Abstract. Long non-coding RNAs (lncRNAs) are involved in the gene expression regulation and usually play important roles in various human cancers, including the renal cell carcinoma (RCC). Dysregulation of certain lncRNAs are associated with the prognosis of patients with RCC. In the present review, several recently studied lncRNAs were discussed and their critical roles in proliferation, migration, invasion, apoptosis and drug resistance of renal cancer cells were revealed. The research on lncRNAs further increases our understanding on the development and progression of RCC. It is suggested that lncRNAs can be used as biomarkers or therapeutic targets for diagnosis or treatment of renal cancer.

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1. Introduction

Kidney cancer accounts for ~2% of all cancers, resulting in millions of deaths worldwide each year (1,2). In 2016, 62,700 people were initially diagnosed with kidney cancer, and 14,240 patients succumbed to this disease in the United States (3). Renal cell carcinoma (RCC) is the most common type of kidney cancer, and its incidence is increasing (4-6). A total of ~20% of patients with RCC are diagnosed with tumors in advanced stages, and 30% of patients with localized RCC suffer relapses and metastasis after surgical treatment (7,8). However, specific biomarkers for RCC are rarely reported. Therefore, the further investigation of the molecular mechanism of RCC is urgently needed.

Multiple factors, including DNA methylation, histone modification, genomic instability and gene mutations, are involved in the molecular mechanism of RCC (9,10). The dysregulation of protein-coding genes is known to promote tumorigenesis (11,12). In addition, noncoding RNAs have been proven to be involved in various cellular activities (13‑15), and the aberrant expression of non‑coding RNAs accelerates the formation and development of RCC (16,17).

With the development of lncRNA biology, a growing number of functional lncRNAs in RCC progression have been identified. In patients with RCC, the dysregulation of lncRNAs can promote the progression of RCC, resulting in poor prognosis (31-33). RCC
tumorigenesis is a complex biological process that involves not only mutations in genetic networks but also epigenetic alterations that can trigger imbalances in cellular homeostasis and ultimately lead to abnormal cell growth. During the process of malignant transformation, cells and their microenvironment must acquire various biological properties that favor malignant cell growth. These biological properties include and are not limited to: proliferation, migration, apoptosis and metabolism of RCC cells (34-36). IncRNAs play an important regulatory role in each of these biological events in RCC patients (Fig. 1). Moreover, IncRNAs can activate the expression of encoding genes, miRs and oncogenes to promote the development of RCC cells (37,38). In the present review, the clinicopathological features, biological functions and molecular mechanisms of IncRNAs in RCC development were presented.

2. Features and functions of IncRNAs in carcinogenesis

On the basis of their different transcription sites, IncRNAs are classified into five categories: sense, antisense, bidirectional, intergenic and bidirectional IncRNAs (39). Moreover, their functions are determined by their transcription sites to certain extent. IncRNAs are involved in gene expression regulation at different stages in a variety of tumors. They can recruit chromatin-modifying complexes to promote gene transcriptional expression levels and function with transcription factors, proteins, miRNAs, or mRNAs to control post-transcriptional processes (40-43). They can act as scaffolds to absorb various regulatory molecules at a single locus (44). The number of IncRNAs participating in epigenetic regulation is increasing. IncRNA MALAT1 was revealed to upregulate the expression of EZH2 by binding with miR-205 and promote the apoptosis of acute lymphoblastic leukemia cells (32). In chemo-resistant, castration-resistant prostate cancer, IncRNA HOXD-AS1 utilized histone H3 lysine 4 trimethylation to absorb WDR5, thereby inhibiting PKL1 and AURKA expression (45). In gastric cancer cells, IncRNA FEZF1-AS1 suppressed P21 expression by binding with LSD1 (46).

IncRNAs also execute important roles in the development of cancers. Multiple studies have demonstrated that some cancer-promoting IncRNAs could promote the proliferation and migration and inhibit the apoptosis of cancer cells, such as gastric cancer cells (47,48). In addition, certain IncRNAs could promote cancer drug resistance and alter energy metabolism in cancer cells (49,50).

3. IncRNAs and RCC

Expression profile of IncRNAs in RCC. Microarray and RT-qPCR assays were previously used to determine the relative expression of IncRNAs in RCC. The relative expression levels of IncRNAs in RCC are shown in Table I.

IncRNAs are associated with the prognosis of patients with RCC. Numerous studies have shown that the aberrant expression of IncRNAs is closely associated with the pathological features and prognosis of patients with RCC. NEAT1 overexpression was significantly associated with the tumor size, histological grade, and lymph node metastasis of patients with RCC, thus worsening overall survival (51). He et al (35) found that the expression of IncRNA FTX in RCC tissues was 5-fold higher than that in adjacent normal tissues. The high expression of FTX was positively correlated with large tumor size, lymphatic metastasis and high TNM stage. Xiong et al (52) found that IncRNA ATB was obviously overexpressed in RCC tissues, and the augmented expression of ATB was closely associated with histological grade, tumor stage, lymph node metastasis and distant metastasis. IncRNA RCCRT1 was also elevated in RCC tissues. Correlations have been found between RCCRT1 expression and pathological features, including histological grade, distant metastasis and lymph node metastasis (53). Moreover, IncRNAs MALAT1, Inc-ZNF180-2, Linc00152, HOTAIR, and HEIRCC were upregulated in RCC tissues compared with normal kidney tissues (32,54-57). In patients with RCC, high MALAT-1 expression resulted in large tumor size, high tumor stage and lymph node metastasis (32). In patients with RCC, the decreased expression of IncRNA H19 caused high histological grade and tumor stage, as well as lymph node and distant metastasis (58). The correlations between clinicopathological features and the expression of other cancer-promoting IncRNAs are shown in Table I. Certain IncRNAs, including IncRNAs TCL6, CADM1-AS1, GAS5, and LOC389332, are downregulated in the progression of RCC (59-62). The expression of IncRNA TCL6 was negatively correlated with TNM stage, lymph node metastasis, and distant metastasis (59). The relationships between clinicopathological features and other tumor-suppressor IncRNAs are shown in Table I.

IncRNAs control the proliferation of RCC cells. Infinite proliferation is an important feature of cancer cells (63,64). RCC cells can proliferate with impunity when nutrition and space are enough. Moreover, RCC cells can compress their surrounding tissue during proliferation (65). IncRNAs play important roles in the proliferation of RCC cells. Oncogene IncRNAs can promote the proliferation of RCC cells, whereas tumor suppressors can inhibit proliferation. The relevant biological functions in which IncRNAs are involved are presented in Table II.

Zhang et al (32) and Chen et al (36) demonstrated that the knockdown of IncRNA MALAT-1 inhibited the proliferation of RCC cells.

Wu et al (55) showed that the amplification of IncRNA Linc00152 enhanced the proliferation of RCC cells. Wu et al (66) found that the inhibition of IncRNA HOTAIR suppressed the proliferation of RCC cells. Moreover, the percentage of G2/M phase cells was reduced significantly. Xiong et al (57) discovered that IncRNA HEIRCC promoted the proliferation of RCC cells. In addition, RCC cell proliferation was significantly downregulated when IncRNA ATB was suppressed (52). Cellular proliferation was inhibited when IncRNA FTX was knocked down in RCC cells (35). Ning et al (51) found that the knockdown of IncRNA NEAT1 weakened the proliferation of RCC cells. Furthermore, IncRNA UCA1 could strengthen the proliferation of RCC cells (67). Zhai et al (68) identified an interesting IncRNA, IncRNA SARCC, that was differentially expressed in the hypoxic environment depending on the expression of von Hippel-Lindau (VHL). The overexpression of IncRNA SARCC inhibited the proliferation of VHL-mutant RCC cells by decreasing the stability and expression of androgen...
The decreased expression of AR protein suppressed HIF-2α and C-MYC expression. C-MYC is the downstream effector of HIF-2α. Finally, Zhai et al. (68) clearly demonstrated that the signals of lncRNA SARCC/AR/HIF-2α/C-MYC/p27/E2F1 were present in the absence of oxygen, thus opening up a new molecular pathway for RCC cancer progression under hypoxic conditions.

Tumor-suppressor IncRNAs can suppress the proliferation of RCC cells. The overexpression of lncRNA TCL6, GAS5, or LOC389332 can restrain RCC cell proliferation (48,50,51). IncRNAs affect the migration and invasion of RCC cells. Metastasis is a massive problem for cancer therapy. The migration and invasion of cancer cells are the main reasons for tumor metastasis (69,70). Hence, a deep insight into RCC cell migration and invasion will contribute to the research on tumor metastasis. The relevant biological functions in which IncRNAs are involved are shown in Table II.

Xiong et al. (52) revealed that the decreased expression of lncRNA ATB reduced the migration and invasion ability of RCC cells by repressing the epithelial-mesenchymal transition (EMT). He et al. (35) demonstrated that the inhibition of lncRNA FTX weakened the migration and invasion of RCC cells. Ning et al. (51) found that NEAT‑1 accelerated EMT to enhance the invasiveness of RCC cells. RCC cell motility was significantly decreased when the cellular expression of IncRNA UCA1 was inhibited (67). The silencing of IncRNA HEIRCC suppressed RCC cell migration and invasion by inhibiting the EMT program (57). Chiyomaru et al. (71), Xia et al. (56) and Wu et al. (66) demonstrated that the knockdown of lncRNA HOTAIR weakened the migration and invasion of RCC cells, whereas the overexpression of HOTAIR produced opposite results. The increased expression of Linc00152 promoted the invasion of RCC cells, whereas the deletion of Linc00152 resulted in contrasting results (55). RCC cells with decreased RCCRT1 expression showed attenuated migration ability (53). Finally, Xiao et al. (72) and Zhang et al. (32) reported that the deletion of lncRNA MALAT‑1 inhibited cell migration and invasion. However, the amplification of the tumor-suppressor IncRNA LOC389332 suppressed the migration of RCC cells (55).

IncRNAs affect the apoptosis of RCC cells. The apoptosis of normal cells is promoted by complicated apoptotic mechanisms, and a series of genes and signaling pathways are activated (73,74). However, the apoptosis of cancer cells is not controlled by programmed cell death (75,76). The apoptosis of RCC cells is obviously suppressed and the expression of apoptosis-related genes is activated during the progression of RCC (77,78). With the improved understanding of IncRNAs,
certain apoptosis-related genes in RCC have been reported. The relevant biological functions in which lncRNAs are involved are shown in Table II.

Xiong et al (52) reported that the decreased expression of lncRNA ATB promoted the apoptosis of RCC cells, indicating that lncRNA ATB restrained apoptosis during...
the development of RCC cells. Chen et al (34) detected the role of CCAT1 in cell apoptosis and found that CCAT1 knockdown led to an increase in apoptotic RCC cells, as well as caspases 3, 7, and 9. However, the antiapoptotic protein Bcl-2 was downregulated upon CCAT1 knockdown. CCAT1 exerted its anti-apoptosis effect by increasing the expression of Livin. Ning et al (51) confirmed that the deletion of IncRNA NEAT1 enhanced the apoptotic rate of RCC cells. Li et al (67) identified the negative effect of IncRNA UCA1 on RCC cell apoptosis. Hirata et al (37) and Chen et al (36) showed that the knockdown of IncRNA MALAT-1 obviously strengthened the apoptosis of RCC cells, whereas the enforced expression of MALAT1 inhibited cell apoptosis. Chiyomaru et al (71) discovered that the suppression of IncRNA HOTAIR increased apoptotic RCC cells by inhibiting the expression of miR-141. miR-141 is a member of the miR-200 family that acts as a tumor suppressor in the progression of cancers. The amplification of miR-141 promotes the apoptosis of cancer cells (79,80). Xiong et al (57) investigated the effect of IncRNA HEIRCC on RCC cell apoptosis and detected increased apoptosis when HEIRCC was knocked down. Moreover, IncRNAs H19, Linc00152, and RCCRT1 could inhibit the apoptosis of RCC cells (53,55,58).

The dysregulation of tumor-suppressor IncRNAs is associated with the progression of RCC. Qiao et al (61) found that the enforced expression of IncRNA GAS5 increased the percentage of early apoptotic cells and total apoptotic cells in RCC cells. Liu et al (81) identified that the attenuated expression of IncRNA TRIM52-AS1 facilitated RCC cell apoptosis. Yao et al (60) observed that the rate of apoptotic RCC cells was increased in the IncRNA CADM1-AS1 knockdown group compared with that in the negative control group. Su et al (59) demonstrated that the upregulation of IncRNA TCL6 enhanced the apoptosis of RCC cells.

**IncRNAs are responsible for the tumorigenicity and expansion of RCC cells in vivo.** Current studies have provided valuable novel insights into the IncRNA-induced tumorigenicity and expansion of RCC cells in vivo (82,83). The amplification of certain IncRNAs can facilitate tumor formation and expansion by enhancing angiogenesis and altering the intracellular environment (84,85). During carcinogenesis, carcinoma cell lines can grow out of control, stifling reef recovery. However, the impaired expression of carcinogenic IncRNAs, such as HOTAIR, MALAT-1, IncARS, and IncSARCC, can reduce the size and weight of RCC tissues in vivo (66,72,86-88). The relevant biological functions in which IncRNAs are involved are shown in Table II.

Wu et al (66) injected RCC cells expressing low HOTAIR levels into mice. The growth rate and weight of tumors induced by the RCC cells were significantly lower than those in the negative control groups. Moreover, the knockdown of HOTAIR upregulated the expression levels of p53, p21 and p16 in vivo. Xiao et al (72) revealed that the inhibition of IncRNA MALAT-1 in vivo significantly reduced the tumor size and quality of RCC. Qu et al (87) identified that silencing IncRNAs weakened the tumorigenicity and metastasis of renal tumor-initiating cells by binding to the Yes-associated protein (YAP). Mechanistically, the 5' end of IncARSR binds to YAP to interrupt LATS1-mediated YAP phosphorylation. To sum up, the IncARSR-YAP axis functions as a promising therapeutic target in patients with RCC.

**IncRNAs contribute to the drug resistance of RCC cells.** Tumor drug treatments, such as chemotherapy and targeted therapy, have been widely used in cancer treatment. In renal cancer, drug treatment is known to gradually become insensitive. Although the mechanisms of tumor drug resistance have been studied and reported, no one could completely explain all the observations. Two recent works have highlighted the involvement of IncRNAs in the drug resistance of RCC cells. Qu et al (38) reported an uncharacterized IncRNA, IncARSR, to be highly expressed in sunitinib-resistant RCC cells and functionally required for the resistant phenotype. IncARSR acts as a ceRNA for miR-34 and miR-449, resulting in the upregulation of AXL/c-MET and the activation of STAT3, AKT and ERK signaling. It was also found that IncARSR could be used to predict the poor response of patients with RCC. Notably, this IncRNA could also be secreted from resistant cells through exosomes, thereby transforming sunitinib-sensitive cells into resistant cells. Xu et al (89) identified IncRNA SRLR, which was upregulated in intrinsically soraifenib-resistant RCC cells. The knockdown of IncRNA SRLR sensitized non-responsive RCC cells to sorafenib treatment. By contrast, the overexpression of IncRNA SRLR conferred soraifen resistance to sensitive RCC cells. The potential molecular mechanism of this IncRNA and was further studied and it was revealed that IncRNA SRLR directly bound to NF-κB, enhanced IL-6 transcription and led to the activation of STAT3 and the development of soraifen tolerance. IncRNA SRLR functioned as not only a predictive marker for soraifen resistance but also as a therapeutic target to enhance responses to soraifenib in patients with RCC. The relevant biological functions in which IncRNAs are involved are shown in Table II.

4. Conclusions

Renal cancer is a fatal disease with aberrant gene expression (90,91). Although the treatments for renal cancer have been rapidly improved over the past few decades, the survival of patients with RCC has not been significantly improved (92,93). Recurrence and metastasis are the major reasons for RCC treatment failure (94-96). However, the clear molecular mechanisms of RCC initiation and progression remain largely mysterious.

Coding genes were once believed to act as the major regulators during the development of cancers (97-99). Protein-coding genes have been reported to account for ~1-2% of the human genome, and non-protein-coding genes constitute more than 90% of the human genome (100). With the development of whole-genome sequencing, IncRNAs have been reported to be important regulators in the development of RCC, and a growing number of unknown IncRNAs have been identified. The dysregulation of certain IncRNAs is closely associated with the occurrence and clinicopathological features and prognosis of RCC (101,102). Further studies revealed that IncRNAs are involved in the proliferation, migration, apoptosis and drug resistance of RCC cells (38,103,104). Moreover, a series of molecular mechanisms...
and signaling pathways have been reported. IncRNA SARCC inhibited the proliferation of VHL-mutant RCC cells by regulating the androgen receptor/HIF-2α/C-MYC axis (68). HOTAIR facilitated RCC cell migration by downregulating the expression of miR-141. miR-141 decreased the HOTAIR downstream target genes ABL2 and PCDH10 (71). IncRNA MALAT1 inhibited the apoptosis of RCC cells by increasing EZH2 and decreasing miR-205 expression. c-Fos acted as an upstream regulator in the MALAT1/EZH2/miR-205 axis (37). IncRNA ARSR promoted sunitinib resistance in RCC and could be used to predict the poor responses of patients with RCC. Moreover, IncRNA ARSR served as a ceRNA for miR-449 and miR-34 to enhance the expression of c-MET and AXL. In general, IncRNAs perform important roles in the development of RCC (38).

Although numerous studies on IncRNAs in RCC have been reported, no study on energy metabolism and internal environment regulation exists. Furthermore, the concentrations of IncRNAs in the sera of patients with RCC remain unclear. This situation greatly hinders the clinical application of IncRNAs. The number of follow-up patients is insufficient, and the follow-up time is still too short. Hence, additional detailed studies on the biological functions of IncRNAs in RCC are needed. Deeply understanding the content of IncRNAs in the human body and molecular mechanisms of IncRNAs in RCC may contribute to the application of IncRNAs in clinical work. Studies searching for IncRNA-related nucleic acids and proteins may be useful for investigating the post-transcriptional controls of IncRNAs and their regulatory networks in RCC. RNAi therapies targeting IncRNAs may also be used in advanced RCC animal models and even clinical trials. In conclusion, IncRNAs can serve as molecular biomarkers to predict the prognosis of patients with RCC and can be used as the therapeutic targets to fight against RCC in the future.

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Availability of data and materials

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

Authors' contributions

ZS, JA, GX and CG designed the present study. FZ and GX integrated and analyzed the data. HC wrote the manuscript. ZS edited and revised the manuscript. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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