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circ_0010729 靶向 miR-654-3p 介导高糖诱导的肾小球系膜细胞凋亡及炎症反应

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[摘　要]　**目的：**探讨circ_0010729对高糖诱导的肾小球系膜细胞损伤的影响。**方法：**将人肾小球系膜细胞HMCL分为对照组、高糖(high glucose，HG)组、HG+si-NC组、HG+si-circ_0010729组、HG+miR-NC组、HG+miR-654-3p组、HG+si-circ_0010729+anti-miR-NC组、HG+si-circ_0010729+anti-miR-654-3p组。Real-time PCR检测circ_0010729和miR-654-3p的表达水平；流式细胞术检测细胞凋亡；ELISA检测白细胞介素-6(interleukin-6，IL-6)、肿瘤坏死因子-α(tumor necrosis factor-α，TNF-α)水平；双荧光素酶报告实验验证circ_0010729和miR-654-3p的靶向关系。**结果：**与对照组比较，HG组circ_0010729表达水平升高，miR-654-3p表达水平降低，细胞凋亡率升高，TNF-α、IL-6水平升高($P<0.05$)。抑制circ_0010729表达或过表达miR-654-3p后，高糖诱导的人肾小球系膜细胞中细胞凋亡率降低，TNF-α、IL-6水平降低($P<0.05$)。circ_0010729靶向调控miR-654-3p；干扰miR-654-3p表达逆转了抑制circ_0010729表达对高糖诱导的人肾小球系膜细胞凋亡及炎症反应的作用。**结论：**抑制circ_0010729表达可能通过靶向上调miR-654-3p表达抑制高糖诱导的肾小球系膜细胞凋亡及炎症反应。

[关键词]　circ_0010729；miR-654-3p；肾小球系膜细胞；凋亡；炎症反应

circ_0010729 targeting miR-654-3p mediates glomerular mesangial cell apoptosis and inflammation induced by high glucose

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Abstract　**Objective:** To investigate the effect of circ_0010729 on high glucose-induced mesangial cell injury. **Methods:** Human glomerular mesangial cells HMCL were divided into a control group, a high glucose (HG) group, a HG + miR-NC group, a HG + miR-654-3p group, a HG + si-NC group, a HG+si-circ_0010729 group, a HG + si-circ_0010729 + anti-miR-NC group, and a HG + si-circ_0010729 + anti-miR-654-3p group. Real-time PCR was performed to detect the expression levels of miR-654-3p and circ_0010729; flow cytometry was performed to

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detect the apoptosis of glomerular mesangial cells; ELISA was performed to detect interleukin-6 (IL-6) and tumor necrosis factor-α (TNF-α) levels; dual luciferase report experiment was used to verify the targeting relationship between circ_0010729 and miR-654-3p. **Results:** Compared with the control group, the circ_0010729 expression was increased, the miR-654-3p expression was decreased, the apoptosis rate was increased, the TNF-α and IL-6 levels were increased in the HG group (P<0.05). After inhibiting the expression of circ_0010729 or overexpression of miR-654-3p, the apoptosis rate of human glomerular mesangial cells induced by high glucose was decreased, the levels of TNF-α and IL-6 were decreased (P<0.05). circ_0010729 targeted and regulated miR-654-3p; interfering with the expression of miR-654-3p reversed the effect of inhibiting the expression of circ_0010729 on the apoptosis and inflammation of human glomerular mesangial cells induced by high glucose. **Conclusion:** Inhibiting the expression of circ_0010729 may inhibit the apoptosis and inflammation of glomerular mesangial cells induced by high glucose through targeting up-regulation of miR-654-3p expression.

Keywords circ_0010729; miR-654-3p; glomerular mesangial cells; apoptosis; inflammatory response

糖尿病肾病(diabetic nephropathy，DN)是终末期肾病的主要原因，影响糖尿病患者的生活质量，深入研究DN发病的分子机制以开发合适的治疗策略是临床治疗的重点[1]。肾小球系膜细胞凋亡是肾小球硬化的重要机制之一，其增加蛋白尿并促进DN的发展[2]。此外，炎症反应也在DN进程中起重要作用[3]。研究[4]表明：circRNA在急性肾损伤、狼疮肾炎、DN等多种疾病的发生发展过程中具有重要作用，可作为诊断或预测的生物标志物。研究[5]报道：circ_0010729在缺氧诱导的血管内皮细胞损伤中高表达，干扰circ_0010729表达可通过靶向miR-186/缺氧诱导因子-1α(hypoxia-inducible factor-1α，HIF-1α)增加缺氧诱导的血管内皮细胞活性，抑制细胞凋亡。沉默circ_0010729可通过上调miR-145-5p保护人心肌细胞免受氧葡萄糖剥夺引起的损伤[6]。然而circ_0010729对高糖诱导的肾小球系膜细胞损伤尚不清楚。在DN中miR-654-3p表达明显下调，miR-654-3p抑制剂可诱导炎症因子的表达[7]。miR-654-3p靶向抑制去整合素金属蛋白水解酶10(a disintegrin and metalloprotease 10，ADAM10)和RAB22A调节动脉粥样硬化的炎症反应[8]。然而miR-654-3p对高糖诱导的人肾小球系膜细胞损伤的影响，且circ_0010729是否通过靶向调控miR-654-3p的表达影响高糖诱导的人肾小球系膜细胞损伤目前还尚未可知。因此，本实验旨在研究circ_0010729靶向miR-654-3p对高糖诱导的肾小球系膜细胞凋亡及炎症反应的影响。

1 对象与方法

1.1 对象

人肾小球系膜细胞HMCL购自美国ATCC公司；DMEM培养基购自江苏齐氏生物科技有限公司；葡萄糖购自美国Sigma公司；凋亡检测试剂盒购自上海经科化学科技有限公司；双荧光素酶报告基因检测试剂盒购自美国AAT Bioquest公司；蛋白质提取试剂盒、BCA试剂盒购自北京百奥莱博科技有限公司；荧光定量PCR试剂盒购自百奥迈科生物技术有限公司；ELISA试剂盒购自上海江莱生物科技有限公司。载体质粒均由上海吉玛公司提供。

1.2 细胞处理与分组

用含10%胎牛血清、30 mmol/L葡萄糖的DMEM培养基培养的HMCL细胞作为高糖(high glucose，HG)组；用含10%胎牛血清、5.5 mmol/L葡萄糖的DMEM培养基培养的HMCL细胞作为对照(Con)组；将si-NC、si-circ_0010729、miR-NC、miR-654-3p分别转染HMCL细胞，用30 mmol/L葡萄糖处理，分别记为HG+si-NC组、HG+si-circ_0010729组、HG+miR-NC组、HG+miR-654-3p组；将si-circ_0010729与anti-miR-NC、si-circ_0010729与anti-miR-654-3p共转染HMCL细胞，用30 mmol/L葡萄糖处理，分别记为HG+si-circ_0010729+anti-miR-NC组和HG+si-circ_0010729+anti-miR-654-3p组。将pcDNA、pcDNA-circ_0010729、si-NC、si-circ_0010729转染至肾小球系膜细胞，按real time PCR检测miR-654-3p表达水平。

1.3 Real-time PCR 检测 miR-654-3p 和 circ_0010729 的表达水平

提取各组细胞总RNA，合成cDNA后进行PCR，相对表达量用$2^{-\Delta\Delta Ct}$法计算。circ_0010729和miR-654-3p分别以GAPDH和U6为内参。

1.4 流式细胞术检测细胞凋亡

取转染48 h后细胞，预冷PBS漂洗2次，结合缓冲液重悬，加入Annexin V-FITC和PI各5 μL，避光孵育10 min；流式细胞仪检测细胞凋亡率。

1.5 蛋白质印迹法检测蛋白质表达

提取细胞总蛋白质，定量后进行SDS-PAGE后，转膜，封闭，加一抗4 ℃孵育过夜，加二抗室温孵育2 h，显影，分析蛋白质条带灰度值。

1.6 ELISA 检测 TNF-α、IL-6 水平

收集各组培养48 h后细胞上清液，按照试剂盒说明操作。

1.7 双荧光素酶报告实验验证circ_0010729和miR-654-3p的靶向关系

将circ_0010729野生型载体(WT-circ_0010729)和突变型载体(MUT-circ_0010729)，分别与miR-NC、miR-654-3p共转染至肾小球系膜细胞中，转染48 h后，按试剂盒说明检测荧光素酶活性。

1.8 统计学处理

用SPSS 20.0统计学软件分析数据。计量资料用均数±标准差($\bar{x}\pm s$)表示，比较行t检验；各组间先行单因素方差分析，组间有差异后进行两两比较。P<0.05为差异有统计学意义。

2 结果

2.1 circ_0010729 和 miR-654-3p 在高糖诱导的人肾小球系膜细胞损伤中的表达

HG组miR-654-3p表达水平低于对照组，circ_0010729表达水平高于对照组(P<0.05，表1)。

2.2 抑制 circ_0010729 表达对高糖诱导的人肾小球系膜细胞凋亡及炎症反应的影响

HG组circ_0010729表达水平、细胞凋亡率、Bax表达水平、TNF-α、IL-6水平均高于Con组，Bcl-2表达水平低于对照组(均P<0.05)；HG+si-circ_0010729组circ_0010729表达水平、细胞凋亡率、Bax表达水平、TNF-α、IL-6水平均低于HG+si-NC组，Bcl-2表达水平高于HG+si-NC组(均P<0.05；表2，图1)。

2.3 circ_0010729 靶向调控 miR-654-3p 的表达

图2为circ_0010729与miR-654-3p互补的核苷酸序列。WT-circ_0010729与miR-654-3p共转染的细胞荧光素酶活性低于与miR-NC共转染的细胞(P<0.05，表3)。pcDNA-circ_0010729组miR-654-3p表达水平低于pcDNA组；而si-circ_0010729组miR-654-3p表达水平高于si-NC组(均P<0.05，表4)。

2.4 miR-654-3p 过表达对高糖诱导的人肾小球系膜细胞凋亡及炎症反应的影响

HG+miR-654-3p组细胞凋亡率、Bax表达水平、TNF-α、IL-6水平均低于HG+miR-NC组，miR-654-3p、Bcl-2表达水平高于HG+miR-NC组(均P<0.05；图3，表5)。

表1 circ_0010729和miR-654-3p在高糖诱导的人肾小球系膜细胞损伤中的表达(n=9)

Table 1 Expression of circ_0010729 and miR-654-3p in human mesangial cell injury induced by high glucose (n=9)

组别	circ_0010729	miR-654-3p
对照组	1.00 ± 0.05	1.00 ± 0.07
HG组	3.39 ± 0.22	0.37 ± 0.03
t	31.780	24.817
P	<0.001	<0.001

表2 抑制circ_0010729表达对高糖诱导的人肾小球系膜细胞凋亡及炎症反应的影响(n=9)

Table 2 Effect of inhibiting the expression of circ_0010729 on the apoptosis and inflammation of human glomerular mesangial cells induced by high glucose (n=9)

组别	circ_0010729	凋亡率/%	Bcl-2蛋白	Bax蛋白	TNF-α/(ng·L^{-1})	IL-6/(ng·L^{-1})
对照组	1.00 ± 0.07	7.82 ± 0.51	0.65 ± 0.05	0.28 ± 0.03	28.71 ± 2.55	14.57 ± 1.28
HG组	3.42 ± 0.27*	28.85 ± 2.65*	0.22 ± 0.02*	0.79 ± 0.06*	89.63 ± 6.96*	64.66 ± 3.45*
HG+si-NC组	3.45 ± 0.29	29.91 ± 2.48	0.20 ± 0.02	0.81 ± 0.05	94.22 ± 7.32	68.32 ± 4.96
HG+si-circ_0010729组	1.75 ± 0.16#	11.56 ± 1.06#	0.54 ± 0.03#	0.39 ± 0.03#	39.82 ± 2.49#	25.85 ± 2.70#
F	289.619	325.833	441.357	337.937	355.355	584.292
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

与对照组比较，*P<0.05；与HG+si-NC组比较，#P<0.05。

Compared with the control group, *P<0.05; compared with HG + si-NC group, #P<0.05.

2.5 干扰 miR-654-3p 表达逆转抑制 circ_0010729 表达对高糖诱导的人肾小球系膜细胞凋亡及炎症反应的作用

HG+si-circ_0010729+anti-miR-654-3p组miR-654-3p表达水平、Bcl-2表达水平均低于HG+si-circ_0010729+anti-miR-NC组，细胞凋亡率、Bax表达水平、TNF-α、IL-6水平均高于HG+si-circ_0010729+anti-miR-NC组(均P<0.05；图4，表6)。

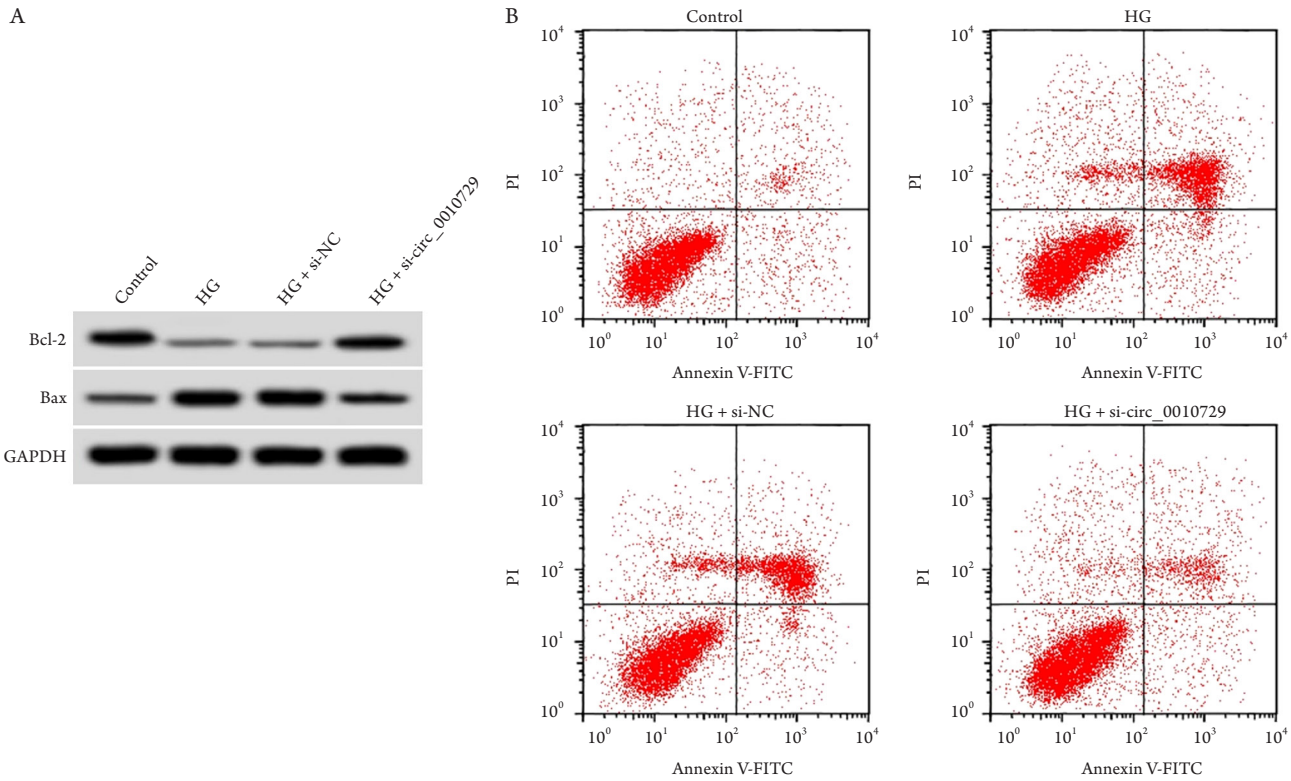

图1 抑制circ_0010729表达对高糖诱导的人肾小球系膜细胞凋亡的影响

Figure 1 Effect of inhibiting the expression of circ_0010729 on the apoptosis of human glomerular mesangial cells induced by high glucose

(A)凋亡相关蛋白质表达；(B)细胞凋亡流式图。

(A) Apoptosis-related protein expression; (B) Apoptosis flow cytometry.

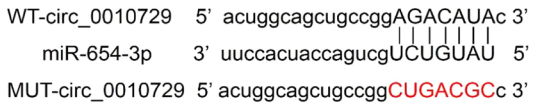

图2 circ_0010729与miR-654-3p互补的核苷酸序列

Figure 2 Complementary nucleotide sequence of circ_0010729 and miR-654-3p

表3 细胞荧光素酶活性(n=9)

Table 3 Cell luciferase activity (n=9)

组别	WT-circ_0010729	MUT-circ_0010729
miR-NC组	1.02 ± 0.08	1.01 ± 0.05
miR-654-3p组	0.56 ± 0.05	1.03 ± 0.08
t	20.670	0.636
P	<0.001	0.534

表4 circ_0010729调控miR-654-3p的表达(n=9)

Table 4 circ_0010729 regulates the expression of miR-654-3p (n=9)

组别	miR-654-3p
pcDNA组	1.00 ± 0.05
pcDNA-circ_0010729组	0.52 ± 0.04*
si-NC组	0.99 ± 0.06
si-circ_0010729组	2.58 ± 0.22#
F	519.759
P	<0.001

与pcDNA组比较，*P<0.05；与si-NC组比较，#P<0.05。

Compared with pcDNA group, *P<0.05; compared with si-NC group, #P<0.05.

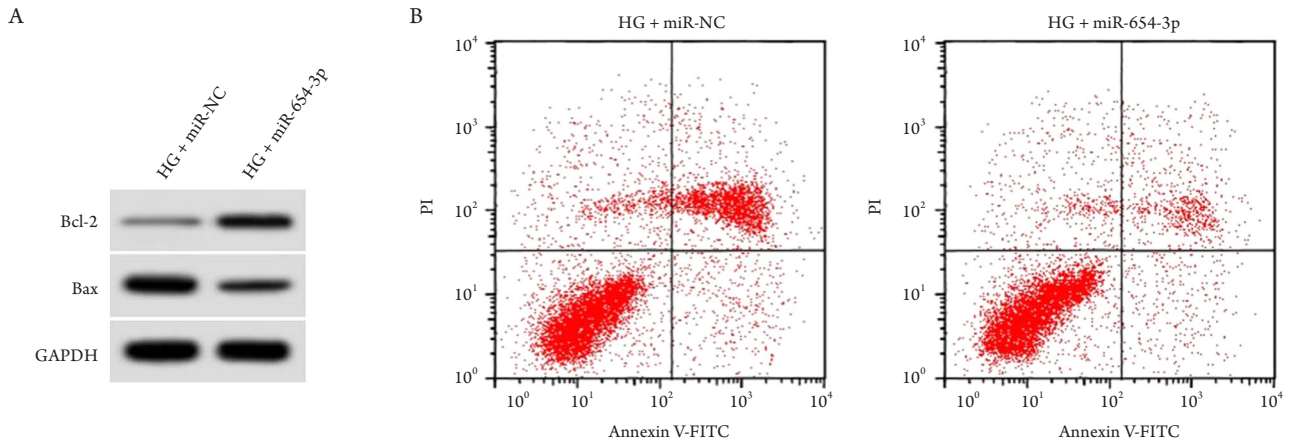

图3 miR-654-3p过表达对高糖诱导的人肾小球系膜细胞凋亡的影响

Figure 3 Effect of miR-654-3p overexpression on the apoptosis of human mesangial cells induced by high glucose

(A)凋亡相关蛋白质表达；(B)细胞凋亡流式图。

(A) Apoptosis-related protein expression; (B) Apoptosis flow cytometry.

表5 miR-654-3p过表达对高糖诱导的人肾小球系膜细胞凋亡及炎症反应的影响(n=9)

Table 5 Effect of miR-654-3p overexpression on human glomerular mesangial cell apoptosis and inflammation induced by high glucose (n=9)

组别	miR-654-3p	凋亡率/%	Bcl-2蛋白	Bax蛋白	TNF-α/(ng·L^{-1})	IL-6/(ng·L^{-1})
HG+miR-NC组	1.00 ± 0.06	29.57 ± 2.45	0.21 ± 0.02	0.80 ± 0.05	90.95 ± 5.27	67.75 ± 4.62
HG+miR-654-3p组	2.53 ± 0.22	14.67 ± 1.15	0.51 ± 0.04	0.44 ± 0.03	44.39 ± 3.62	29.28 ± 2.86
t	20.128	16.516	20.125	18.522	21.847	21.240
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

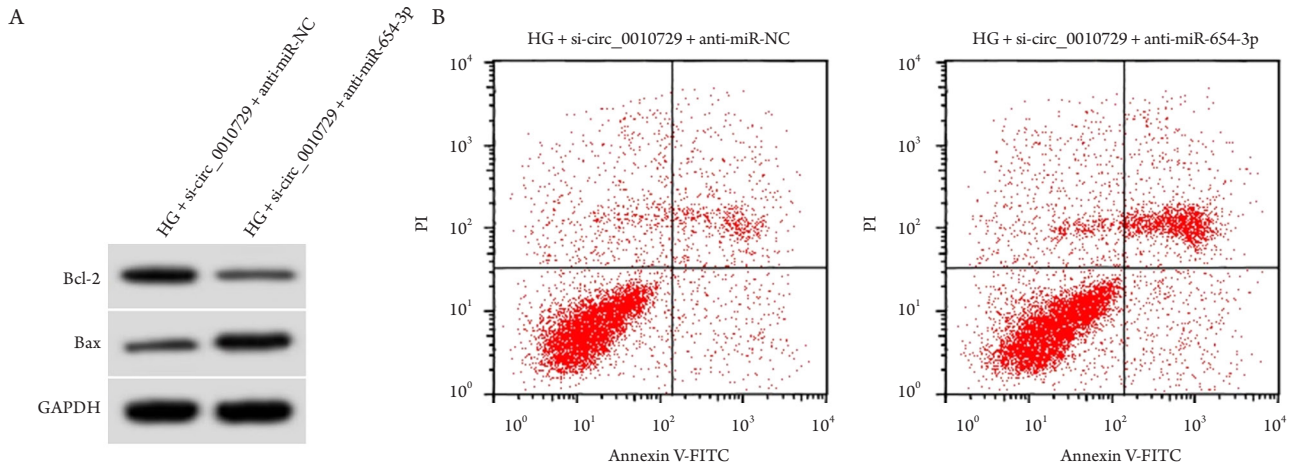

图4 干扰miR-654-3p逆转了抑制circ_0010729表达对高糖诱导的人肾小球系膜细胞凋亡的作用

Figure 4 Interference with miR-654-3p reversed the effect of inhibiting circ_0010729 on the apoptosis of human mesangial cells induced by high glucose

(A)凋亡相关蛋白质表达；(B)细胞凋亡流式图。

(A) Apoptosis-related protein expression; (B) Apoptosis flow cytometry.

表6 干扰miR-654-3p逆转了抑制circ_0010729表达对高糖诱导的人肾小球系膜细胞凋亡及炎症反应的作用(n=9)

Table 6 Interference with miR-654-3p reversed the effect of inhibiting circ_0010729 on the apoptosis and inflammation of human glomerular mesangial cells induced by high glucose (n=9)

组别	miR-654-3p	凋亡率/%	Bcl-2蛋白	Bax蛋白	TNF-α/(ng·L^{-1})	IL-6/(ng·L^{-1})
HG+si-circ_0010729+anti-miR-NC组	1.00 ± 0.09	10.94 ± 1.08	0.57 ± 0.04	0.38 ± 0.03	37.99 ± 3.48	24.20 ± 2.45
HG+si-circ_0010729+anti-miR-654-3p组	0.39 ± 0.03	22.34 ± 2.06	0.30 ± 0.03	0.69 ± 0.05	79.40 ± 5.41	56.04 ± 4.77
t	19.290	14.704	16.200	15.949	19.313	17.813
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

3 讨论

DN是糖尿病常见的并发症，也是导致其死亡的重要原因，肾小球系膜细胞是肾脏内最为活跃的细胞，参与并维持肾的多种功能；系膜细胞可调节肾小球的滤过功能，吞噬凋亡细胞，维持系膜基质稳态等，系膜细胞损伤可导致DN进展[9]。炎症因子的产生可造成肾小球硬化、肾间质纤维化及肾小管萎缩，进一步促进DN的进展[10]。因此，抑制肾小球系膜细胞损伤及炎症因子的释放是治疗DN的重要途径之一。高血糖是各型糖尿病的共同特征，因此本研究用高糖处理肾小球系膜细胞模拟DN细胞模型，结果显示高糖处理肾小球系膜细胞后增加细胞凋亡率、炎症因子TNF-α和IL-6水平，表明高糖可诱导肾小球系膜细胞凋亡及炎症反应，诱导肾小球系膜细胞损伤。

本研究结果显示高糖诱导的肾小球系膜细胞中circ_0010729表达水平升高。研究[11]表明circLRP6可通过海绵化miR-205调节高糖诱导的系膜细胞增殖、氧化应激和炎症反应。circRNA_15698通过miR-185/转化生长因子β1(transforming growth factor beta 1，TGF-β1)加剧了DN系膜细胞的细胞外基质积累[12]。circ-AKT3过表达抑制了高糖处理的小鼠系膜SV40-MES13细胞的凋亡[13]。circRNA_010383 作为 miR-135a 的海绵，其表达下调有助于DN中的肾纤维化[14]。circLRP6 调节高糖诱导的系膜细胞增殖、氧化应激、炎症[15]。circ_LARP4调节高糖诱导的系膜细胞增殖、凋亡和纤维化[16]。circSMAD4通过抑制miR-377-3p介导的骨形态发生蛋白(bone morphogenetic protein 7，BMP7)减轻高糖诱导的肾小球系膜细胞炎症、细胞外基质沉积和细胞凋亡[17]。本实验结果提示circ_0010729可能参与了肾小球细胞的损伤过程。本实验进一步抑制circ_0010729的表达后，高糖诱导的人肾小球系膜细胞中细胞凋亡率、Bax表达水平、TNF-α、IL-6水平降低，Bcl-2表达水平升高，表明抑制circ_0010729表达可减轻高糖诱导的人肾小球系膜细胞损伤。

miRNAs被证实在DN中异常表达，且与DN的发病相关[18]。miR-146b-5p过表达可减轻肾小球系膜细胞的炎症反应[19]。miR-874可减轻DN的肾损伤和炎症反应[20]。已有研究[7]表明miR-654-3p在DN中下调表达，本实验结果显示高糖诱导的人肾小球系膜细胞中miR-654-3p低表达，与该研究结果相符。且本实验还发现过表达miR-654-3p后，高糖诱导的人肾小球系膜细胞中细胞凋亡率、Bax表达水平、TNF-α、IL-6水平降低，Bcl-2表达水平升高；表明过表达miR-654-3p可抑制高糖诱导的人肾小球系膜细胞凋亡和炎症反应。本实验还发现circ_0010729靶向调控miR-654-3p；干扰miR-654-3p表达逆转抑制circ_0010729表达对高糖诱导的人肾小球系膜细胞凋亡及炎症反应的作用。

总之，抑制circ_0010729可通过上调miR-654-3p抑制高糖诱导的肾小球系膜细胞凋亡及炎症反应。但关于miR-654-3p如何调控下游靶基因参与DN发生发展过程尚未明确，仍需进一步验证circ_0010729/miR-654-3p/靶基因分子轴在高糖诱导的肾小球系膜细胞损伤中的作用机制。

参考文献

1. A/L B Vasanth Rao VR, Tan SH, Candasamy M, et al. Diabetic nephropathy: An update on pathogenesis and drug development[J]. Diabetes Metab Syndr, 2019, 13(1): 754-762.
2. Lu Q, Zhou Y, Hao M, et al. The mTOR promotes oxidative stress-induced apoptosis of mesangial cells in diabetic nephropathy[J]. Mol Cell Endocrinol, 2018, 473(1): 31-43.
3. Chen Y, Wang YJ, Zhao Y, et al. Carbohydrate response element binding protein (ChREBP) modulates the inflammatory response of mesangial

cells in response to glucose[J]. Biosci Rep, 2018, 38(6): R20180767.

4. 谢剑腾, 梁田田, 柴春芳, 等. 环状RNA在肾脏疾病的研究进展[J]. 中华肾脏病杂志, 2019, 35(4): 311-315.
XIE Jianteng, LIANG Tiantian, QI Chunfang, et al. Research progress of circular RNAs in renal diseases[J]. Chinese Journal of Nephrology, 2019, 35(4): 311-315.
5. Dang RY, Liu FL, Li Y. Circular RNA hsa_circ_0010729 regulates vascular endothelial cell proliferation and apoptosis by targeting the miR-186/HIF-1α axis.[J]. Biochem Biophys Res Commun, 2017, 490(2): 104-110.
6. Jin Q, Chen Y. Silencing circular RNA circ_0010729 protects human cardiomyocytes from oxygen-glucose deprivation-induced injury by up-regulating microRNA-145-5p[J]. Mol Cell Biochem, 2019, 462(1/2): 185-194.
7. Yao T, Zha D, Hu C, et al. Circ_0000285 promotes podocyte injury through sponging miR-654-3p and activating MAPK6 in diabetic nephropathy[J]. Gene, 2020, 747(1): 144661.
8. Tang X, Yin R, Shi H, et al. LncRNA ZFAS1 confers inflammatory responses and reduces cholesterol efflux in atherosclerosis through regulating miR-654-3p-ADAM10/RAB22A axis[J]. Int J Cardiol, 2020, 315(1): 72-80.
9. 冯欣鑫, 孙晶, 张磊, 等. 肾小球系膜细胞的细胞生物学功能[J]. 国际免疫学杂志, 2020, 43(2): 226-229.
FENG Xinxin, SUN Jing, ZHANG Lei, et al. Cell biological function of mesangial cells[J]. International Journal of Immunology, 2020, 43(2): 226-229.
10. 娄群, 陈兆杰, 姜琦, 等. 老年糖尿病肾病发病机制、诊断及治疗的研究进展[J]. 中国老年学杂志, 2018, 38(1): 244-247.
LOU Qun, CHEN Zhaojie, JIANG Qi, et al. Research progress in pathogenesis, diagnosis and treatment of senile diabetes nephropathy[J]. Chinese Journal of Gerontology, 2018, 38(1): 244-247.
11. Chen B, Li Y, Liu Y, et al. circLRP6 regulates high glucose-induced proliferation, oxidative stress, ECM accumulation, and inflammation in mesangial cells[J]. J Cell Physiol, 2019, 234(11): 21249-21259.
12. Hu W, Han Q, Zhao L, et al. Circular RNA circRNA_15698 aggravates the extracellular matrix of diabetic nephropathy mesangial cells via miR-185/TGF-β1[J]. J Cell Physiol, 2019, 234(2): 1469-1476.
13. Tang B, Li W, Ji TT, et al. Circ-AKT3 inhibits the accumulation of extracellular matrix of mesangial cells in diabetic nephropathy via modulating miR-296-3p/E-cadherin signals[J]. J Cell Mol Med, 2020, 24(15): 8779-8788.
14. Peng F, Gong W, Li S, et al. circRNA_010383 acts as a sponge for miR-135a, and its downregulated expression contributes to renal fibrosis in diabetic nephropathy[J]. Diabetes, 2021, 70(2): 603-615.
15. Chen B, Li Y, Liu Y, et al. circLRP6 regulates high glucose-induced proliferation, oxidative stress, ECM accumulation, and inflammation in mesangial cells[J]. J Cell Physiol, 2019, 234(11): 21249-21259.
16. Wang Y, Qi Y, Ji T, et al. Circ_LARP4 regulates high glucose-induced cell proliferation, apoptosis, and fibrosis in mouse mesangial cells[J]. Gene, 2021, 765: 145114.
17. Wu R, Niu Z, Ren G, et al. CircSMAD4 alleviates high glucose-induced inflammation, extracellular matrix deposition and apoptosis in mouse glomerulus mesangial cells by relieving miR-377-3p-mediated BMP7 inhibition[J]. Diabetol Metab Syndr, 2021, 13(1): 137.
18. 熊思, 彭辉勇, 柳迎昭. MicroRNAs在糖尿病肾病中的研究进展[J]. 中国现代医学杂志, 2019, 29(1): 60-66.
XIONG Si, PENG Huiyong, LIU Yingzhao. Research progress of MicroRNAs in diabetic nephropathy[J]. China Journal of Modern Medicine, 2019, 29(1): 60-66.
19. Sheng ZX, Yao H, Cai ZY. The role of miR-146b-5p in TLR4 pathway of glomerular mesangial cells with lupus nephritis[J]. Eur Rev Med Pharmacol Sci, 2018, 22(6): 1737-1743.
20. Yao T, Zha D, Gao P, et al. MiR-874 alleviates renal injury and inflammatory response in diabetic nephropathy through targeting toll-like receptor-4[J]. J Cell Physiol, 2018, 234(1): 871-879.

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