DIFFERENCES IN THE ELECTROMYOGRAPHIC ACTIVITY OF THE HAMSTRING, GLUTEUS MAXIMUS, AND ERECTOR SPINAES MUSCLES IN A VARIETY OF KINETIC CHANGES

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ABSTRACT
Hirose, N and Tsuruike, M. Differences in the electromyographic activity of the hamstring, gluteus maximus, and erector spinae muscles in a variety of kinetic changes. J Strength Cond Res XX (X): 000–000, 2018—This study aimed to clarify the differences in the electromyographic (EMG) activity of the semitendinosus (ST), semimembranosus (SM), biceps femoris long head (BFl), gluteus maximus (GM), and erector spinae (ES) muscles during leg curl and bridge exercises across different knee angles and isometric contraction outputs. Sixteen male volunteers participated in this study. The EMG of all targeted muscles was measured at 20 and 40% of the maximal voluntary isometric contraction (MVIC) in the leg curl and during bilateral and unilateral bridge exercises. The knee flexion angle was randomly set at 30, 60, 90, and 120° during each of the exercises. The obtained data were normalized by the MVIC of the corresponding muscle, and each of the normalized values was compared with that of the ST. The EMG activity of the ST was significantly greater at 120° of knee flexion than that of 30 and 60° of knee flexion during leg curl regardless of intensity (p < 0.05), in contrast with that of the SM and BFl. However, bridge exercises diminished this inverse relationship. The ES activity changed similarly to that of the hamstrings, and no difference was observed in the activity of the GM regardless of different knee angles during bridge exercise(s). The strength and conditioning professionals should alter the knee joint angle and load during bridge and leg curl exercises according to which hamstring muscle they want to strengthen because ST, SM, and BFl EMG activity varies depending on the intensity and knee angles during these exercises.

KEY WORDS stabilization, hamstring muscle strength, prehabilitation, rehabilitation, preventive medicine

INTRODUCTION
Improvement of muscular strength is important in preventing injury recurrence. Strengthening the hamstring as one of the return-to-play criteria reduces the recurrence rate of a hamstring injury (14,24). Furthermore, increased hamstring strength is necessary after anterior cruciate ligament (ACL) reconstruction (ACL-R) to stabilize the knee joint during jump landing, which reduces strain on the ACL (27). Consequently, various exercises aimed at strengthening the hamstrings, such as leg curl and hip bridge exercises and Nordic hamstrings, are prescribed for rehabilitation (22).

The hamstring group comprises 4 different muscles: the semitendinosus (ST), semimembranosus (SM), biceps femoris long head (BFl), and biceps femoris short head. Each of the hamstring muscles has different morphological features, such as physiological and anatomical cross-sectional area, pennation angle, muscle fiber length, and number of joints that the muscle crosses (4). Compared with other biarticular muscles, such as the SM and BFl, the ST has a unique feature with its long fiber length and fusiform, paralleled fibers without the pennation angle (13). Muscle activity varies with a change in fiber lengths during joint movement (7). Given this length-tension relationship, the ST might exhibit an activity pattern that differs from the SM and BFl. However, little is known about the differences in muscle activity among the hamstrings across different knee joint angles during open- and closed-kinetic chain (OKC and CKC, respectively) exercises (13,15,17).

Hamstring injury mostly occurs in the SM and BFl muscles, but rarely in the ST muscle (11). Weakness of these muscles predisposes to reinjury (24); thus, it can be prevented by strengthening the SM and BFl muscles through proper exercise during rehabilitation. In other cases, the ST muscle tendon is often used as a graft for ACL-R (2), but not the other hamstring muscles. Isometric and isotonic strength training of the hamstring in OKC and CKC exercises with body mass has been recommended even in the early rehabilitation phase (week 2–9
post-ACL-R) (25). However, the harvested ST tendon could be regenerated (20) and has an effect on hamstring strength recovery (10,30). The regeneration of the ST muscle tendon accelerates within 4 weeks after ACL-R (30), and excessive load to the ST should be avoided, especially during early rehabilitation. Hence, strength training in the early rehabilitation phase should focus on activating specific target muscle groups while minimizing the others, such as being aware of the ST muscle activity.

Based on previous research findings, clarifying the magnitude of activity in each of the hamstring muscles during OKC and CKC exercises across different joint angles might help in establishing appropriate rehabilitation and prehabilitation program for preventing injury recurrence. Thus, the study mainly aimed at clarifying the differences in the electromyographic (EMG) activity of the ST, SM, and BFl muscles across various knee joint angles during OKC and CKC exercises. This study used leg curl and hip bridge exercises for OKC and CKC, respectively. Furthermore, this study recorded the EMG activity of the gluteus maximus (GM) and erector spinae (ES) to identify the amount of complementary activity that occurred in those tasks associated with the activity of the hamstring muscles. This study hypothesized that the ST muscle would work more than the SM and BFl muscles at a deep knee flexion angle, whereas the latter muscles would work more than the ST at a lower knee flexion angle, regardless of the kinetic change.

**Methods**

**Experimental Approach to the Problem**

This study adapted a cross-over study design. To reveal the difference in activity of ST, SM, BFl, GM, and ES muscle during OKC and CKC exercises, subjects performed unilateral and bilateral bridge exercises randomly after leg curl in prone position with 20 and 40% of maximum voluntary isometric contraction (MVIC). During these exercises, the knee flexion angle was randomly set at 30, 60, 90, and 120°. The EMG of each muscle was recorded during each exercise for the analyses.

**Subjects**

Sixteen young active male volunteers (mean age, 22.5 ± 3.7 years [age range 18.6 ± 27.4] height, 172.7 ± 15.7 cm; and body mass, 77.5 ± 10.3 kg, all measured in mean ± SD) participated in this study. Subjects with any present injury and history of hamstring strain were excluded. All study protocols were approved by the institutional review board in the Office of Research at San José State University. All subjects were fully informed of the procedure and purpose of this study, and provided written informed consent.

**Procedures**

Before the experiment, the participants performed 5 minutes of warm-up exercises. Then, the participants performed 2 bouts of 5-second MVIC, and their peak torque was measured using a digital handheld dynamometer (MicroFET2; Hoggan, Salt Lake City, UT). The MVIC of the hamstring, GM, and ES was measured using procedures described in previous studies (3,17): prone knee curl at 90° knee angle, hip extension with knee flexed at 90°, and trunk extension, respectively. The greatest torque for each of the muscle activities was used to normalize each of the muscle activities in the subsequent tests. After the MVIC measurement, the participants performed 2 bouts of 5-second isometric leg curl in prone position with 20% (20LC) followed by 40% (40LC) of MVIC using the dominant leg, which was the kicking leg side. The knee flexion torque of each test was monitored by the examiner using the dynamometer, and the participants were asked to generate the force to meet the examiner’s instruction (Figure 1). During the test, the examiner visually checked whether the hip joint is set at neutral position in the frontal and horizontal planes.

![Figure 1](image-url): Leg curl (upper column) and bridge exercise (both leg bridges; lower column). Leg curls were performed at 20 and 40% of MVIC. The knee flexion torque was monitored by examiner using a handheld dynamometer. Bridge exercise was performed with single leg and both legs. The knee angle during both exercises was randomly set at 30, 60, 90, and 120°. MVIC = maximal voluntary isometric contraction.
After performing leg curl, participants performed 3 bouts of bridge exercise with bilateral (BB) and unilateral leg (UB) randomly for 5 seconds (Figure 1). The knee flexion angle was also randomly set at 30°, 60°, 90°, and 120° for each exercise. The examiner monitored the knee joint angle at the start of each exercise using a manual goniometer. The participants had 2 minutes of rest between the exercises. The EMG activity of the ST, SM, BFl, GM, and ES was measured using bipolar surface electromyogram silver electrodes (Bagnoli-8; Delsys Inc., Natick, MA) with a bar length of 10 mm, width of 1 mm, and distance of 1 cm between active recording sites. The EMG electrodes were preamplified (10×) and routed through the EMG mainframe, which further amplified (100×), a total gain of 1,000× and band-pass filtered (20–450 Hz) the signals. Skin impedance was reduced by shaving the hair around the electrode site and wiping the skin with rubbing alcohol before applying the electrodes. The electrodes were placed on each target muscle based on the following landmarks: midpoint of the line between the ischial tuberosity and the medial epicondyle of the tibia (for the ST), midpoint between the ischial tuberosity and the lateral epicondyle of the tibia (for the BFl), midpoint between the spinous process of the L1 vertebra (for the ES). In addition, accurate placement of the electrodes was validated by palpating the muscle bellies and ensuring a clean EMG signal during manually resisted knee flexion for the SM. This study redacted the root mean square (RMS) from all the raw EMG data during the middle 2 seconds of the 5-second exercise for further analysis. The intraclass correlation coefficients (ICCs) of the EMG data of each muscle were analyzed by each exercise. Then, the calculated ICC was evaluated as “almost perfect (ICC > 0.81),” “substantial (ICC = 0.61–0.80),” or “moderate (ICC = 0.41–0.60)” according to a previous study (12). As a result, all EMG data of each muscle were evaluated as “almost perfect,” except for the GM of 20LC at 60° (ICC (1.2) = 0.77) and BB at 30° (ICC (1.3) = 0.63), ES of 20LC at 30, 90, and 120° (ICC (2.1) = 0.77, 0.57, and 0.73, respectively), and 40LC at 90° (ICC (1.3) = 0.71).

### Statistical Analyses

The average value (± SE) of each of the exercises was calculated. Then, the RMS data were normalized as a percentage of

| Table 1. Difference in electromyographic data normalized as a percentage of the maximum isometric values of the semitendinosus (ST), semimembranosus (SM), biceps femoris long head (BFl), gluteus maximus (GM), and erector spinae (ES) at each knee joint angle during each exercise.* |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | 20LC | 40LC | BB   | UB   | Intraexercise difference |
| ST              |       |       |       |       |                  |
| 30°             | 32.3 (2.5) | 48.4 (4.5) | 46.3 (4.1) | 89.4 (7.1) | 20-40,B,U; 40-U; B-U |
| 60°             | 38.3 (3.0) | 53.5 (2.9) | 32.1 (3.6)* | 56.1 (3.7)* | 20-40-U; 40-B; B-U |
| 90°             | 38.8 (2.7)* | 61.3 (2.4)*,† | 18.6 (2.8)*,† | 31.2 (3.0)*, † | 20-40-B,U; 40-B,U; B-U |
| 120°            | 49.3 (6.7)*,†, † | 68.3 (6.6)*,†, † | 10.3 (1.0)*,†, † | 18.6 (2.5)*,†, † | 20-40-B,U; 40-B,U; B-U |
| SM              |       |       |       |       |                  |
| 30°             | 45.6 (4.3) | 65.5 (7.0) | 62.2 (5.3) | 109.4 (7.4) | 20-40-B,U; 40-U; B-U |
| 60°             | 47.0 (4.4) | 64.0 (6.7) | 37.9 (4.9)* | 68.4 (6.8)* | 20-40-U; 40-B; B-U |
| 90°             | 31.1 (3.4)*,† | 50.8 (4.2)*,† | 17.1 (3.3)*,† | 30.5 (2.9)*,† | 20-40-B,U; 40-B,U |
| 120°            | 33.1 (5.7)*,† | 48.3 (5.0)*,† | 9.0 (1.1)*,†, † | 17.2 (2.5)*,†, † | 20-40-B,U; 40-B,U |
| BFl             |       |       |       |       |                  |
| 30°             | 49.0 (4.4) | 68.7 (6.1) | 66.6 (7.8) | 124.5 (12.8) | 20-40-B,U; 40-U; B-U |
| 60°             | 44.8 (5.3) | 62.3 (4.8) | 42.7 (7.4) | 77.0 (10.6)* | 20-40-U; 40-B; B-U |
| 90°             | 31.7 (6.4)*,† | 49.0 (5.7)*,† | 21.9 (5.5)*,† | 38.8 (5.8)*,† | 20-40; 40-BB; BB-U |
| 120°            | 31.7 (5.3)*,† | 46.4 (5.3)*,† | 15.9 (3.6)*,† | 24.1 (5.8)*,†, † | 20-40-BB; BB-U |
| GM              |       |       |       |       |                  |
| 30°             | 17.9 (1.9) | 17.6 (1.9) | 20.9 (2.0) | 34.5 (3.2) | 20-U; 40-U; B-U |
| 60°             | 17.9 (1.9) | 17.4 (1.9) | 23.4 (2.0) | 35.3 (2.9) | 20-B,U; 40-B; B-U |
| 90°             | 17.7 (1.9) | 17.9 (1.9) | 25.1 (2.0) | 34.9 (3.1) | 20-B,U; 40-B; B-U |
| 120°            | 18.0 (1.9) | 18.2 (1.9) | 25.8 (2.1) | 32.2 (3.0) | 20-B,U; 40-B; B-U |
| ES              |       |       |       |       |                  |
| 30°             | 17.6 (0.5) | 24.6 (0.6) | 74.6 (1.3) | 73.7 (1.3) | 20-40,B,U; 40-B,U |
| 60°             | 14.3 (0.5) | 18.7 (0.5)* | 56.8 (0.8)* | 57.8 (1.0)* | 20-B,U; 40-B,U |
| 90°             | 11.5 (0.5)* | 16.1 (0.4)* | 53.0 (0.7)* | 50.1 (1.0)*, † | 20-B,U; 40-B,U |
| 120°            | 14.8 (0.6) | 25.5 (0.9)*,† | 49.2 (0.9)*,† | 45.3 (0.8)*,†, † | 20-40-B,U; 40-B,U |

*The symbols (*30°, †60°, and †90°) and abbreviations (20, 20LC; 40, 40LC; B, BB; and U, UB) indicate statistical significance (p < 0.05).
the maximum isometric values (normalized EMG [NEMG]). The NEMG of the ST was divided by that of the SM and BFl to calculate the ratio ST of SM and BFl, which were used to investigate the work ratio of the ST with that of the SM and BFl. A 2-way repeated-measures analysis of variance design was used to compare the NEMG and ST ratio of each muscle across different exercises, intensities, and knee joint angles. Where appropriate, the simple main effect and the Tukey’s post hoc test were used to measure any difference. In addition, partial $\eta^2$ and statistical power were also analyzed by using SPSS (version 24.0; IBM, New York, NY). The statistical power ranged from 0.95 to 1.00. The statistical significance level was set at 0.05.

**RESULTS**

A significant interaction between exercise and knee joint angle was observed in the ST, SM, BFl, GM, and ES muscles ($F_{9,135} = 35.7, 30.5, 19.7, 4.4, \text{and} 10.6$, respectively) ($p < 0.05$; partial $\eta^2 = 0.60, 0.44, 0.44, 0.18, \text{and} 0.30$, respectively).

The ST EMG activity significantly increased according to the knee flexion angle during leg curl ($p < 0.05$), with the EMG measured at $120^\circ$ being significantly highest in 20LC and 40LC, and was higher at $90^\circ$ than at $30^\circ$ (20LC and 40LC) and $60^\circ$ (40LC) ($p < 0.05$). By contrast, the ST EMG activity significantly decreased according to knee flexion, whereas the knee joint angle increased in both bridge exercises ($p < 0.05$). Meanwhile, the EMG activity of the SM and BF decreased as the knee flexion angle increased during both leg curl and bridge exercises. The EMG activity of these muscles at $90$ and $120^\circ$ were lower than that at $30$ and $60^\circ$ during 20LC and 40LC ($p < 0.05$). Likewise, the EMG activity decreased as the knee flexion angle increased during both bridge exercises ($p < 0.05$) (Table 1).

Regarding the ST/SM and ST/BFl ratios, there was a significant interaction ($F_{9,135} = 2.68$ and 6.76, respectively) ($p < 0.05$; partial $\eta^2 = 0.118$ and 0.253, respectively). Both ratio values at $90$ and $120^\circ$ were higher than those at $30$ and $90^\circ$ during 20LC and 40LC. The ST/SM ratio was higher during BB at $90$ and $120^\circ$ than those at $30$ and $60^\circ$ ($p < 0.05$), whereas no difference was observed in the ST/BFl ratio. In addition, a significant main effect among exercises was observed in the ST, SM, BFl, and ST/SM ($p < 0.05$) (Figure 2).

There was no difference in the GM across knee joint angles, whereas ES showed a significant difference ($p < 0.05$). The ES EMG activity at $90^\circ$ was lower than that of $30^\circ$ in 20LC. In addition, the ES EMG activity at $30$ and $120^\circ$
was higher than those at 90 and 60° in 40LC. The ES EMG activity significantly decreased as the knee flexion angle increases, except between 60 and 90° and between 90 and 120° in BB (Table 1). With regards to the ST/GM and ST/ES ratios, there was a significant interaction \( F_{(8,135)} = 16.00 \) and 4.86 \( (p < 0.05; \text{partial } \eta^2 = 0.44 \text{ and } 0.195, \text{respectively}) \). The ratio of ST/GM was higher at 120° than that of 30, 60, and 90° in 20LC and 40LC \( (p < 0.05) \). In addition, the ST/ES ratio was lower at 30° than that at 60, 90, and 120° in 20LC and 40LC \( (p < 0.05) \). Moreover, the ST/GM ratio significantly decreased as the knee flexion angle increased except between 90 and 120° in both BB and UB \( (p < 0.05) \). Meanwhile, there was no significant difference in ST/ES ratio across different knee joint angles in both bridge exercises (Figure 2).

**DISCUSSION**

This study demonstrated that the ST EMG activity was higher than that of the SM and BFl at deep knee flexion angles during leg curl. However, the inverse relationship between the ST and the SM was diminished during the UB and BB exercises, and the ST and BFl worked synergistically regardless of the difference in the knee joint angle.

In this study, the EMG activity of each of the hamstrings varied at different knee joint angles during leg curl exercises. The increase in the ST/SM and ST/BFl ratios with the increase in knee flexion angle indicates that the ST works more at deep knee flexion angles than the other 2 hamstrings, which is in agreement with that of a previous study (13,21). Based on these findings, each hamstring muscle appears to have functional differences, with the SM and BFl working harder at the initial phase of knee flexion and ST working greater at deep flexion angles to complement the decrease in the other 2 muscles during the OKC exercise.

Several factors, such as differences in morphological feature and moment arm, may be responsible for the difference in the EMG activity of the hamstrings at different knee joint angles. The ST muscle, which has a fusiform shape with longitudinal fibers, in contrast to the SM and BFl muscles, which are composed of unipennate fibers (4). The ST muscle can potentially shorten across a large amount of knee joint angles compared with the SM and BFl because of its long fiber length and higher number of sarcomeres (13). This morphological characteristic enables the ST to contract sufficiently even at a deep knee flexion angle. On the contrary, aside from their short fiber length and fewer sarcomeres, the SM and BFl are categorized as pennate muscles, and the increase in angle during isometric contraction (5) could not produce active force at a deeper knee flexion angle because they reached the most shortened position earlier than the ST. Indeed, previous literatures have reported a decrease in the EMG activity and torque of pennate muscles with an increase in the joint angle in the SM (15). In addition, the difference in the knee flexion moment arm of the hamstrings also appears to be responsible for the difference in EMG activity. Because the ST terminates more distally than the other 2 muscles, the moment arm of the ST is maximized at deep knee flexion angles, whereas the moment arm of the SM and BFl decreases as the knee flexion angle increases once they reach the peak value at 75° (6). Arnold et al. (1) demonstrated that the knee flexion moment arm of the ST was larger than that of the SM, especially over 60° of knee flexion. This kinetic difference might also lead to the difference in the EMG activity of the hamstrings at various knee joint angles.

Hip extension and knee flexion are required during bridge exercise, whereas leg curl requires only knee flexion. This kinematic difference between the 2 exercises can be responsible for the minimized inverse relationship among the ST, SM, and BFl during bridge exercises. Aside from the hamstrings, the GM also contributes to hip extension (16). Furthermore, the SM and BFl work more in hip extension and the ST works more in knee flexion (18,19). Moreover, the moment arm of the ST and SM is similar during hip extension, whereas that during leg curl varies according to the knee flexion angle (1). The characteristics of kinematic features could result in the minimized compensational relationship among the ST, SM, and BFl during bridge exercises.

Although a number of studies investigated the EMG activity of the hamstring, hip, and trunk muscles, little is known about the difference in the EMG activity of each muscle across different knee joint angles (8,9,22). The EMG activity of the ST, SM, and BFl during UB with the knee flexion angle set at 30° (89.4, 109.4, and 124.5%, respectively) was the highest and reached 4.8–6.4 times of those at 120° of knee flexion. As part of the kinematic chain, bridge exercise generates external knee extension torque along with hip extension. This clearly showed that the hamstrings contracted not only for hip extension but also for knee flexion to generate the internal knee flexion torque for resisting the external knee extension torque. As the horizontal distance from the knee (fulcrum) to the foot (effort point) is longer, the required knee flexion force should be increased. Moreover, the ES EMG activity also decreased as knee flexion angle increased. As the EMG activity of the hamstrings has the same mechanism of change, minimum effort will be required for the ES to stabilize the trunk during bridge exercises as the distance between the shoulder (fulcrum) and foot (effort point) shortened.

In contrast to the remarkable change in the EMG activity of the hamstrings and ES, the GM EMG activity did not change across different knee angles during bridge exercise. The same trend was reported by Kim and Park (9) during BB exercise. Youdas et al. (29) also found no significant difference between UB (33.8% MVIC) and supine hip extension (34.7% MVIC). The GM muscle, one of the major hip extensors (16), might contribute to the lift-up and stabilize the pelvis, as well as the ST, SM, and BFl during bridge exercise. The EMG activity of the GM during prone hip extension with 0° of hip angle reaches approximately 90% MVIC (28).
Even in nonresisted OKC, quadraped arm/lower extremity lift shows 56% MVIC in the GM (3). Based on these findings, bridge exercise may not be sufficient to activate the GM as much as other muscles measured in this study, regardless of knee joint angles. Nevertheless, both BB and UB exercises depend on the GM activity at the knee joint angles of 120°, which minimizes the activity of the hamstring.

To prevent the recurrence of hamstring strains, improving the strength of the injured muscle is critical (2). Based on the epidemiological characteristics of hamstring injury, the BFl and SM are most susceptible to injury (11), suggesting that leg curl and hip bridge exercises at lower knee flexion angle might be preferable in strengthening the BFl and SM. Although eccentric exercises such as the Nordic hamstring curl have been advocated to prevent reinjury (23), we believe that activating and strengthening specific injured muscle using isometric and concentric exercises is effective in preventing reinjury. Meanwhile, clinicians need to consider the regeneration of the ST tendon after harvesting for ACL graft, in terms of recovery of the cross-sectional area and strength of the ST (10,30). Consequently, conservative treatment of the ST might be recommended during strength training in the process of accelerated regeneration process. In this regard, hip bridge exercise will be preferable in minimizing ST activity. Thus, this study recommends the following progression exercises for strengthening the ST: initially, BB at 120–60° to minimize the ST activity, followed by UB at 120–60°, BB at 30°, and then eventually UB at 30°.

This study has several limitations. The participants controlled their muscular force according to the examiner’s verbal command, leading to unstable force generation in some cases. Thus, a further study using a visual feedback system is recommended. The other possible factors that can affect the change in EMG during leg curl, such as the change in the position of the electrode relative to the muscle during joint movement, should not be ignored. However, as Vigreux et al. (26) reported, such a factor may not significantly influence the EMG activity. In addition, further study that measures the MVC at each knee angle and calculates normalized values using these data will be warranted. Finally, this study only found the functional difference among ST, SM, and BFl during isometric contraction. Thus, we need to conduct further research to clarify the functional difference of hamstring muscles including the biceps femoris short head during both eccentric and concentric exercises.

**Practical Applications**

This study proposes that leg curl and hip bridge exercises with knee flexion angles between 30 and 60° to activate the SM and BFl during rehabilitation. Meanwhile, if clinicians treat the ST conservatively during strength training of the hamstrings, such as post-ACL-R, this study recommends BB exercise with knee flexion angles between 60 and 120°. In addition, clinicians can minimize the activity of hamstring while relatively maintaining the activity of the GM through hip bridge exercise at knee flexion angle of 120°.

This study revealed that the muscle activity of the ST is higher than that of the SM and BFl at knee flexion angles over 60° during leg curl exercise, whereas this inverse relationship was minimized in the hip bridge exercise. Although bridge exercise is known to increase the strength of core muscles such as the GM and ES, the actual GM EMG activity is absolutely lower than that of the hamstrings at difference knee flexion angles except for 120° of knee flexion, whereas the activity of the ES is similar to that of the hamstrings.

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**References**


