

# Total Knee Arthroplasty Improves Locomotive Syndrome in Patients with Knee Disease: A Prospective Cohort Study Focused on Total Clinical Decision Limits Stage 3

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## Research Article

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# Abstract

## ***Background:***

In 2020, the Japanese Orthopaedic Association added a new clinical decision limit (CDL), stage 3, to evaluate the stages of locomotive syndrome (LS). However, so far there has been no study of total knee arthroplasty (TKA) to examine the efficacy of LS treatment and there are no motor function indicators to predict LS improvement, focusing on stage 3. The purpose of this study is to investigate the treatment efficacy of TKA on LS focusing on total CDL stage 3 leading to revealing the motor function indicators that can predict LS improvement in patients who had received TKA.

## ***Methods:***

This prospective cohort study was conducted with 59 patients among 70 patients who underwent TKA, with total CDL stage 3 before TKA evaluation. LS was evaluated using stand-up test, two-step test, and 25-Question Geriatric Locomotive Function Scale. In addition, the motor function indicators which could predict the LS improvement were examined. All assessments were conducted before TKA and three months after TKA.

## ***Results:***

Of the 59 subjects who were evaluated to be in total CDL stage 3 before TKA, 17 patients (28.8%) were determined to show improvements in total CDL. From the result of the decision tree analysis, when the CDL of the two-step test before TKA was 1 or less, the improvement rate was 77.8%. Even if the CDL of the two-step test before TKA was higher than 2 and if the 3m-Timed Up & Go test (3m-TUG) before TKA was 9.15 or less, the improvement rate was 60%.

## ***Conclusions:***

As of three months after surgery, TKA can improve LS in about 30% of patients. A two-step test before TKA and 3m-TUG before TKA can be used as motor function indicators to predict LS improvement. This study provides useful information for setting the goal for rehabilitation prior to surgery.

## **1. Background**

Total knee arthroplasty (TKA) is surgical implantation performed to relieve pain and improve daily living activities in patients with knee joint diseases. Patients who underwent this treatment can be expected to regain social wellbeing at an early stage. In a previous study of 5,649 patients, the first 25–30 years long-term follow-up conducted on TKA, reported the implant survival rate of 94.2% at 25 years and 92.4% at 30 years. Thereafter, patients have 38.1 times high risk of experiencing death for various reasons rather than experiencing failing implantation [1]. The current TKA shows to have long-term functioning durability. In addition, TKA and related physical therapy have been reported to reduce pain and improve motor function in many patients [2–5]. Thus, TKA used for therapeutic treatment is increasing worldwide.

However, not all patients reported having a high level of satisfaction after TKA. Several studies showed that the level of satisfaction and function in patients after TKA are lower than THA [6, 7]

Locomotive syndrome (LS) is a concept introduced by the Japanese Orthopaedic Association (JOA) in 2007. LS refers to symptoms related to a decline in locomotor function such as sitting, standing, and walking due to musculoskeletal disorder [8]. When the symptoms progress and impact on daily life, nursing care becomes necessary [8, 9]. LS is caused by locomotor diseases including osteoarthritis, osteoporosis, degenerative spondylosis, spinal canal stenosis due to spondylosis, and sarcopenia [10]. The JOA developed LS risk tests aimed to identify LS patients. The LS risk tests consist of three assessments: stand-up test, two-step test, and 25-Question Geriatric Locomotive Function Scale (GLFS-25) [11]. The JOA also proposed clinical decision limits (CDL) as a guideline for evaluating the risks of LS [12]. In 2015, CDL included two stages: stage 1 for the early signs of declining mobility, and stage 2 for progressively declining mobility. After JOA investigated how the LS could be improved and applied in medical treatment, stage 3 was added in 2020. Stage 3 for progressively declining mobility with difficulty in social participation was based on results of studies on the relationship between LS and frailty.

Previous studies reported the treatment efficacy of LS in knee surgeries including TKA, unicompartmental knee arthroplasty, or high tibial osteotomy. According to the results, all 43 patients (100%) with knee joint diseases were total CDL stage 2 before surgery. Among them, 11.6% of patients showed improvement from stage 2 to stage 1 six months after surgery [13]. However, up to now, there are no studies on the treatment efficacy focusing on stage 3 for TKA alone.

The purpose of this study is to investigate the treatment efficacy of TKA on LS focusing on total CDL stage 3 leading to revealing the motor function indicators that can predict LS improvement in patients who had received TKA.

## **2. Methods**

### **2.1. Study design and statement of ethics**

This prospective cohort study was approved by the Institutional Research Ethics Board of the authors' institution. Informed consent, which was publicly announced on the institution's website, had been obtained from all participants.

### **2.2. Patient selection**

At our hospital, unilateral TKA is performed in a single operation, and bilateral TKA is performed in a separate operation. The target subjects of this study were patients who underwent TKA in one knee between October 2018 and October 2020. Among them, patients were selected with total CDL stage 3 in the evaluation before TKA who consented to participate in the evaluations both before and three months after TKA. In addition, patients who could not walk without support in evaluations before TKA due to

musculoskeletal disorders (hip, knee and spinal disorders), neurological disorders, or dementia were excluded from this study.

There were 70 patients with complete data sets of outcome measures: 0 patients in total CDL stage 1, 11 patients in stage 2, and 59 patients in stage 3. Therefore, the subjects for the analysis of this study were 59 patients with total CDL stage 3 (Table 1). There were 16 subjects who received bilateral TKA after receiving unilateral TKA during this period. These subjects had knee joint diseases including osteoarthritis, osteonecrosis, trauma, and rheumatoid arthritis.

The typical length of hospital stay for TKA was 18 days. The number of rehabilitation days was 15 days, excluding days of hospitalization, surgery, and discharge. Post-TKA rehabilitation started the day after TKA when all subjects were allowed to support their full body weight. All subjects underwent rehabilitation for three months after TKA with the aims of reducing pain, increasing range of motion, and improving activities of daily life by strengthening the muscles and motor functions.

## 2.3. Outcome measures

### 2.3.1. Primary outcome measures

In this study, LS improvement was evaluated by using the LS risk tests introduced by JOA: the stand-up test, the two-step test, and the GLFS-25 [11]. LS was conducted before and three months after TKA. The results of the CDL for each test and the total CDL were classified as stage 0, 1, 2, or 3.

1. The stand-up test is to assess leg strength. The stools of four different heights 40, 30, 20, and 10 cm in accordance with JOA guidelines were prepared. The subjects were tested by standing up from a sitting position, first with both legs and then with one leg, at each height starting from 40 cm. This test is to quantify leg strength [9]. A nine performance scoring system was adopted [11]: 0 (inability to stand); 1, 2, 3, or 4 (stand using both legs from a height of 40, 30, 20, and 10 cm, respectively); and 5, 6, 7, and 8 (stand using one leg from a height of 40, 30, 20, and 10 cm, respectively). Scores  $< 2$ ,  $< 3$ , and  $< 5$  were classified as CDL stages 3, 2, and 1, respectively.
2. The two-step test is for measuring stride length. Furthermore, the results of this test can also be used to assess walking ability, including leg strength, balance, and flexibility of the patients. The subjects were tested by taking two steps with the longest possible stride, and then the stride lengths for the two steps were measured. The test score was calculated using the total length of the two steps divided by the subject's height. Scores  $< 0.9$ ,  $\geq 1.1$  to  $< 1.3$ , and  $\geq 0.9$  to  $< 1.1$  were classified as CDL stages 3, 2, and 1, respectively.
3. GLFS-25, a self-assess questionnaire of 25 questions, was used for assessing the physical status and living circumstances. This test measures the physical pain and activities of daily life over the past month prior to the test. Scores  $\geq 24$  points,  $\geq 16$  to  $< 24$  points, and  $\geq 7$  to  $< 16$  points were classified as CDL stages 3, 2, and 1, respectively.

4. The total CDL is determined based on the results of the tests mentioned above, namely the stand-up test, two-step test, and GLFS-25. The stage from each of the tests that showed the mobility function has decreased the most was used to classify the patient's final total CDL outcome for analysis.

## 2.3.2. Secondary outcome measures

Electronic equipment was used for measuring quiet standing posture and walking movement: optical motion capture system (Vicon Nexus 2.10, Vicon Motion Systems, London, UK) with 13 infrared cameras (MX T20-S and Vantage 8, Vicon Motion Systems) and six force plates (OR6-5 and BP400600, Advanced Mechanical Technology, Inc., Watertown, MA, USA). The sampling frequency was set at 100 Hz, and all the equipment took the measurements synchronously. The subjects were required to wear skin-tight clothes (Under Armour, Baltimore, MD, USA). Thirty-five, 14-mm-diameter, reflective markers were attached to the subjects according to the Plug-in-Gait model protocol [14,15]. All outcome measures were taken both before and three months after TKA.

### 1. Mean weight-bearing ratio of the quiet standing posture:

Quiet standing posture was measured for five seconds using two force plates. The mean weight-bearing ratio (the mean load on the operated side divided by the mean load on the unoperated side) was calculated from the data for the measured quiet standing posture using analysis software (Vicon Nexus 2.10).

### 2. Temporo-spatial parameters in walking:

The patients were asked to practice walking barefoot freely on a floor force plate. Measurements were taken three times when patients could walk without feeling uncomfortable. The data from the movement which the subjects were most satisfied with were adopted. The analysis software (Vicon Nexus 2.10) was used to calculate the cadence, stride time, step time, single support time, double support time, stride length, step length, and walking speed on the operated side of the knees. In addition, presentation software (Polygon 4.3) was used to standardize one gait cycle as 100%.

### 3. 3m-Timed Up & Go test (3m-TUG):

The subjects were asked to stand up from a sitting position on a chair, walk to a marked spot of 3 meters away, return to the chair, and sit down. The time taken for these actions was measured twice and the shorter one was adopted for analysis [16].

## 2.4. Statistical Analysis

All data were expressed as means  $\pm$  standard deviation (SD). The distribution of each CDL stage ratio for the three LS tests and the total CDL stage was performed using Wilcoxon's signed-rank test. The paired t-

test was applied to examine the changes in various LS test scores and each motor functional parameter between before TKA and three-month-after TKA groups. The unpaired t-test was applied to examine the differences in age, body mass index (BMI), preoperative various LS test score, each of the preoperative motor functional parameter between the two groups; improvement and non-improvement groups, which were divided based on the improvement of the total CDL stage before TKA to three months after TKA. Stepwise multiple logistic regression and decision tree analyses were performed to determine the most important preoperative factors of improvement in total CDL stage. All statistical analyses were performed with a significance threshold set at  $p < .05$  using IBM SPSS 27.0 (IBM Corp., Released 2020. Armonk, NY, USA).

### 3. Results

The distribution of the CDL stage for the three LS tests and the total CDL stage for all subjects are shown in Table 2. There was a significant change in the percentage of subjects across all four CDL stages: before TKA, three months after TKA, GLFS-25, and total CDL stage ( $p < .001$ ). At three months, the percentage of subjects with total CDL stage 3 decreased, with a concomitant increase in the percentage of subjects with total CDL stage 2, 1, and 0, with the same change in grade distribution for each of the three tests. There was no significant change observed in the stand-up test from before TKA to three months after TKA.

Table 3 shows the change in the values of each test before and after TKA. The GLFS-25, weight-bearing ratio ( $p < .001$ ), step length ( $p < .01$ ), two-step test, single support time, double support time, and walking speed ( $p < .05$ ) showed significant improvements.

Table 4 shows the difference in each parameter between the improvement group and the non-improvement group. There were significantly higher values in the before TKA improvement group observed in the two-step test ( $p < .001$ ), GLFS-25, 3 m-TUG, double support time ( $p < .01$ ), weight-bearing ratio, stride length, step length, and walking speed ( $p < .05$ ). The results of the stepwise multiple logistic regression analysis demonstrated that the preoperative two-step test ( $p < .01$ ), preoperative stand-up test, and weight-bearing ratio ( $p < .05$ ) were significant factors associated with the total CDL stage improvement (Table 5).

A decision tree was applied to determine the most important preoperative factors of improvement in the total CDL stage. The decision tree was categorized into 2 branches. Based on the preoperative factors, two-step test and 3 m-TUG, the branches were further divided into four subgroups as shown in Fig. 1. The overall LS improvement rate was 28.8%. The preoperative two-step test was determined to be the most relevant factor to the improvement of total CDL stage. In the preoperative two-step test, in the case of CDL stage 0 or less group, the improvement of total CDL was 77.8% (7 out of 9 cases); in the case of CDL stage 2, the improvement of total CDL was 36.8% (7 out of 19 cases); in the case of CDL stage 3, the improvement of total CDL was 9.7% (3 out of 31 cases). In the subgroup of CDL stage 3, 3 m-TUG was extracted as an improvement factor for the two subgroups. In the subgroup of 9.15 seconds or less, the

improvement of total CDL was 60.0% (3 out of 5 cases) whereas in the subgroup of greater than 9.15 seconds, the improvement of total CDL was 0% (0 out of 26 cases).

## 4. Discussion

The subjects of this study were patients who underwent TKA and were evaluated as total CDL stage 3 before TKA. We investigated the effectiveness of LS in total CDL, quiet standing posture, and walking movement before TKA and three months after TKA. In addition, we established the motor function indicators which can predict LS improvement. With the focus on total CDL stage 3, this study is the first, as of this writing, to examine the therapeutic effectiveness of TKA on LS improvement and to identify motor function indicators. The most important finding of this study was that of the 70 patients who underwent TKA, 84.3% progressed to total CDL stage 3 which can be said to be closely related to LS; at three months after TKA, 28.8% of patients improved from total CDL stage 3 to stage 2 or 1. The two-step test and the 3 m-TUG before TKA assessment can be used as indicators to predict the improvement of total CDL.

TKA is a widely accepted treatment because of its noted effectiveness to relieve pain so that patients are able to resume their normal life in society. Therefore, it is important to clarify the extent of improvements made in terms of total CDL after TKA. In a previous cohort study, examining the effects of TKA in patients with knee joint surgery including TKA who were total CDL stage 2 before surgery with LS in a progressive state, it was reported that 11.6% patients improved in total CDL stage six months after TKA [13]. On the other hand, this study showed a 28.8% improvement in stage 3, the maximum stage of total CDL, despite the short-term assessment of merely three months after TKA. In our comparison with other studies, this result indicated a high improvement rate. Consequently, even with the conditions of decline in motor function or hindrance in social participation, TKA is a surgical treatment that is expected to be effective within a short period.

The LS risk test showed significant improvement in the two-step test and GLFS-25, but no significant improvement in the stand-up test. The stand-up test was report to show no CDL improvement in the knee joint surgery including TKA one year after surgery [13]. The standing motion requires a proper joint range of motion, flexibility, and balance in addition to lower limb strength [9, 11]. Specifically, knee extension muscular strength centering around the hip joint, knee joint range of motion, and quadriceps femoris is important. A systematic review of lower limb strength after TKA by Schache *et al* [17] reported that despite the emphasis on strengthening the quadriceps muscle in most rehabilitation protocols, patients showed persistently weaken quadriceps muscle strength compared to the patients in the control group. This suggests that the alleviation of knee joint pain contributes to the recovery of motor function, but not so much to improving the weakening of the quadriceps muscles.

3 m-TUG has been widely used to assess motor function in the elderly because it is highly related to daily living functions such as lower limb muscle strength, balance, walking ability, and susceptibility to falls [16]. Gait movement tends to become impaired with age. The parameter is shown as follows: walking

independently 3 m-TUG < 10 seconds, nearly independent at 11–19 seconds, unstable at 20–29 seconds, and impaired at  $\geq 30$  seconds. The results of this study showed that walking speed improved from 12.65 seconds before TKA to 10.63 seconds three months after TKA which suggests that patients could recover to walk almost independently three months after TKA. Although there was a significant difference in walking speed at three months after TKA, the reason that there was no significant improvement in the 3 m-TUG could be caused by the time required to get up from a chair in the stand-up test. This suggests that after TKA, there was insufficient motion to keep balance when shifting vertically. The mean weight-bearing ratio in the quiet standing posture improved significantly from 0.87 before TKA and 1.05 at three months after TKA. This indicates that the weight-bearing ratio increased on the operated side which was high on the unoperated side before TKA, but three months after TKA the ratio became almost equal on both operated and unoperated sides. Compared with before TKA, walking speed improved three months after TKA in the temporo-spatial parameters in walking that was influenced by prolonged single support time and shortened double support time of the increasing weight-bearing ratio on the operated side. According to Yoshida *et al* [18], there were concomitant symmetrical improvements in temporo-spatial and kinetic parameters in walking as interlimb differences in quadriceps muscle strength decreased after TKA. As a result, there were significant improvements in TUG, stair-climbing test, knee range of motion, strength, and vertical ground reaction force between three months to one year after TKA due to the decrease in interlimb differences in quadriceps muscle strength. In addition, the improvement in biomechanical symmetry due to the decrease in the interlimb differences is attributed to the muscle weakness on the unoperated side. Thus, at three months after TKA, improvements in posture and walking ability were demonstrated in parallel with improvements in mobility. These improvements accompanied by the decrease in interlimb differences in the quadriceps muscle strength may continue beyond three months after TKA.

A discrepancy in the motor function assessment parameters was found in the before TKA parameters between the total CDL improvement group and the non-improvement group. In particular, it was considered that the higher the function before TKA, the better improvement can be expected in the two-step test, 3 m-TUG, walking speed, etc. Therefore, the present study examined the motor function indicators that influence the improvement of LS. A stepwise multiple logistic regressions analysis was performed for each parameter. Before TKA, CDL of two-step test, CDL of stand-up test, and weight-bearing ratio were found to be significantly related to improvements in total CDL. A decision tree was established to identify the characteristics of subjects who were expected to show improvements from the groups with different improvement rates. As a result, four groups with different improvement rates were identified. When the CDL was  $\leq 1$ , the improvement rate was 77.8% in the CDL of two-step test before TKA. Even if the CDL was  $> 2$  in the CDL of two-step test before TKA, if the 3 m-TUG was  $\leq 9.15$ , the improvement rate was 60%. On the other hand, if the CDL was  $> 2$  in the CDL of two-step test before TKA and the 3 m-TUG was  $> 9.15$ , the improvement rate was the lowest at 0%. Therefore, it can be determined that the two-step test and the 3 m-TUG before TKA can be motor function indicators to identify the effects of LS improvements. The two-step test as well as the 3 m-TUG can be used primarily as motor function assessment to estimate walking ability. Maintaining walking function as much as possible before TKA is

considered effective in LS improvement after TKA. To date, no motor function indicators are used to predict LS improvements in patients with TKA. The results of this study provide useful information for considering when to conduct TKA in order not to miss the “windows of opportunity”. Furthermore, the evaluation of the two-step test and the 3 m-TUG before TKA make it possible to predict functional improvement after TKA. This study is of great clinical significance in providing useful information for setting the goal of rehabilitation prior to implementation.

## **5. Conclusions**

Among the 70 patients who underwent TKA, 84.3% progressed to total CDL stage 3. At three months after TKA, 28.8% of the patients made an improvement from total CDL stage 3 to stage 2 or 1. The two-step test before TKA and the 3 m-TUG before TKA were identified to be the main motor function indicators for predicting the improvement of total CDL. Making efforts to maintain walking function before TKA is considered effective in improving LS after TKA. This information will be useful in setting goals for rehabilitation before surgery.

## **Abbreviations**

LS: Locomotive syndrome; CDL: Clinical decision limits; TKA: Total knee arthroplasty; 3m-TUG: 3m-timed up & go test; JOA: Japanese Orthopaedic Association; GLFS-25: 25-Question Geriatric Locomotive Function Scale; SD: Standard deviation; BMI: Body mass index

## **Declarations**

## **Ethics approval and consent to participate**

This prospective cohort study was conducted after receiving the approval of the Research Ethics Committee of the Faculty of Medicine, University of Miyazaki (Approval number 0-0783). This study was conducted in accordance with the Declaration of Helsinki. The informed consent which was publicly announced on the institution’s website had been obtained from all patients. Their rights were protected.

## **Consent for publication**

Not applicable.

## **Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

# Competing interests

All authors declare no conflicts of interest.

# Funding

Financial support for this study was not provided.

# Authors' contributions

Research conception and design: SM, SY, KT. Data collection: SM, SY. Interpretation of data: SM, SY, KT. Statistical analysis: KT, YF. Drafting the manuscript: SM. Manuscript review: AH, HA, EC. Study supervision: EC. All authors had full access to data in the study and made substantial contributions in preparing the final version of the paper. All authors approved the final manuscript, and agreed to be accountable for all aspects of this research.

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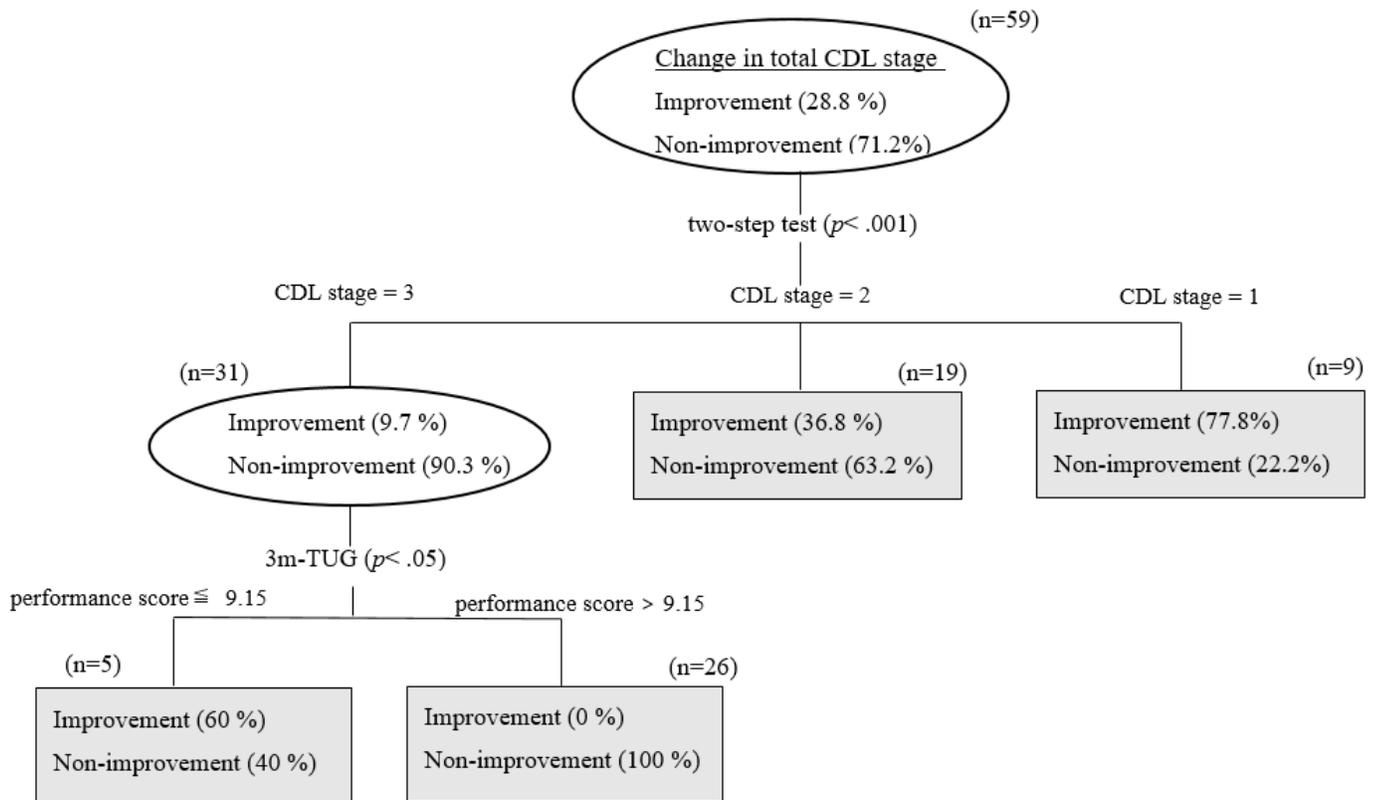
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## Tables

Due to technical limitations, all tables are only available as a download in the Supplemental Files section.

## Figures



**Figure 1**

Decision tree analysis. Decision tree analysis was performed to identify the most important preoperative factors related to improvement in total CDL stage.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

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