Inflammation-Related circRNA Polymorphism and Ischemic Stroke Prognosis

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Abstract
CircRNAs belong to a novel class of noncoding RNAs that are generated by exons of genes by alternative mRNA splicing and involved in pathophysiological processes of ischemic stroke by regulating neuro-inflammation. A total of 982 patients were enrolled in our study for stroke recovery analysis. The aim of our study was to first explore the association between the inflammation-related circRNA polymorphism and functional outcome 3 months after ischemic stroke by using multivariate logistic regression model. Next, we further investigated the role of circRNA polymorphism in predicting stroke recurrence by using Cox proportional hazard regression model. Five circRNA polymorphisms were genotyped by using polymerase chain reaction and ligation detection reaction method. We identified circ-STAT3 (signal transducer and activator of transcription) rs2293152 GG genotype to be associated with poorer recovery 90 days after stroke (OR = 1.452, 95% CI: 1.165–4.362, p = 0.016). After adjusting for confound factors, the association for rs2293152 with 3 months outcome after IS was stronger, suggesting a mechanism that rs2293152 is an independent risk factor for stroke recovery (OR = 2.255, 95% CI: 1.034–2.038, p = 0.031). However, no other circRNA polymorphisms (circ-DLGAP4 rs41274714, circ-TRAF2 rs10870141, circ-ITCH rs10485505, rs4911154) were associated with functional outcome 3 months after stroke in any genetic models. Subgroup analysis revealed that the negative effect of rs2293152 GG genotype was greater in female and older patients, subjects with history of hypertension. Additionally, all the circRNA polymorphisms were not correlated with recurrent risk of ischemic stroke. Our results indicated that circ-STAT3 might be a novel biomarker for predicting functional outcome after stroke and an important contributor to the ischemic stroke recovery.

Keywords Ischemic stroke · Prognosis · circRNA · Polymorphism · Inflammation

Introduction
Ischemic stroke ranks the major cause for mortality and disability in China (Wang et al. 2017). Although thrombolysis is the most effective method to improve the functional outcome for the IS patients, only a small part of patients can access to this treatment due to limited window (Wang et al. 2017). In order to develop more effective and feasible strategies for ameliorating brain injury and disability after stroke, we need to understand the pathophysiology of cerebral ischemia from the molecular perspective. Genetic factors could influence functional recovery and recurrent stroke risk, accounting for unexplained factor in stroke recovery (Lindgren and Maguire 2016). Previous studies have reported that some candidate SNPs such as apolipoprotein E and BDNF (brain-derived neurotrophic factor) gene variants were associated with post-stroke recovery functional outcome after ischemic stroke (Stanne et al. 2014). However, the studies on the functional roles of circRNA in brain injury and repair after IS are just beginning. Identifying non-coding features would provide a comprehensive map and uncover potential processes of IS.

Circular RNAs (circRNAs) are new class of noncoding RNA generated by the back-splicing of introns or exons (Li et al. 2018). CircRNAs may act as miRNA sponges by binding to microRNA response elements and regulate the expression of miRNA (Gao et al. 2017). Besides, circRNAs could also exert transcriptional regulation and post-transcriptional regulation on gene expression by binding to RNA-associated proteins (Jeck and Sharpless 2014). The generation procedure of circRNAs competed with linear spicing and influenced production of linear mRNAs. Recent study indicated
that several circRNAs were aberrantly expressed in the ischemic cerebral tissue in MACO animal model as well as blood of IS patients (Dong et al. 2020). It is suggested that circRNAs could be biomarkers for IS diagnosis and prediction of stroke outcomes. Furthermore, circRNA was reported to contribute to pathophysiology process of stroke by mediating neuro-inflammation, apoptosis, atherosclerosis, and neurogenesis (Wang et al. 2020).

Recent studies have provided evidence on single-nucleotide polymorphisms (SNPs) associated with circRNA expression. Ahmed et al. (2019) integrated circular RNA expression from RNA-seq data of lymphoblastoid cell lines with genome sequence variation from the 1000 Genomes Project and identified thousands of cis-acting genetic variants at the circRNA influencing its expression, referred to as circRNA quantitative trait loci (circQTLs). Additionally, circQTLs existed independently of eQTLs and exerted no effect on mRNA expression. Furthermore, recent studies have also identified 196,255 circQTLs, which might influence circRNA expression by altering the canonical back-splicing sites (Liu et al. 2019). Holdt's work revealed that the presence of specific intronic binding sites may contribute to circRNA biogenesis (Holdt et al. 2016). These results revealed that genetic factors could influence circRNA expression variation and enrich for the GWAS SNP associated with complex diseases. However, the study about genetic variants within circRNAs and ischemic stroke is in the early stage.

CircRNA DLGAP4 was located on chrome 20 and generated from the exons 8, 9, and 10 of DLGAP4 gene. Bai et al. (2018) first found that circDLGAP4 controlled the endothelial–mesenchymal transition and be involved in blood–brain barrier (BBB) integrity. Circ-DLGAP4 promoted the maintenance of BBB integrity and improved functional outcome after stroke by sponging miR-143. Subsequently, Zhu's study indicated that circ-DLGAP4 was negatively related with the inflammation cytokine level (TNF-α, IL-6, IL-8, IL-22) in IS patients (Zhu et al. 2019). Additionally, Wang et al. identified that circ-ITCH suppressed the active of Wnt/β-catenin signaling activation by sponging miR-214 and miR-17 through increasing expression of its ITCH linear isoform (Wang et al. 2019). The Wnt/β-catenin signaling not only played important roles in microglia activity and neuro-inflammation but also be crucial for regulating synaptic plasticity and BBB integrity and function (Jia et al. 2019). Circ-STAT3 were derived from exons 12, 13, and 14 of STAT3 (Signal Transducer and Activator of Transcription 3) and involved in pro-inflammatory cytokine signaling (Paraboschi et al. 2018). Another study by Zhang et al. (2020) has found that circ-TRAF2 was associated with colorectal cancer risk through regulating neuro-inflammation. Neuro-inflammation is a vital pathogenesis after stroke, which can cause secondary brain damage and unfavorable functional recovery (Shen et al. 2019). Furthermore, microglia activation and BBB integrity are two important factors in the regulation of ischemia-induced neuro-inflammatory process. Under this background, we speculated that circ-DLGAP4, circ-ITCH, circ-TRAF2, and circ-STAT3 were involved in the progression of IS recovery. The prognosis on neurological deficit can be divided into functional outcome and stroke recurrence. The aim of our study was to first explore the association between the neuro-inflammation-related circRNA SNPs and functional outcome after stroke. Next, we further investigated the role of circRNA polymorphisms in predicting stroke recurrence.

**Method**

**Study Subjects**

Our study included 982 first-ever suffered from ischemic stroke and hospitalized in Department of Neurology, the First Affiliated Hospital of China Medical University between November 2016 and December 2019. Eligible cases were diagnosed ischemic stroke for the first time according to clinical manifestation and neurological examination (computed tomography and magnetic resonance imaging). The National Institute of Health stroke scale (NIHSS) score and modified Rankin Scale (mRS) score were used to assess stroke severity and functional outcome of the disease; the former was carried out on admission and the later was implemented after 3 months of the disease onset, respectively. Patients with mRS score less than or equal 2 were defined as good outcome, while others were classified into poor outcome group. Patients who emerged new neurological impairments or pre-existing symptoms exacerbated after 21 days from the first-ever attacked were considered as recurrent cases. Moreover, the definition and boundary of hypertension, diabetes mellitus, dyslipidemia, smoking, and drinking were same as our previous study (Liu et al. 2020). All the patients were followed up by clinical visit or telephone interview until stroke recurrence or the latest follow-up. Our study was approved by Ethics Committee of the First Hospital of China Medical University and in accordance with the principles of the Helsinki Declaration; all participants have signed the informed consents.

**SNP Selection and Genotyping**

The dbSNP database (http://www.ncbi.nlm.nih.gov/SNP) and circBase (http://www.circbase.org) were used for selecting SNP for circRNAs. The rule for tagSNP selection is as follows: minor allele frequency (MAF) larger than 0.05 and linkage disequilibrium (LD) pattern R² less than 0.8. circ-DLGAP4 rs41274714; circ-STAT3 rs2293152; circ-TRAF2
rs10870141; and circ-ITCH rs10485505, rs4911154 were selected for our study. All polymorphisms were genotyped by PCR-LDR method (polymerase chain reaction and ligation detection reaction), which have been described in our previous research (Liu et al. 2020).

Statistical Analysis

We used Chi-square and t-test to calculate and compare the discrepancy of categorical and continuous variables, respectively. The associations between circRNA SNPs and functional outcome after stroke were accessed using multivariate logistic regression model; 95% confidence interval (95% CI) and odds ratio (OR) were calculated. The associations between circRNA SNP polymorphisms and stroke recurrence risk were accessed by Cox proportional hazard regression model and by calculating hazard ratio (HR) and 95% CI. Data analysis was performed by using the SPSS 17. P < 0.05 was considered as statistical significance. The potential functional effect of circRNA polymorphisms on functional outcome of IS was performed by using Haploreg v4.1 webserver (http://www.broadinstitute.org/mammals/haploreg/haploreg/Php).

Results

Clinical Characteristic of Patient Group by Short-Term Outcome

The clinical characteristics of participants were listed in Table 1. Among them, 263 cases (29.9%) were recognized as poor outcome, and 615 patients (70.1%) had a favorable outcome. The age, NIHSS score, diabetes, and stroke subtype were associated with functional outcome of IS. Patients with mRS of 3–6 are prone to older, diabetes status, large-artery atherosclerosis-IS, and higher NIHSS score.

Table 1 Clinical characteristics of patients grouped by short-term prognosis

| Variable      | MRS (0–2) N=615 | MRS (3–5) N=263 | p       |
|---------------|-----------------|-----------------|---------|
| Age ≥ 60      | 350             | 186             | 0       |
| Male          | 424             | 170             | 0.212   |
| Hypertension  | 474             | 208             | 0.511   |
| Diabetes      | 221             | 126             | 0.001   |
| Hyperlipidemia| 247             | 93              | 0.181   |
| Smoking       | 253             | 115             | 0.477   |
| Drinking      | 134             | 68              | 0.19    |
| NIHSS         | 3.86 ± 1.784    | 10.34 ± 3.284   | 0.0001  |
| TOAST         | 293             | 190             | 0.19    |

CircRNA Polymorphisms and Short-Term Outcome of IS

Short-term prognosis of IS was assessed at 3 months after stroke by mRS, and the results were shown in Table 2. Patients with GG genotype had a trend to be unfavorable outcome compared to CC genotype (p = 0.071). Furthermore, we identified circ-STAT3 rs2293152 GG genotype to be associated with poorer outcome and greater disability under recessive model 90 days post-stroke (OR = 1.452, 95% CI: 1.034–2.038, p = 0.031). In other words, compared with GG, patients with the CG + CC genotype had a higher probability of good recovery. After adjusting confound factors, the GG genotype of rs2293152 is associated with a 2.255-fold higher risk of having a poorer outcome as compared to CG + CC genotype, which is statistically significant (OR = 2.255, 95% CI: 1.165–4.362, p = 0.016), as shown in Table 3. And the AUC was 0.966, indicating that circ-STAT3 may be valuable bio-markers for ischemic stroke prognosis. However, no other circRNA polymorphisms (circ-DLGAP4 rs41274714, circ-TRAF2 rs10870141, circ-ITCH rs10485505, rs4911154) were associated with functional outcome 3 months after stroke in any genetic models.

Stratification Analysis

To further access the effect of circRNA polymorphisms on functional outcome of post-stroke, stratified analysis was performed by subgroups of common factors using recessive model (GG vs CG + CC) (Table 4). The increased risk for rs2293152 GG genotype was more evident in subgroup of older subjects (OR = 1.701, 95% CI = 1.12–2.586, p = 0.012), females (OR = 2.256, 95% CI = 1.289–3.957, p = 0.004), indicating that the effect was enhanced by the potential interactions between rs2293152 and age, gender. Additionally, individuals with the GG genotype had a 1.906-fold increased risk of unfavorable outcome in hypertension group, which indicated that the negative effect was more pronounced in subjects who had history of hypertension (OR = 1906, 95% CI: 1.309–2.775, p = 0.001).

CircRNA Polymorphisms and IS Recurrence

A total of 982 the patients were enrolled in our study for stroke recurrence analysis; among them 42 patients (1.5%) were lost to follow-up. The median follow-up time was 14 months. Basic characteristics of patients classified by stroke recurrence were summarized in Table 5. We found that age and stroke subtype were related to IS recurrence. In the further analysis, none of the five polymorphisms was significantly associated with stroke recurrence in any genetic models from Cox regression analysis (Table 6).
In our study, we accessed the possibility of circRNA polymorphisms as prognostic biomarkers for IS. To the best of our knowledge, our study is the first study to examine the role of circ-RNA in the recurrence and recovery of IS. Our findings identified that circ-STAT3 rs2293152 GG genotype was significantly associated with unfavorable functional outcome of IS, and rs2293152 could be served as prognostic biomarker for IS patients. However, the other four SNPs were not associated with functional outcome of IS after 3 months. We also failed to find the association between all the circRNA polymorphisms and IS recurrence risk. Our study will provide novel perspectives for prognosis prediction and target gene therapy for IS.
Recent studies have suggested that circRNAs might be novel diagnostic and prognostic biomarkers for the disease. Zuo et al. (2020) found three differentially expressed circRNAs (circFUNDC1, circPDS5B, and circCDC14A) in blood of IS patients through two stage studies. Subsequently, the study of Dong et al. (2020) indicated that 521 differentially expressed circRNAs (373 increased and 148 circRNAs decreased) in the IS group compared with controls. CircRNA expression profiles were altered significantly in the PBMCs of IS patient and may be participate in the pathogenesis of IS. Meantime, recent association studies revealed that circRNA polymorphisms conferred prognostic and susceptibility biomarkers for the disease. Burd et al. (2010) suggested that the rs7341786 within 9p21 contribute to atherosclerotic vascular disease susceptibility through regulation of ANRIL splicing and circular ANRIL expression. In addition, Paraboschi et al. reported that hsa-circ_0043813 from the STAT3 gene was associated with multiple sclerosis risk and the genotype CC of rs2293152 could increase circ-STAT3 expression (Paraboschi et al. 2018). Moreover, Zhang et al. (2020) have found that rs25497 in circ-TUBB was associated with colorectal cancer risk and the genotype CC of rs2293152 could increase circ-STAT3 expression (Paraboschi et al. 2018). Furthermore, Guo et al. (2017) found that circ-ITCH rs10485505 and rs4911154 were significantly associated with increased hepatocellular carcinoma risk. Until now, study about the circRNA polymorphisms and stroke prognosis is fewer.

| Variables | GG mRS (0–2)/(3–5) | CC + CG mRS (0–2)/(3–5) | p   | OR (95% CI) |
|-----------|--------------------|-------------------------|-----|-------------|
| Age (years) |                   |                         |     |             |
| < 60 | 56/17 | 209/60 | 0.858 | 1.057 (0.572–1.954) |
| ≥ 60 | 65/52 | 285/134 | 0.012 | 1.701 (1.12–2.586) |
| Gender |                    |                         |     |             |
| Male | 85/37 | 339/133 | 0.64 | 1.11 (0.718–1.714) |
| Female | 36/32 | 155/61 | 0.004 | 2.256 (1.289–3.957) |
| Hypertension |                |                         |     |             |
| No | 33/6 | 108/49 | 0.049 | 0.401 (0.158–1.019) |
| Yes | 88/63 | 386/145 | 0.001 | 1.906 (1.309–2.775) |
| Diabetes |                  |                         |     |             |
| No | 74/35 | 320/102 | 0.091 | 1.484 (0.937–2.350) |
| Yes | 47/34 | 174/92 | 0.226 | 1.32 (0.823–2.275) |
| Hyperlipidemia |              |                         |     |             |
| No | 66/43 | 302/127 | 0.048 | 1.549 (1.001–2.397) |
| Yes | 55/26 | 192/67 | 0.272 | 1.355 (0.787–2.332) |

| Variables | Patients | Recurrence | Log-rank p |
|-----------|----------|------------|------------|
| Age | N = 940 (%) | N = 139 |      |
| ≤ 55 | 358 | 42 | 0.019 |
| > 55 | 582 | 97 |   |
| Sex | N = 940 (%) | N = 139 |      |
| Male | 634 | 94 | 0.78 |
| Female | 306 | 45 |   |
| Diabetes | N = 940 (%) | N = 139 |      |
| No | 560 | 76 | 0.096 |
| Yes | 380 | 63 |   |
| Smoking | N = 940 (%) | N = 139 |      |
| No | 551 | 84 | 0.286 |
| Yes | 589 | 55 |   |
| TOAST | N = 940 (%) | N = 139 |      |
| LAA | 527 | 91 | 0.024 |
| SVD | 413 | 48 |   |
| Hypertension | N = 940 (%) | N = 139 |      |
| No | 211 | 26 | 0.132 |
| Yes | 729 | 113 |   |
| Hyperlipidemia | N = 940 (%) | N = 139 |      |
| No | 574 | 83 | 0.918 |
| Yes | 366 | 56 |   |
| Drinking | N = 940 (%) | N = 139 |      |
| No | 724 | 108 | 0.536 |
| YES | 216 | 31 |   |

Table 3 Stratification analysis for rs2293152 with short-term outcome according to the common factors
Our study demonstrated that circ-STAT3 rs2293152 predicted functional outcome after stroke, carrying GG genotype exhibited worse outcomes 3 months post-stroke. We identified that the GG genotype was associated with increased risk of unfavorable outcome of stroke and that the CC + CG genotype was associated with a better outcome at 3 months. After adjustment for NIHSS score and other factors, the association for rs2293152 after 3-month outcome after IS was stronger, suggesting that rs2293152 is an independent risk factor for stroke recovery. However, no significant association between circ-DLGAP4 rs41274714, circ-TRAF2 rs10870141, circ-ITCH rs10485505, rs4911154 and short-term outcome of stroke was detected. Sub-group analysis revealed that the negative effect of rs2293152 GG genotype was greater in female, older patients, and subjects with hypertension status. The results indicated the interaction of age, sex, blood pressure, and rs2293152 enhanced the poor recovery of IS. There is a fact that risk factors for

| Genotype of SNP | Patients | Recurrence | Log-rank $p$ | HR | 95% CI |
|-----------------|----------|------------|--------------|----|--------|
| rs10485505      |          |            |              |    |        |
| CC              | 687      | 97         | 0.25         |    |        |
| CT              | 233      | 39         | 0.701        |    |        |
| TT              | 20       | 3          | 0.686        | 1.267 | 0.402–3.999 |
| Dominant model  |          |            |              |    |        |
| CT + TT vs CC   | 97/687   | 42/253     | 0.227        | 1.252 | 0.87–1.802 |
| rs10870141      |          |            |              |    |        |
| AA              | 698      | 105        | 0.535        |    |        |
| AG              | 217      | 32         | 0.394        |    |        |
| GG              | 25       | 2          | 0.679        |    |        |
| Dominant model  |          |            |              |    |        |
| GG + AG vs AA   | 105/698  | 34/242     | 0.884        | 0.600–1.303 |
| rs10485505      |          |            |              |    |        |
| CC              | 267      | 37         | 0.726        |    |        |
| GC              | 467      | 70         | 0.697        |    |        |
| GG              | 204      | 32         | 0.716        | 1.073 | 0.736–1.564 |
| Dominant model  |          |            |              |    |        |
| GG + GC vs CC   | 37/267   | 102/673    | 0.881        | 1.031 | 0.693–1.534 |
| Rs2293152       |          |            |              |    |        |
| CC              | 267      | 37         | 0.616        |    |        |
| GC              | 467      | 70         | 0.616        |    |        |
| GG              | 204      | 32         | 0.473        |    |        |
| Dominant model  |          |            |              |    |        |
| AA + AG vs GG   | 116/797  | 23/143     | 0.93         | -   | -      |
| Rs41274714      |          |            |              |    |        |
| AA              | 140      | 23         | 0.349        |    |        |
| AG              | 797      | 116        | 0.349        |    |        |
| Dominant model  |          |            |              |    |        |
| AA + AG vs GG   | 139/937  | 5/306      | 0.33         | 1.19 | 0.839–1.686 |
| Rs49111154      |          |            |              |    |        |
| AA              | 634      | 89         | 0.349        |    |        |
| GA              | 266      | 45         | 0.781        |    |        |
| Dominant model  |          |            |              |    |        |
| AA + GA vs GG   | 89/634   | 50/306     | 0.691        | 0.834 | 0.341–2.039 |
| Rs49111154      |          |            |              |    |        |
| AA              | 40       | 5          | 0.691        | 0.834 | 0.341–2.039 |
| Dominant model  |          |            |              |    |        |
| AA vs GA + GG   | 134/900  | 5/40       | 0.691        | 0.834 | 0.341–2.039 |

Table 6 Association between circRNA polymorphism and IS recurrence
stroke recovery including hypertension, depression, and atrial fibrillation were significantly more common in women (Arboix et al. 2006), which may contribute the different risk among the gender. Moreover, individuals with older age are prone to have other chronic disease compared with younger, which may influence stroke recovery. Additionally, all the circRNA polymorphisms were not correlated with a recurrent ischemic stroke risk.

The possible explanation of circ-STAT3 role in short-term prognosis might be as follows. First, the genetic variation at circ-STAT3 might influence the expression of STAT3 by functioning as miRNA sponge (Chen 2016). Second, we speculated that circ-STAT3 rs2293152 located at flanking intron may act as circ-eQTL and affect the circRNA biogenesis, which eventually influenced the expression level of circ-STAT3 (Holdt et al. 2016). This is consistent with Liu et al. study that genetic variants of circRNA within flanking intron region would influence circRNA expression (Liu et al. 2019). Third, functional prediction revealed that rs2293152 was located at potential functional regions and might alter the binding affinity of regulatory motifs, which would influence circ-STAT3 expression. From the above evidence, we can speculate that the effects of circ-STAT3 rs2293152 on short-term prognosis of stroke seem to be mediated by regulating of circ-STAT3 expression. The increased expression of circ-STAT3 might promote the release of inflammatory cytokines and activate the inflammatory response. In addition, STAT3 may also regulate astrocyte activation through targeting of the JAK2/STAT3 pathway (Chen et al. 2017). Astrocyte activation can aggravate inflammatory reactions and brain injury. Thus, circ-STAT3 may influence IS recovery by influencing the neuro-inflammation processes after neural injury.

The highlights of this study were as follows. First, previous studies focused mainly on protein-coding genes, but our studies emphasized non-coding RNAs such as circRNAs. Our study is first and comprehensive study to demonstrate the potential role of circRNA polymorphisms for functional outcome after stroke. Besides, NIHSS score was an important factor for the short-term outcome after stroke, which was took into account in our study. Thus, logistic regression was applied in our study to adjust the confound factors. Finally, we also did stratification analysis to find the interactions between rs2293152 and sex, age. However, there are limitations in our study. First, the sample size of our study was not large enough; further studies in different populations with larger sample are needed to validate the association between the circRNA polymorphisms and functional outcome after stroke. Moreover, functional mechanisms of rs2293152 on the short-term prognosis after stroke are still not clear, which is needed to be clarified in the further study. The circulating serum levels of circ-STAT3 in IS patients should be detected in further study. The specificity and sensitivity of circ-STAT3 should also be calculated to determine whether serum circ-STAT3 might be valuable potential for predicting functional outcome after stroke.

Our study demonstrated that circ-STAT3 rs2293152 GG genotype was associated with unfavorable outcomes 3 months after stroke. Moreover, rs2293152 of circ-STAT3 can also be used as the biomarker for predicting functional outcome after stroke. Further research is needed to explore the exact biological mechanism of these genetic variations on stroke recovery. A comprehensive understanding of genetic variants effect on stroke recovery is needed for setting up personalized therapeutic interventions after stroke.

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Author Contribution Designed the experiments: Ruixia Zhu, Xu Liu; performed the experiments: Ruixia Zhu, Xu Liu, Jingjing Zhao; analyzed the data: Xu Liu, Qianwen Wang, Hongtao Chang; wrote the paper: Ruixia Zhu, Qianwen Wang.

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Availability of Data and Material The data used in our study are available from the authors on reasonable request.

Declarations

Consent to Participate This study was approved by the ethics committee of the First Affiliated Hospital of China Medical University approval, in accordance with the principles of the Helsinki Declaration (AF-SOP-07–1.0–01). Written informed consents were obtained from all the participants.

Conflicts of Interest The authors declare no competing interests.

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