Anatomic reconstruction of the anterior cruciate ligament of the knee with or without reconstruction of the anterolateral ligament: A meta-analysis

Jianjian Yin, Kaiyuan Yang, Dong Zheng and Nanwei Xu

Abstract
Purpose: To systematically analyze the effectiveness between combined anterior cruciate ligament and anterolateral ligament reconstruction (ACL+ALLR) and isolated anterior cruciate ligament reconstruction (ACLR) for treatment of patients with injured ACL. Methods: We performed a systematic search in MEDLINE, EMBASE, PubMed, Web of Science, Cochrane databases, Chinese Biomedical Literature Database, CNKI, and Wanfang Data for all relevant studies. All statistical analysis was performed using Review Manager version 5.3. Results: A total of six articles with 460 study subjects were included, with 193 patients in ACL+ALL reconstruction group and 267 patients in ACL reconstruction group. The results of the meta-analysis showed that the ACL+ALL reconstruction group had significantly lower KT measured value (P < 0.00001), Lachman test positive-rate (P = 0.02), Pivot-shift test positive-rate (P < 0.00001) and graft rupture rate (P = 0.02) compared with the ACL reconstruction group. Higher IKDC score (P < 0.00001) and Lysholm score (P < 0.00001) were measured in ACL+ALL reconstruction group, while infection rate (P = 0.86) and other complications rate (P = 0.29) showed no significant differences between the two groups. Conclusions: Anatomic reconstruction of the ACL of the knee with reconstruction of the ALL indicates better postoperative knee function and clinical outcomes compared with isolated ACL reconstruction. The infection rate and other complications rate showed no significant difference between two groups.

Keywords
anterior cruciate ligament reconstruction, anterolateral ligament reconstruction, graft rupture, IKDC score, KT measured value, Lachman test, Lysholm score, meta-analysis, Pivot-shift test

Introduction
Anterior cruciate ligament (ACL) rupture is one of the most common sports injuries in the knee and particularly significant ratio of all knee ligament surgeries involves ACL surgery.1 ACL reconstruction has conventionally been recommended for the restoration of anterior-posterior as well as rotatory knee laxity in young healthy patients with the desire to engage in pivoting sports.2,3 However, after ACL reconstruction, it was reported that rotational instability of knee joint was still residual in up to 30% of all patients,
which eventually lead to the failure of ACL reconstruction surgery. Rotation instability of the knee joint is associated with a number of factors, including increased tibial slope, injury of the lateral meniscus, posterolateral structure, and recently, the important role of anterolateral ligament (ALL) in maintaining the rotational stability have been discovered. During the last few years, several contributions have investigated the anatomical features and biomechanical role of ALL. Whatever anatomical structure, whereas based on biomechanical evidence, isolated ACL reconstruction cannot restore normal knee kinematics when ACL and ALL structures are simultaneously injured with a positive pivot shift.

As results of anatomic and biomechanical studies, several ALL reconstruction techniques have emerged along with ACL reconstruction to reduce anterolateral rotational instability. However, related problems such as over-constrain, infection and prolonged operation time come with additional surgical procedures. The aim of this meta-analysis is to evaluate whether combined ALL reconstruction can improve the clinical results of ACL rupture’s treatment.

Materials and methods

Study selection and search strategy
A comprehensive search was performed in MEDLINE, EMBASE, PubMed, Web of Science, Cochrane databases Chinese Biomedical Literature Database, CNKI, and Wanfang Data databases to identify all relevant studies available from their inception to January 31st 2020. We also searched trial registries of ongoing trials. When the criteria for inclusion or exclusion of a study were controversial, the corresponding author was consulted. The search strategy followed the identification and screening guidelines established by PRISMA statement. The following Mesh search headings and key words were used: (“anterior cruciate ligament reconstruction, anterolateral ligament reconstruction, ACL, ALL, ALLR, ACL+ALLR, combined ACL+ALLR”). These terms were used in different Boolean combinations. We retrieved all eligible studies and evaluated the reference lists of the identified studies and reviews.

Inclusion criteria
We included the following studies from the meta-analysis: (1) study design: comparing ACL+ALLR reconstruction with ACL reconstruction for treatment of ACL injuries patients, (2) include more than 20 patients in each group, (3) studies provided surgical complication outcomes, and (4) available data for each surgical regimen. The most recent was used if dual (or multiple) studies were reported by the same institution. Study designs included randomized controlled trials and retrospective/prospective cohort or case-control studies.

Exclusion criteria
Studies were excluded if they met the following criteria: (1) studies that included patients suffering from meniscus repairs, joint infection, acute fracture, tumor, deformity, osteoporosis or rheumatoid arthritis. (2) duplicate studies; review articles; case reports; biomechanical and cadaveric studies. (3) studies involving non arthroscopic surgery or reoperation.

Data extraction
Two reviewers (Jianjian Yin and Kaiyuan Yang) independently extracted the relevant data from the reports. The extracted data described the characteristics of the investigations regarding study design, gender, time from injury to surgery, mean age, sample size and follow-up period. The outcomes pooled in this analysis included KT measured value, IKDC score, Lysholm score, Lachman test positive-rate, Pivot-shift test positive-rate, graft rupture rate, infection rate and other complications rate. Disagreements were resolved by a third referee.

Risk of bias assessment
As for risk of bias, the risk of bias of four randomized clinical trials (RCTs) was evaluated using the Cochrane Collaboration tool. And the risk of bias of the cohort studies was assessed using the Newcastle-Ottawa Scale. Risk of bias of the included studies were independently assessed by two review authors (Jianjian Yin and Kaiyuan Yang). Any disagreement during the process of data extraction and quality assessment would be solved by discussion with the third author.

Data synthesis and statistical analysis
This study was statistical analyzed by using Review Manager version 5.3 (Cochrane Collaboration). Odds ratio (OR) is used to calculate the dichotomous data in this meta-analysis. The continuous data were calculated by mean difference (MD) with 95% CI. We derived the missing standard deviations from other statistics, such as $P$ values or CI if needed. For example, $P = 0.00001$ was assumed when a $P$ value was reported as $P < 0.00001$. Cochran’s test and the degree of inconsistency ($I^2$) were used to assess heterogeneity among combined study results. A fixed-effects model was used if a $P > 0.05$ and $I^2 < 50\%$. Otherwise, data were pooled by using the random-effects. $P < 0.05$ indicated statistical significance in the integration results. Publication bias in outcomes was assessed and treated using standard methodology. The funnel plots were used to analyze publication bias.
Study characteristics

The detailed results of the search for relevant literature based on the strategy described above was shown in Figure 1. A total of six articles\textsuperscript{22–30} that enrolled 460 patients (193 cases for ACL+ALL group and 267 cases for ACL group) met the inclusion criteria. Of the six studies, four articles\textsuperscript{25,28–30} were randomized studies, and two studies\textsuperscript{26,27} were retrospective studies. Of all study participants included had minimum 5-months follow-up. The concrete characteristics of the included studies were summarized in Table 1. Evaluation index data in included study were summarized in Table 2.

Study quality assessment

The quality assessments for RCTs according to NOS were listed in Table 3. The quality of non-randomized trials was assessed by Newcastle-Ottawa Scale (Table 4). Two non-randomized studies were seven and eight points (low RoB). In general, the quality of included studies was moderate to high.

Meta-analysis results

KT measured value

The KT (KT-1000/2000 arthrometer) measured value were analyzed in three studies including 103 patients in the ACL+ALL group and 130 patients in the ACL group. Analysis indicated that there was high heterogeneity among the studies ($P < 0.00001$, $I^2 = 99\%$) and a random effect model was used. Based on the complete analysis, there was no significant difference between the ACL+ALL and ACL groups (MD, $-1.67$; 95\% CI, $-4.09$ to $0.75$) (Figure 2(a)). Subgroup analysis evaluated just for studies measured with...
KT-1000 value \((P = 0.35, I^2 = 0\%\) because of the high heterogeneity. And based on the subgroup analysis, the KT measured value (MD, \(-0.59; 95\% \text{ CI}, -0.88 \text{ to } -0.30\)) were significantly lower in the ACL+ALL group than in the ACL group (Figure 2(b)).

IKDC score

The IKDC score were analyzed in four studies including 101 patients in the ACL+ALL group and 178 patients in the ACL group. Analysis indicated that there was low heterogeneity among the studies \((P = 0.31, I^2 = 16\%)\) and a

### Table 1. Baseline characteristics of the studies included in the meta-analysis.

| Study (author, years) | Design | Operation | Patients (M/F) | Age (years) | Time from injury to surgery (m) | Follow-up (m) | Operation and graft |
|-------------------|--------|-----------|---------------|-------------|-------------------------------|---------------|-------------------|
| Goncharov, 2019   | RCT    | ACL       | 30            | 16-40       | NA                            | 24            | Anatomic single-bundle ACL reconstruction (patellar tendon) |
|                   |        | ACL+ALL   | 18            | 16-40       | NA                            | 24            | Gracilis or semitendinosus tendon |
| Helito, 2018      | Retrospective | ACL | 68 (59/9)   | 33.9 ± 6.1  | 14 (12-30)                     | 26 (24-29)    | Anatomic single-bundle ACL reconstruction (double gracilis and double semitendinosus tendons) |
|                   |        | ACL+ALL   | 33 (30/3)    | 33.1 ± 8.8  | 15 (13-18)                     | 25 (24-28)    | Remaining gracilis tendons |
| Helito, 2019      | Retrospective | ACL | 60 (28/32)  | 29.9 ± 8.1  | 12.4 ± 14.2                    | 29.6 ± 6.2    | Anatomic single-bundle ACL reconstruction (triple semitendinosus and single gracilis tendons) |
| Ibrahim, 2017     | RCT    | ACL+ALL   | 30 (13/17)   | 27.0 ± 9.1  | 13.1 ± 12.8                    | 27.1 ± 4.2    | Remaining gracilis tendons |
|                   |        | ACL       | 50 (50/0)    | 26 (21-32) | 3 (2.0-4.6)                    | 27 (25-30)    | Anatomic single-bundle ACL reconstruction (triple semitendinosus and single gracilis tendons) |
| Zhang, 2016       | RCT    | ACL+ALL   | 39 (20/19)   | 35.98 ± 3.18| NA                            | 5             | Double gracilis tendon |
|                   |        | ACL       | 20 (13/7)    | 22.3 ± 5.3  | 12.3 ± 4.3                     | 12            | Iliotibial band tendon |
|                   |        | ACL+ALL   | 20 (12/8)    | 26.3 ± 6.8  | 16.3 ± 3.6                     | 12            | Iliotibial band tendon |

### Table 2. Evaluation index data in included study.

| Study (author, years) | Operation | KT measured value (mm) | IKDC score | Lysholm score | Lachman test positive-rate | Pivot-shift test positive-rate | Graft rupture rate | Infection rate | Other complications |
|-------------------|-----------|------------------------|------------|---------------|---------------------------|-------------------------------|-------------------|---------------|-------------------|
| Goncharov, 2019   | ACL       | NA                     | 90.3 ± 3.7 | 92.1 ± 3.9    | 5 (16.7%)                 | 11 (36.7%)                   | NA                | NA            | NA                |
|                   | ACL+ALL   | NA                     | 96.3 ± 1.8 | 97.4 ± 1.18   | 0 (0%)                    | 0 (0%)                       | NA                | NA            | NA                |
| Helito, 2018      | ACL       | NA                     | 87.1 ± 9.0 | 90.0 ± 7.1    | NA                        | 24 (35.3%)                   | 5 (7.4%)          | NA            | 2 (2.9%)          |
|                   | ACL+ALL   | NA                     | 92.7 ± 5.9 | 95.4 ± 5.3    | NA                        | 3 (9.1%)                     | 0 (0%)            | NA            | 1 (3.0%)          |
| Helito, 2019      | ACL       | 2.3 ± 1.4              | 84.3 ± 9.8 | 86.3 ± 7.8    | NA                        | 31 (51.7%)                   | 13 (21.7%)        | 1 (1.7%)       | 0.00%             |
|                   | ACL+ALL   | 1.5 ± 1.1              | 86.9 ± 9.3 | 88.3 ± 7.3    | NA                        | 8 (26.7%)                    | 1 (3.3%)          | 0%             | 1 (3.3%)          |
| Ibrahim, 2017     | ACL       | 1.8 ± 1.22             | NA         | 96 ± 5.3      | 5 (10%)                   | 6 (12%)                      | NA                | 0%            | NA                |
|                   | ACL+ALL   | 1.3 ± 0.3              | NA         | 98 ± 5.6      | 4 (7.5%)                  | 5 (9.4%)                     | NA                | 1 (1.9%)       | NA                |
| Wang, 2019        | ACL       | 7.1 ± 0.3              | 89.1 ± 2.6 | 89.3 ± 2.3    | 10 (50%)                  | 11 (55%)                     | NA                | 1 (5%)         | 0%                |
|                   | ACL+ALL   | 3.4 ± 0.2              | 96.2 ± 1.6 | 96.3 ± 1.6    | 5 (25%)                   | 4 (20%)                      | NA                | 0%            | 1 (5%)            |
fixed effect model was used. Based on the complete analysis, the IKDC score (MD, 6.15; 95% CI, 5.29 to 7.02) were significantly higher in the ACL+ALL group than in the ACL group (Figure 3).

**Lysholm score**

The Lysholm score were analyzed in six studies including 193 patients in the ACL+ALL group and 267 patients in the ACL group. Analysis indicated that there was high heterogeneity among the studies ($P < 0.0001$, $I^2 = 81\%$) and a random effect model was used. Based on the complete analysis, the Lysholm score (MD, 5.40; 95% CI, 3.41 to 7.38) were significantly higher in the ACL+ALL group than in the ACL group (Figure 4).

**Lachman test positive-rate**

The Lachman test positive-rate were analyzed in four studies including 130 patients in the ACL+ALL group and 139 patients in the ACL group. Analysis indicated that there was low heterogeneity among the studies ($P = 0.68$, $I^2 = 0\%$) and a fixed effect model was used. Based on the complete analysis, the Lachman test positive-rate (OR = 0.46, 95% CI, 0.24 to 0.86) were significantly lower in the ACL+ALL group than in the ACL group (Figure 5).

**Pivot-shift test positive-rate**

The Pivot-shift test positive-rate were analyzed in five studies including 154 patients in the ACL+ALL group and
228 patients in the ACL group. Analysis indicated that there was low heterogeneity among the studies \((P = 0.31, I^2 = 16\%)\) and a fixed effect model was used. Based on the complete analysis, the Pivot-shift test positive-rate \((\text{OR} = 0.27, 95\% \text{CI}, 0.16 \text{ to } 0.48)\) were significantly lower in the ACL+ALL group than in the ACL group (Figure 6).

### Graft rupture rate

The graft rupture rate was analyzed in three studies including 102 patients in the ACL+ALL group and 167 patients in the ACL group. Analysis indicated that there was low heterogeneity among the studies \((P = 0.69, I^2 = 0\%)\) and a fixed effect model was used. Based on the complete analysis, the graft rupture rate \((\text{OR} = 0.19, 95\% \text{CI}, 0.05 \text{ to } 0.73)\) were significantly lower in the ACL+ALL group than in the ACL group (Figure 7).

### Infection rate

The infection rate was analyzed in three studies including 103 patients in the ACL+ALL group and 130 patients in the ACL group. Analysis indicated that there was low heterogeneity among the studies \((P = 0.63, I^2 = 0\%)\) and a fixed effect model was used. Based on the complete analysis, there was no significant difference between the ACL+ALL and ACL groups \((\text{OR} = 0.86, 95\% \text{CI}, 0.16 \text{ to } 4.62)\) (Figure 8).
Other complications rate

The other complications rate was analyzed in three studies including 83 patients in the ACL+ALL group and 148 patients in the ACL group. Analysis indicated that there was low heterogeneity among the studies ($P=0.67$, $I^2=0\%$) and a fixed effect model was used. Based on the complete analysis, there was no significant difference between the ACL+ALL and ACL groups (OR = 2.31, 95% CI, 0.49 to 10.91) (Figure 9).

Discussion

Abnormal and severely abnormal IKDC scores in 36.4% of patients with hyperlaxity undergoing ACL reconstruction with hamstrings tendons and in 20% of patients undergoing reconstruction with patellar tendons were reported in Kim et al.’s systematic review.31 What’s more, a greater laxity index closely related to greater residual postoperative instability and lower IKDC and Lysholm functional scale scores. One study32 showed that almost one-third of patients with hyperlaxity and ACL reconstruction experienced graft rupture, contralateral ACL rupture, or excessive laxity. Above data encourage search for methods of additional rotation stabilization of the knee joint, one of them being reconstruction of anterolateral ligament of the knee. That does not mean ALL reconstruction should not be performed routinely for patients undergoing ACL reconstruction. ALL reconstruction is now recognized as a reliable option to control rotatory instability during the surgery of ACL reconstruction.17 Sonnery-Cottet et al.33 proposed that combined ACL and ALL reconstruction should be considered for patients who present at least with one
decisive criteria which including ACL revision, grade 2 or 3 positive pivot shift, Segond fracture, pivoting sport and hyperlax. Contralateral ACL rupture, Lachman test >7 mm, deep lateral femoral notch sign and less than 25 years old were defined as secondary criteria, patients suffered two of the secondary criteria were also recommended for combined ALL reconstruction. Some published literature shows that combined anterior cruciate ligament and anterolateral ligament reconstruction improves the postoperative results. The review of Saithna et al. indicated that the results of combined ACLR+ALL reconstruction demonstrate significant advantages over isolated ACLR with respect to these key clinical outcomes. Based on 502 high-risk young patients who underwent ACL reconstruction alone or combined with ACL reconstruction, Sonnery-Cottet et al. found no significant difference in Lysholm score and IKDC score with minimum follow-up of 2 years. In our meta-analysis, the Lysholm score, IKDC score, KT-1000 value, Lachman test positive-rate, Pivot-shift test positive-rate are significant better in ACL+ALL reconstruction group compared with ACL reconstruction group. Although, combined with more incision, more tendon grafts, additional surgical procedure and longer operation time, the results of Lysholm score and IKDC score indicate that ACLR+ALL reconstruction gains better postoperative knee function. Clinical outcomes after combined ACL and ALL reconstruction are promising despite the long-term functional effect of all reconstruction still needs further study.

It is generally known that KT-1000 value and Lachman test are more objective and accurate to evaluate laxity after ACL reconstruction, and Pivot-shift test is the most important index to evaluate the rotation stabilization of knee joint. In the biomechanical experiment of anterior cruciate ligament transection model, the Pivot-shift test of knee joint rarely exceeds grade 1. However, ACL injury patients with Pivot-shift test grade 2 or 3 are often encountered in clinical work. There should be additional anatomic structural damage that leads to the increase of Pivot-shift test theoretically. At present, ALL injury is considered to be one of the factors leading to the high grade of Pivot-shift test. Compared with isolated ACL reconstruction group, anteroposterior and rotation stabilization of the knee joint showed significant improvement in combined group based on our meta-analysis.

Clinical results after isolated ACL reconstruction in a high-risk population are disappointing. Some scholars reported that the risk of the recurrent rupture is 1.8 to 14% after isolated ACL reconstruction. And the rate of patients who return to their pre-injury level of sport remains low. However, the failure rate decreases more than 50% by adding the extra-articular reconstruction. According to the study of Inderhaug et al., the extra-articular reconstruction restores normal knee biomechanics in combined injuries of the ACL and the anterolateral structures, and another biomechanical study found that the forces in the ACL graft decreases by approximately 43% when a lateral extra-articular tenodesis was added. A study of 502 patients confirmed that anterolateral ligament reconstruction is associated with significantly reduced ACL graft rupture rates. And patients are more likely to return to pre-injury level of sports activities. Graft failure rates of <3% were seen in the two studies from the SANTI group with a minimum follow-up of 2 years. Our meta-analysis demonstrated a significant lower graft rupture rate compared with isolated ACL reconstruction. ALL reconstruction may protect the ACL graft and may therefore serve as a complement to ACL reconstruction.

Postoperative infection is a very rare complication in the article of Panisset et al., with only 1 case (0.2%) in 392 patients. Brophy et al. reported 0.8% in a series of 2198 patients, and diabetes, allograft and hamstring graft as risk factors. ALL reconstruction was indicated as a risk factor of postoperative infection with incidence rate of 0.61%. However, in our meta-analysis, there was no significant increasing in postoperative infection and while combined with ALL reconstruction. As well, Thaunat et al. do not support concerns regarding a potentially increased risk of infection-related complications when ALL reconstruction is added. It is likely related to the minimally invasive technique of ALL reconstruction compared with traditionally large incisions.

The addition of an ALL reconstruction demonstrated a very low complication rate (0.5%) related to the ALL graft. Some specific complications of ALL reconstruction were observed in included studies, such as pretibial infections and peroneal nerve palsy. However, the incidence rate of these complications was low, and the overall complication rate was acceptable. Moreover, the minimally invasive technique of ALL reconstruction significantly reduces postoperative pain and improves patient satisfaction.

| Study or Subgroup | ACL+ALL Events | Total | ACL Events | Total | Weight | Odds Ratio M-H, Fixed, 95% CI |
|-------------------|----------------|-------|------------|-------|--------|-----------------------------|
| Helito 2018       | 1              | 33    | 2          | 68    | 61.8%  | 1.03 [0.99, 1.10]           |
| Helito 2019       | 1              | 30    | 0          | 60    | 15.6%  | 6.15 [0.24, 155.65]         |
| Zhang 2016        | 1              | 20    | 0          | 20    | 22.6%  | 3.15 [0.12, 82.16]          |
| Total (95% CI)    | 83             | 148   | 100.0%     |       |        | 2.31 [0.49, 10.91]          |

**Figure 9.** The forest plot for other complications rate between two groups.
cyst formation in tunnel, femoral anchor loosening with irritation of the lateral soft parts of the knee, cyclops-type lesion formation and arthroscopic removal of the arthrofibrosis was required. As well, no significant difference in other complications rate was observed between two groups. Combined ACL and ALL reconstruction have proven to be a safe procedure with an overall reoperation rate that is comparable with those reported for isolated ACL reconstructions. Schön et al. showed in a cadaveric study that anatomic ALLR in conjunction with an ACLR significantly reduced rotatory laxity of the knee beyond 30° of knee flexion, but resulted in significant over constraint of the knee at any fixation angle. Although the study was carried out on specimens, the results still have some guiding significance and deserve our deep thinking. Further investigation into the application and target population for ALLR is strongly recommended.

The authors acknowledge some limitations to the meta-analysis. Except for four randomized controlled trial, two included studies are retrospective and have a non-randomized design. In these studies, the risk of selection bias could not be excluded. Second, the heterogeneity of meta-analyses for some clinical variables was obvious, which might lower the reliability of the results.

The Pivot-shift test and Lachman test usually measured by subjective physical exam which may cause measurement errors between observers in different studies. What’s more, the severity of these test cannot be only represented based on the positive or negative rate. It is hoped that more specific and detailed classification of injury degree can be adopted, so as to interpret the clinical results more accurately. Third, the presence of meniscal injuries, preoperative pivot-shift and preoperative KT-1000 showed no significant difference between the two groups based on the characteristics of our included studies. However, we found that whether ACL injury patient combined with ALL injury pre-operation may affecting the measurement of Pivot-shift test and cause certain impact on the accuracy of the results. The authors did not make definite diagnosis on the presence or absence of ALL injury. At present, there is no specific clinical examination to diagnose ALL injury. Of all the visualized anterolateral ligaments, 162 (78.8%) knees demonstrated radiological combined ALL abnormalities in the MR images of 206 included knees. The primary diagnosis of ALL injury is mainly through injury mechanism, physical examination and imaging examination. Another limitation is the lack of long-term follow-up studies that could minimize reoperation rates, which is known to increase with time elapsed from the surgery. Therefore, randomized controlled clinical trials and studies with longer follow-up times are needed to confirm the compelling clinical evidence for the efficacy of combined ACL and ALL reconstruction. Despite these limitations, the current study still provided new evidence to surgeons selecting the appropriate reconstruction for ACL injury patient.

**Conclusion**

Anatomic reconstruction of the ACL of the knee with reconstruction of the ALL indicates better postoperative knee function and clinical outcomes compared with isolated ACL reconstruction. The infection rate and other complications rate showed no significant difference between two groups.

**Authors’ note**

Jianjian Yin and Kaiyuan Yang are the co-first authors.

**Author contributions**

Jianjian Yin and Kaiyuan Yang wrote the main manuscript text, and Jianjian Yin prepared figures and detected the data.

**Declaration of conflicting interests**

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**Ethical approval**

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**Informed consent**

Informed consent was obtained from all individual participants included in the study.

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