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World J Gastroenterol 2017 April 21; 23(15): 2635-2818



**EDITORIAL**

- 2635 Dietary compliance in celiac disease

Freeman HJ

- 2640 Is there still a role for the hepatic locoregional treatment of metastatic neuroendocrine tumors in the era of systemic targeted therapies?

Cavalcoli F, Rausa E, Conte D, Nicolini AF, Massironi S

REVIEW

- 2651 Hepatitis B virus infection and alcohol consumption

Iida-Ueno A, Enomoto M, Tamori A, Kawada N

- 2660 Endoscopic management of pancreatic fluid collections-revisited

Nabi Z, Basha J, Reddy DN

ORIGINAL ARTICLE**Basic Study**

- 2673 Overexpression of fibrinogen-like protein 2 protects against T cell-induced colitis

Bartczak A, Zhang J, Adeyi O, Amir A, Grant D, Gorczynski R, Selzner N, Chruscinski A, Levy GA

- 2685 Changes in human hepatic metabolism in steatosis and cirrhosis

Schofield Z, Reed MAC, Newsome PN, Adams DH, Günther UL, Lalor PF

- 2696 Effect of *Lactobacillus rhamnosus* HN001 and *Bifidobacterium longum* BB536 on the healthy gut microbiota composition at phyla and species level: A preliminary study

Toscano M, De Grandi R, Stronati L, De Vecchi E, Drago L

- 2705 Effects of Hwangryunhaedok-tang on gastrointestinal motility function in mice

Kim H, Kim I, Lee MC, Kim HJ, Lee GS, Kim H, Kim BJ

- 2716 Role of $\Delta 133p53$ isoform in NF- κ B inhibitor PDTC-mediated growth inhibition of MKN45 gastric cancer cells

Zhang HM, Sang XG, Wang YZ, Cui C, Zhang L, Ji WS

Retrospective Cohort Study

- 2723 Optimal treatment for Siewert type II and III adenocarcinoma of the esophagogastric junction: A retrospective cohort study with long-term follow-up

Hosoda K, Yamashita K, Moriya H, Mieno H, Watanabe M

Retrospective Study

- 2731 Colorectal and interval cancers of the Colorectal Cancer Screening Program in the Basque Country (Spain)

Portillo I, Arana-Arri E, Idigoras I, Bilbao I, Martínez-Indart L, Bujanda L, Gutierrez-Ibarluzea I

- 2743 Performance of 18-fluoro-2-deoxyglucose positron emission tomography for esophageal cancer screening

Sekiguchi M, Terauchi T, Kakugawa Y, Shimada N, Saito Y, Matsuda T

- 2750 Association of obesity with
- Helicobacter pylori*
- infection: A retrospective study

Xu MY, Liu L, Yuan BS, Yin J, Lu QB

- 2757 Outcomes and prognostic factors of patients with stage IB and II A pancreatic cancer according to the 8
- th
- edition American Joint Committee on Cancer criteria

Li Y, Tang CG, Zhao Y, Cao WY, Qu GF

Clinical Trials Study

- 2763 Patients with non-viral liver disease have a greater tumor burden and less curative treatment options when diagnosed with hepatocellular carcinoma

Mohsen W, Rodov M, Prakoso E, Charlton B, Bowen DG, Koorey DJ, Shackel NA, McCaughan GW, Strasser SI

- 2771 Urinary metabolomics analysis identifies key biomarkers of different stages of nonalcoholic fatty liver disease

Dong S, Zhan ZY, Cao HY, Wu C, Bian YQ, Li JY, Cheng GH, Liu P, Sun MY

Observational Study

- 2785 Age-related impairment of esophagogastric junction relaxation and bolus flow time

Cock C, Besanko LK, Burgstad CM, Thompson A, Kritas S, Heddle R, Fraser RJL, Omari TI

- 2795 Endoscopic ultrasound-guided cutting of holes and deep biopsy for diagnosis of gastric infiltrative tumors and gastrointestinal submucosal tumors using a novel vertical diathermic loop

Liu YM, Yang XJ

- 2802 Non-ALT biomarkers for markedly abnormal liver histology among Chinese persistently normal alanine aminotransferase-chronic hepatitis B patients

Cheng JL, Wang XL, Yang SG, Zhao H, Wu JJ, Li LJ

CASE REPORT

- 2811 One step minilaparotomy-assisted transmesenteric portal vein recanalization combined with transjugular intrahepatic portosystemic shunt placement: A novel surgical proposal in pediatrics

Pelizzo G, Quaretti P, Moramarco LP, Corti R, Maestri M, Iacob G, Calcaterra V

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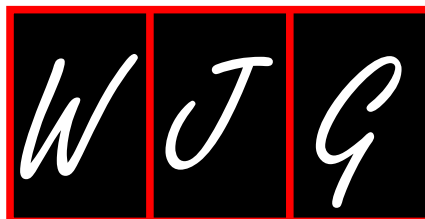
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Basic Study

Role of $\Delta 133p53$ isoform in NF- κ B inhibitor PDTC-mediated growth inhibition of MKN45 gastric cancer cells

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Abstract

AIM

To investigate the role of $\Delta 133p53$ isoform in nuclear factor- κ B (NF- κ B) inhibitor pyrrolidine dithiocarbamate (PDTC)-mediated growth inhibition of MKN45 gastric cancer cells.

METHODS

The growth rate of MKN45 cells after treatment with different concentrations of only PDTC or PTDC in combination with cisplatin was detected by the CCK-8 assay. mRNA expression levels of $\Delta 133p53$, p53 β , and the NF- κ B p65 subunit and p65 protein levels were detected by reverse transcription-polymerase chain reaction (RT-PCR) and immunofluorescence, respectively. Growth of MKN45 cells was significantly inhibited by PDTC alone in a dose-dependent manner ($P < 0.01$). Moreover, the inhibitory effect of cisplatin was remarkably enhanced in a dose-dependent manner by co-treatment with PDTC ($P < 0.01$).

RESULTS

RT-PCR analysis revealed that mRNA expression of p65 was curbed significantly in a dose-dependent manner by treatment with only PDTC ($P < 0.01$), and this suppressive effect was further enhanced when

co-treated with cisplatin ($P < 0.01$). With respect to the other p53 isoforms, mRNA level of $\Delta 133p53$ was significantly reduced in a dose-dependent manner by treatment with only PDTC or PTDC in combination with cisplatin ($P < 0.01$), whereas p53 β mRNA expression was not altered by PDTC treatment ($P > 0.05$). A similar tendency of change in p65 protein expression, as observed for the corresponding mRNA, was detected by immunofluorescence analysis ($P < 0.01$). Pearson correlation analysis demonstrated that $\Delta 133p53$ and p65 mRNA expression levels were positively related, while no significant relationship was observed between those of p65 and p53 β ($r = 0.076$, $P > 0.01$).

CONCLUSION

$\Delta 133p53$ isoform (not p53 β) is required in PDTC-induced inhibition of MKN45 gastric cancer cells, indicating that disturbance in the cross-talk between p53 and NF- κ B pathways is a promising target in pharmaceutical research for the development of treatment strategies for gastric cancer.

Key words: Gastric cancer; p53 isoforms; Nuclear factor- κ B

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Core tip: Intestinal-type of gastric cancer develops from chronic gastritis. $\Delta 133p53$ isoform has been recently identified as an oncogenic actor that is pivotal in *Helicobacter pylori*-driven progression of chronic gastritis to gastric cancerogenesis. These results suggest that $\Delta 133p53$ isoform is required in pyrrolidine dithiocarbamate-induced inhibition of MKN45 gastric cancer cells, and disturbance in the cross-talk between p53 and nuclear factor- κ B pathways is a promising target in pharmaceutical research for the development of treatment strategies against intestinal-type gastric cancer.

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INTRODUCTION

The association between chronic inflammation and cancer has been researched extensively. Few cases of gastric cancer, at early stages of cancerogenesis, have been ascribed to germline mutations in *CDH1*, encoding E-cadherins, or rarely other genes^[1,2]. In fact, most cases of gastric carcinoma develop from chronic gastritis and its associated lesions and diseases. In addition, *Helicobacter pylori* (*H. pylori*) is considered

the common pathogen of both chronic gastritis and gastric carcinoma. Thus, elucidation of the underlying molecular mechanisms of *H. pylori*-associated gastritis and cancerogenesis could contribute immensely to the treatment of associated diseases. Both the nuclear factor-kappa B (NF- κ B) and p53 pathways display significant modifications, some of which are *H. pylori*-driven, in the progression of chronic gastritis to cancerogenesis^[3-6]. A previous study reported that the interaction of mutant p53 and NF- κ B promoted persistent tissue damage and extended inflammation and progressed to inflammation-associated human colorectal cancer^[7]. Results from a recent study further indicated that $\Delta 133p53$ isoform is a crucial molecule in this process, and focusing on the changes in this isoform can provide insight into the association of *H. pylori* infection with chronic gastritis, precancerous lesions, and gastric cancerogenesis^[8,9]. Therefore, understanding the crosstalk between NF- κ B and p53 pathways could significantly contribute to cancer prevention and treatment strategies in inflammation-associated gastric cancerogenesis. Therefore, the present study was designed to evaluate the role of $\Delta 133p53$ isoform under an NF- κ B-inhibited condition (using the NF- κ B inhibitor pyrrolidine dithiocarbamate, PDTC) and the combined biological effect in MKN45 cells, a gastric cancer cell line with wild-type p53^[10-12].

MATERIALS AND METHODS

Cell culture

The MKN45 human gastric cancer cell line was supplied by the Cell Bank of Chinese Academy of Medical Science (Beijing, China) and used before the tenth passage. Cells were tested for mycoplasma infection and cultured in RPMI-1640 medium, supplemented with 10% fetal bovine serum, at 37 °C in an atmosphere containing 5% CO₂. Cells in the exponential growth phase were collected for the following experiments.

CCK-8 analysis

MKN45 cells in the exponential growth phase were digested, seeded in a 96-well plate (5×10^4 cells/well), and then cultured for 24 h. PDTC, at concentrations of 25, 50, and 75 μ mol/L alone or in combination with 4 μ g/mL cisplatin or an equal volume of phosphate-buffered saline (PBS), was added to the cells, which were then cultured for another 48 h. Medium without any cells or drugs was placed in the empty wells. Subsequently, the culture medium was discarded, 20 μ L of a mixture of CCK-8 and the medium at a 1:10 ratio was added to each well, and the cells were cultured for another 1 h. Three replicate wells were established for each condition. Optical density (OD) of the cells was measured at 450 nm using a Multiskan FC microplate reader (Thermo Fisher Scientific, Inc., Waltham, MA, United States), and the

Table 1 Primer sequences

| Primer | | Primer sequence (5'-3') | Length (bp) |
|---------|-------|---|-------------|
| p53β | Outer | Sense: GTCACGTGCCATGGAGGAGCCGCA Antisense: GACGCACACCTATTGCAAGCAAGGGTTC | 1050 |
| | Inner | Sense: ATGGAGGAGCCGAGTCAGAT Antisense: TTGAAAGCTGGTCTGGTCTCTGA | |
| Δ133p53 | Outer | Sense: CTGAGGTGTAGACGCCAACTCTCTCTAG Antisense: TGTCAGTCTGAGTCAGGCCCTTCTGTC | 750 |
| | Inner | Sense: GCTAGTGGGTTCAGGAGGTGCTTACGC Antisense: CTCACGCCACGGATCTGA | |
| p65 | | Sense: TATGACCAACATGACAG Antisense: CTGGATCTGTGAAACTTTGA | 145 |
| β-actin | | Sense: GTGGGGCGCCCCAGGCACCA Antisense: CTCCTTAATGTCACGCACGATTTC | 539 |

growth inhibition rate was calculated as follows:

$$IC = 1 - [(A_{Exp} - A_{Emp}) / (A_C - A_{Emp})] \times 100\%$$

Where IC is the growth inhibition rate, A_{Exp} is the absorbance in the experimental group, A_C is the absorbance in the control group, and A_{Emp} is the absorbance in the empty group.

Reverse transcription-polymerase chain reaction

MKN45 cells in the exponential growth phase were digested, seeded in a 96-well plate (5×10^4 cells/well), and then cultured for 24 h. PDTC, at concentrations of 25, 50, and 75 μmol/L alone or in combination with 4 μg/mL cisplatin or an equal volume of PBS (control wells), was added to the cells, which were then cultured for another 48 h. RNA extraction and cDNA synthesis were performed according to the manufacturer's instructions provided along with the TRIzol extraction and reverse transcription PCR kits. PCR was performed to amplify Δ133p53, p53β, p65, and β-actin using the primers shown in Table 1. Lengths of the amplified products were 690 bp for p53, 1050 bp for p53β, and 539 bp for β-actin. PCR conditions were set as 35 cycles at 94 °C for 1 min for denaturation, 58 °C for 50 s for annealing, and 72 °C for 1 min for extension. PCR was performed with a BIO-RAD IQ5 Thermal Cycler (Bio-Rad Laboratories, Hercules, CA, United States). The cycle threshold (CT) value was detected, and the relative mRNA expression level was calculated as $2^{-\Delta\Delta CT}$.

Immunofluorescence

MKN45 cells were digested as a single-cell suspension and plated in a 96-well plate. PDTC, at concentrations of 25, 50, and 75 μmol/L alone or in combination with 4 μg/mL cisplatin or an equal volume of PBS (control wells), was added to the cells, which were then cultured for another 48 h. Cells were fixed in 4% paraformaldehyde for 30 min, incubated with 0.1% TritonX-100 PBS solution for 10 min, and then with 3% H₂O₂ for another 10 min. Subsequently, 1% bovine serum albumin solution was added to block non-

specific sites, and the cells were incubated with NF-κB p65 antibody (Abcam, E379 ab32536, Aibokang Corporation Ltd., Shanghai, China) at a 1:200 dilution overnight and then with a secondary antibody (goat-anti-rabbit-596nm, ZF0316, Zhongshan Jinqiao Biotechnology Corporation Ltd., Beijing, China) at a 1:200 dilution for another 2 h. Nuclei were stained with 4',6-diamidino-2-phenylindole for 10 min, and the cells were examined under a fluorescence microscope (Olympus, Japan). p65 protein expression was measured as the integral optical value.

Statistical analysis

SPSS version 17.0 (International Business Machines, Armonk, NY, United States) software package was used for statistical analyses. Data are recorded as the mean ± SD. Differences between two groups were analyzed by the least significant difference *t*-test, and differences among more than two groups were evaluated by one-way analysis of variance. Correlations between variables were tested with Pearson linear relevancy analysis.

RESULTS

Growth inhibition

Growth inhibition rates of gastric cancer cells under different treatments are shown in Figure 1. PDTC significantly inhibited the growth of MKN45 cells in a dose-dependent manner ($F = 167.10$, $P < 0.01$). Moreover, the inhibitory effect of cisplatin was enhanced in a dose-dependent manner by co-treatment with PDTC ($F = 52.23$, $P < 0.01$).

p65 expression

Results of reverse transcription-polymerase chain reaction (RT-PCR) analysis showed that PDTC significantly downregulated p65 mRNA expression in a dose-dependent manner ($P < 0.01$, Figure 2A). Although p65 mRNA expression was up-regulated by treatment with cisplatin alone, the combination of PDTC and cisplatin resulted in inhibitory enhancement ($P < 0.01$, Figure 2A). Similar trends in p65 protein

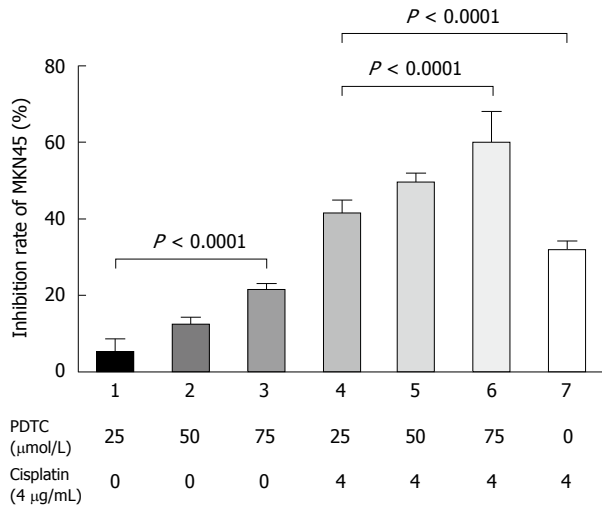


Figure 1 Cellular growth inhibition of pyrrolidine dithiocarbamate alone or with Cisplatin on MKN45 cells. PDTC: Pyrrolidine dithiocarbamate.

level changes were detected ($P < 0.01$, Figure 2B).

Expression of $\Delta 133p53$ and $p53\beta$

RT-PCR analysis results showed that PDTC treatment significantly downregulated the expression of $\Delta 133p53$ mRNA in a dose-dependent manner ($P < 0.01$, Figure 2C), and inhibitory enhancement was observed after co-treatment with cisplatin ($P < 0.01$, Figure 2C). However, $p53\beta$ mRNA remained stable in the presence of PDTC ($P > 0.05$, Figure 2D). It was down-regulated after cisplatin treatment, and no inhibitory enhancement was observed after co-treatment with cisplatin and PDTC ($P > 0.05$, Figure 2D).

Relevancy analysis between $p65$ and $p53$ isoforms

Changes in mRNA levels of $p65$ paralleled those of $\Delta 133p53$ mRNA in MKN45 cells treated with PDTC and/or cisplatin (Figure 3). Pearson linear relevancy analysis demonstrated that expression levels of $p65$ were positively correlated with those of $\Delta 133p53$ ($r = 0.085$, $P < 0.01$). However, there was no relationship between the expression levels of $p65$ and $p53\beta$ ($r = 0.076$, $P > 0.05$).

DISCUSSION

Over the past two decades, p53 has proven to be a tumor-suppressor, but it loses this ability in various malignant diseases, such as gastric carcinoma. p53 mutations are commonly detected in gastric carcinoma, but are seldom clinically significant^[13-19]. Recently, in the last decade, research focusing on the clinical application of p53 isoforms has progressed significantly. More than 12 p53 isoforms have been reported to date, namely, $p53\alpha$ (the canonical wild-type p53), $p53\beta$, $p53\gamma$, $\Delta 40p53\alpha$, $\Delta 40p53\beta$, $\Delta 40p53\gamma$, $\Delta 133p53\alpha$, $\Delta 133p53\beta$, $\Delta 133p53\gamma$, $\Delta 160p53\alpha$, $\Delta 160p53\beta$, and $\Delta 160p53\gamma$. The p53 isoform expression

pattern is remarkably altered in breast cancer^[20], kidney cancer^[21,22], colorectal cancer^[23], ovarian malignancy^[24-27], leukemia^[28], medulloblastoma^[29], and neuroblastoma^[30]. Accumulating evidence has indicated that some of these isoforms function as p53 co-activators (e.g., $p53\beta$), while others function as its antagonists with oncogenic characteristics (e.g., $\Delta 40p53\alpha$ and $\Delta 133p53\alpha$)^[31-33].

A few years ago, our research group investigated the expression of p53 isoforms in different gastric tissues, and we observed a significant increasing trend for $\Delta 133p53\alpha$ expression but the opposite for $p53\beta$ as the tissue progressed from superficial gastritis, atrophic gastritis, and para-cancerous lesion to gastric carcinoma^[12]. As per the Lauren classification, most cases of gastric carcinoma belong to the intestinal type, gastritis-associated carcinogenesis. In 2015, a clear link between *H. pylori* infection, gastritis, and gastric cancerogenesis was demonstrated, indicating that $\Delta 133p53$ isoform plays an essential role in the process^[8,9]. These results indicate that changes in the cross-talk between inflammatory and apoptotic pathways are likely to play an important role in gastric cancerogenesis, especially in cases of the intestinal type. Previously, the NF- κ B pathway was reported to be essential in *H. pylori*-driven chronic gastritis and cancerogenesis. We now speculate that the oncogenic role of the NF- κ B pathway cooperates with alterations in the expression patterns of p53 isoforms.

The present experiment was designed to evaluate changes in p53 isoforms ($\Delta 133p53$ and $p53\beta$) and their combined biological effect in MKN45 cells under an NF- κ B-inhibited condition. We confirmed that NF- κ B was effectively blocked by PDTC treatment in MKN45 cells, and cellular growth was significantly inhibited in a dose-dependent manner. In addition, the inhibitory effect of cisplatin was remarkably enhanced in a dose-dependent manner by co-treatment with PDTC. These inhibition results indicate that NF- κ B signal blockade is a promising strategy in the treatment and prevention of intestinal-type gastric cancer.

However, it is important to explore the underlying molecular mechanisms further in future studies. In the cross-talk between NF- κ B and p53 pathways, few molecules such as $\Delta 133p53$ have very distinct and significant functions. In the present study, down-regulation of the NF- κ B $p65$ subunit (curbed by PDTC alone or in combination with cisplatin) correlated with growth inhibition of MKN45 cells and $\Delta 133p53$ expression. In addition, we found that the $p53\beta$ isoform was not altered by PDTC intervention, reinforcing that $\Delta 133p53$ is a key molecule that is involved in the mediation of cross-talk between the NF- κ B inflammatory and p53 apoptotic pathways, especially in gastritis-associated cancerogenesis. Thus, $\Delta 133p53$ is a useful marker and candidate target for diagnosis, treatment, and prognosis of intestinal-type gastric cancer.

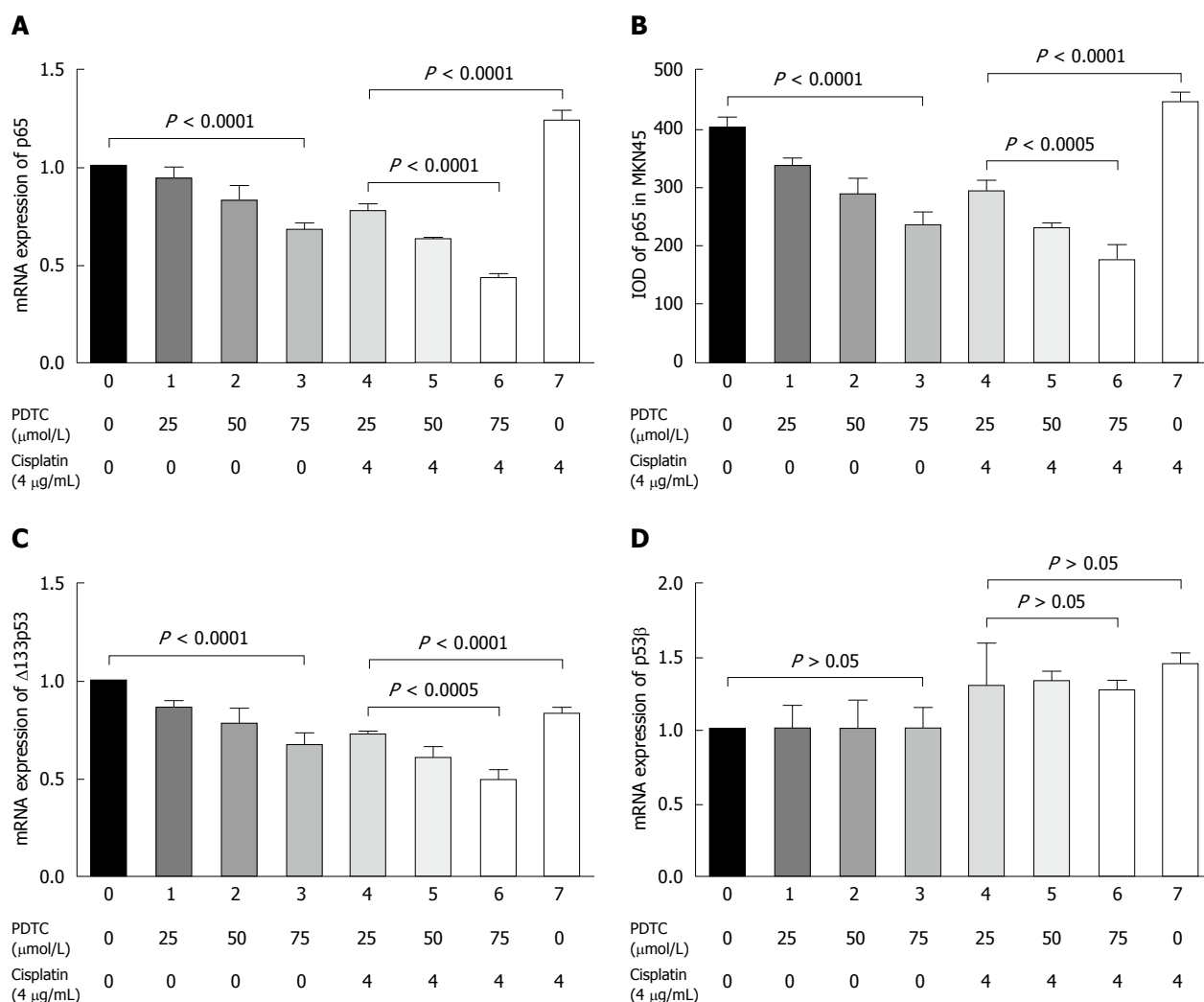


Figure 2 Expression of p65 and p53 isoforms in MKN45 cells. A: Expression of p65 mRNA in MKN45 cells; B: Expression of p65 protein in MKN45 cells; C: Expression of Δ 133p53 mRNA in MKN45 cells; D: Expression of p53 β mRNA in MKN45 cells.

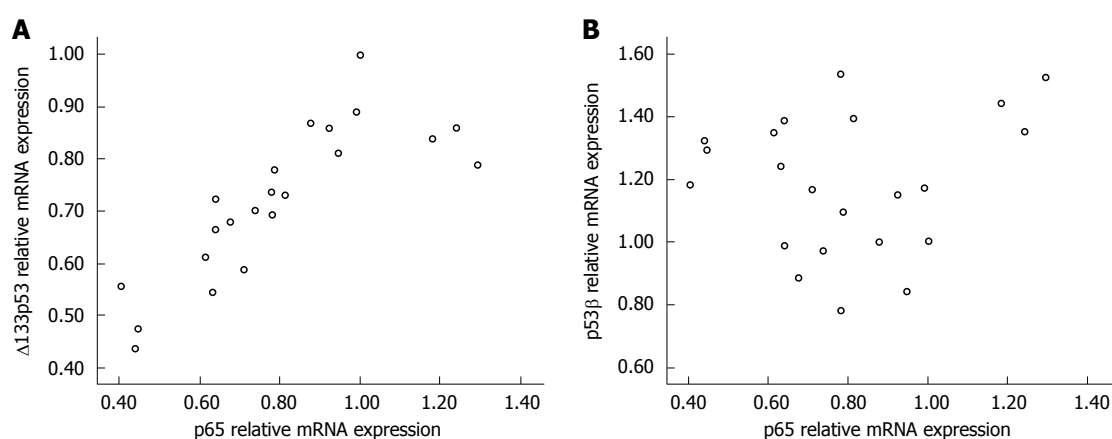


Figure 3 Correlation of p65 and p53 isoforms mRNA expression in MKN45 cells. A: Correlation of p65 and Δ 133p53 mRNA expression in MKN45 cells; $r = 0.085$, $P < 0.01$; B: Correlation of p65 and p53 β mRNA expression in MKN45 cells. $r = 0.076$, $P > 0.05$.

In recent years, our research group completed a series of experiments to investigate the roles of p53 isoforms in gastric carcinoma for improved diagnosis and pharmacological development and found that

the change of p53 isoforms is common in gastric cancerogenesis^[12]. Furthermore, up-regulation of the p53 β isoform is induced by cisplatin or fluorouracil^[34], while down-regulation of Δ 133p53 is induced by

recombinant mutant human tumor necrosis factor^[35], indicating that $\Delta 133p53$ and $p53\beta$ isoforms are strong targets for further diagnosis and pharmacological research. Combined with inferences reported by other study groups^[8,9], we now realize that $\Delta 133p53$ is an essential factor involved in gastritis-associated carcinoma. According to the Lauren classification^[36,37], intestinal gastric carcinoma is roughly ascribed to chronic inflammation, and it develops from multi-genetic alterations and a multi-step process. Therefore, it might be feasible to refine the classification on the basis of molecules identified to be essential in the cross-talk between NF- κ B and p53 pathways. Our previous and present results suggest that $\Delta 133p53$ is one such good candidate for refining gastric carcinoma classification. The latent value of these findings is that introduction of anti-inflammation agents that target these isoforms could enhance the effect of chemotherapy and improve the prognosis of intestinal-type gastric carcinoma. Further research should focus on two main aspects: development of a simple method to detect these markers and screening for effective agents based on this new perspective.

In summary, $\Delta 133p53$ (but not $p53\beta$) is a requisite factor in PDTC-induced inhibition of MKN45 gastric cancer cells, and the disturbed cross-talk between p53 and NF- κ B pathways is a hopeful target for further diagnosis and pharmaceutical research of intestinal-type gastric cancer.

COMMENTS

Background

Accumulating evidence suggests that some p53 isoforms function as p53 co-activators (e.g., $p53\beta$); others, its antagonists that possess oncogenic characteristics (e.g., $\Delta 133p53\alpha$). Results obtained by our research group and others demonstrate a clear link between *Helicobacter pylori* (*H. pylori*) infection, gastritis, and gastric cancerogenesis, with $\Delta 133p53$ isoform being essential in the process. Thus, changes in the cross-talk between inflammatory and apoptotic pathways likely play an important role in gastric cancerogenesis, especially in cases of the intestinal type.

Research frontiers

Expression patterns of p53 isoforms instead of mutant p53 are significant for various malignant diseases. $\Delta 133p53\alpha$ has been proven to be a good indicator that could be used for the diagnosis and prognosis of breast and ovarian cancers. Moreover, $\Delta 133p53\alpha$ is also essential in *H. pylori*-driven gastritis and cancerogenesis.

Innovations and breakthroughs

Disturbed cross-talk between p53 and nuclear factor- κ B (NF- κ B) pathways is possibly involved in the progression of chronic gastritis to cancerogenesis. $\Delta 133p53$, among other p53 isoforms, is key to the association of *H. pylori* infection with gastritis and cancerogenesis. These results indicate that $\Delta 133p53$ is an important aspect of the NF- κ B inhibitor PDTC-mediated biological effect.

Applications

$\Delta 133p53$ could serve as a promising target for diagnosis, treatment, and prognosis of gastric cancer.

Terminology

p53 isoforms are produced by alternative splicing of *TP53*. At least twelve

isoforms have been identified. Existence of these isoforms results in the regulation of p53 function. Disturbance in the pattern of these p53 isoforms has been observed to be involved in cancerogenesis in various tissues.

Peer-review

This is a very significant study that involved investigation of the role of $\Delta 133p53$ isoform in NF- κ B inhibitor pyrrolidine dithiocarbamate-mediated growth inhibition of MKN45 gastric cancer cells.

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