,[53] and gluteus maximus.[28] The results may help clarify some existing confusion in the literature and guide both clinical practice and future studies on clinical populations.

Conclusion

In conclusion, the results of this study support the hypothesis that there are functional subdivisions in the GM muscle. The anterior GM demonstrates higher levels of activation during isometric hip movements than either the middle or posterior GM. Furthermore, the GM is most active during abduction and internal rotation of the hip. This study provides an insight into the complex role of the functional subdivisions of the GM in normal subjects. There is a need for future studies to investigate the activation of the functional subdivisions of the GM in clinical populations with lower limb pathologies. An improved understanding of the role of the GM and its functional subdivisions may provide insight into the mechanisms of numerous lower limb injuries and ultimately enable clinicians to provide effective targeted rehabilitation.

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