Targeted Efficacy of Dihydroartemisinin for Translationally Controlled Protein Expression in a Lung Cancer Model

Lian-Ke Liu¹, Heng-Fang Wu², Zhi-Rui Guo², Xiang-Jian Chen², Di Yang², Yong-Qian Shu¹, Ji-Nan Zhang²*

Abstract

Objective: Lung cancer is one of the malignant tumors with greatest morbidity and mortality around the world. The keys to targeted therapy are discovery of lung cancer biomarkers to facilitate improvement of survival and quality of life for the patients with lung cancer. Translationally controlled tumor protein (TCTP) is one of the most overexpressed proteins in human lung cancer cells by comparison to the normal cells, suggesting that it might be a good biomarker for lung cancer. Materials and Methods: In the present study, the targeted efficacy of dihydroartemisinin (DHA) on TCTP expression in the A549 lung cancer cell model was explored. Results and Conclusions: DHA could inhibit A549 lung cancer cell proliferation, and simultaneously up-regulate the expression of TCTP mRNA, but down-regulate its protein expression in A549 cells. In addition, it promoted TCTP protein secretion. Therefore, TCTP might be used as a potential biomarker and therapeutic target for non-small cell lung cancers.

Keywords: Translationally controlled tumor protein - NCSLC - dihydroartemisinin - biomarker - targeted therapy

Introduction

Lung cancer, one of the malignant tumors, has high morbidity and mortality around the world, and its 5-year survival rate is only 8%-15% (Molina et al., 2006; Al-Hashimi et al., 2014; Cui et al., 2014). In addition, the incidence of lung cancer has been rising steadily (Jemal et al., 2011; Fathallah et al., 2013; Liu et al., 2014). Non-small cell lung cancer (NSCLC) accounts for 80% of all pulmonary carcinomas. In spite of the development in diagnostic and therapeutic methods, the outcome after treatment remains poor mainly because of the potential of tumor cells to invade and metastasize (Jemal et al., 2011; Fathallah et al., 2013; Liu et al., 2014). Targeted therapies are commonly used in combination with traditional chemotherapy currently (Li et al., 2014). Under these circumstances, discovery of novel and effective biomarkers for lung cancer diagnosis and prognosis as well as new therapeutic targets becomes imperative.

The translationally controlled tumor protein (TCTP), a highly conserved protein present in eukaryotic organisms, has been suggested as a tumor-associated antigen. TCTP, also called histamine releasing factor (HRF), tumor protein translationally controlled 1 (Tpt1), p23 or fortilin, is over-expressed in various malignancies. It has been shown to play an important role not only in physiological events, such as cell proliferation, cell death and immune responses, but also in stress response and tumor reversion (Wang et al., 2013; Ma et al., 2010; Lee et al., 2008; Susini et al., 2008; Dong et al., 2009; Nagano-Ito et al., 2012; Miao et al., 2013). Many researches show that TCTP level in tumor is higher than that in the corresponding normal tissues, indicating its critical role in tumorigenesis (Amson et al., 2011; Amson et al., 2013). Among 20 screened proteins in lung cancer, TCTP is one of the most over-expressed proteins in human lung cancer cells compared with the normal cells, suggesting that TCTP can be a good biomarker for lung cancer (Lo et al., 2012; Baylot et al., 2012; Acunzo et al., 2014).

Dihydroartemisinin (DHA) is a kind of the sesquiterpene lactones isolated from the sweet worm wood artemisia annua. As a main active metabolite of artemisinin derivatives, it is also used as a first-line antimalarial drug in various countries with low toxicity (Keating, 2012). DHA is shown to have anticancer effects in a wide variety of cancer models in vitro and in vivo (Jiao et al., 2007; Sun et al., 2014). Many studies have shown that DHA inhibits cell proliferation, and induces apoptosis in various human cancer cell lines via down-regulating
### Materials and Methods

#### Cell culture

Lung cancer cell line A549 was provided by Shanghai Cellular Institute of China Scientific Academy. Cells were cultured in RPMI 1640 medium containing 10% fetal calf serum (FCS) and with 100 μg/mL penicillin and 100 μg/mL streptomycin. The cells were incubated at 37°C in 5% CO₂ atmosphere and medium was replaced every other day.

#### Cell proliferation inhibitory study

The cells were plated at a density of 1×10⁵ cells/well in 96 well plates at 37°C in 5% CO₂ atmosphere. After 24 h of culture, the medium in the wells was replaced with the fresh medium containing 0-100 nmol/L DHA. And the final concentration of DMSO was 0.1% (v/v) for each treatment. After 24 h, 48 h and 72 h, the medium was removed and the cells were rinsed twice with fresh medium, then 20 μL of MTT (3, 4, 5-dimethylthiazol-yl-2, 5-diphenyl tetrazolium, Sigma) dye solution (5 mg/mL in medium) was added to each well. After 4 h of incubation at 37°C, the medium was removed and Formazan crystals were dissolved in 150 μL dimethylsulphoxide (DMSO) and quantified by measuring the absorbance of the solution at 490/630 nm by a microplate reader (Model 680, Bio-RAD). The spectrophotometer was calibrated to zero absorbance, using culture medium without cells. The absorbance, using culture medium without cells, was visualized by an enhanced chemiluminescence kit (Pierce, USA). GAPDH was used as an internal reference. The RT-PCR analysis was performed with LightCycler 480 (Roche, Switzerland). For relative quantification, the ΔΔCt method was employed, using GAPDH as the endogenous standard for each sample (Livak et al., 2001).

#### Western Blot Assay

Protein extracts were prepared from the cell lines using lysis buffer containing 50 mM Tris-HCl (pH 7.4), 1% NP-40 (Sigma, St. Louis, MO, USA), 0.25% sodium deoxycholate, 150 mM NaCl, 1 mM phenylmethylsulfonyl fluoride, 1 μg/mL aprotinin, 1 μg/mL leupeptin and 1 μg/mL pepstatin. The protein concentrations were determined by Bradford assay. The protein lysate (35 μg) was separated on a 10% SDS-PAGE gel and transferred onto polyvinylidene difluoride membranes (Millipore, Billerica, MA, USA) for western blot analysis detection. The blot was blocked with 5% non-fat dry milk in a buffer containing 10 mM Tris (pH 7.5), 100 mM NaCl and 0.1% Tween-20 (Sigma) for 1 h at 37°C. The blot was washed and incubated with primary polyclonal anti-TCTP antibody (1:1 000 dilution, Abcam, UK) for 1 h and then incubated for 30 min with secondary goat anti-rabbit antibody conjugated with horseradish peroxidase (1:3000 dilution, Abcam, UK). Immunoreactive protein signals were visualized by an enhanced chemiluminescence kit (Pierce, USA). GAPDH was used as an internal reference. Quantitative evaluation of proteins was determined by Polymerase chain reaction (PCR)

PCRs were performed using a standard Taqman PCR kit (Takara, Dalian, China) protocol on the PTC-150 MiniCyclerTM PCR amplification (Perkin Elmer, USA). Total RNA was prepared using TRIzol (Invitrogen, USA) and reverse transcribed using SuperScript reverse transcriptase (Takara, Dalian, China) following the instructions of the manufacturer. The Primers for PCR were showed in the Table 1. The 50 μL PCR reaction included 1 μL cDNA, 5 μL 10×PCR buffer, 4 μL dNTP (2.5 mM), 0.5 μL Taq DNA polymerase, 1 μL Primer F (S) (10 pmol/μL), 1 μL Primer R (A) (10 pmol/μL) and 38.5 μL water. The reactions were incubated in a 96-well plate at 95°C for 5 min, 94°C for 30 s, 55°C for 30 s, followed by 35 cycles of 72°C for 1 min. A final extension of 5 min at 72°C was performed prior to storing the samples at 4°C. Following PCR, the products were analyzed by 1% agarose gel electrophoresis.

### Table 1. Primer Pairs and Sizes for PCR

| Human | Forward (F) and reverse (R) primers | Size (bp) |
|-------|-------------------------------------|-----------|
| TCTP-F | AGACCAGAAAGAGTAAPA | 2512 |
| TCTP-R | TCCACCTCAAAATAACACAG | |
| GAPDH-F | ACCACAGTCCATGGCATCAC | 452 |
| GAPDH-R | TCCACACCCGTGTGGCTGTA | |

### Table 2. Primer Pairs and Sizes for Real-time PCR

| Human | Forward (F) and reverse (R) primers | Size (bp) |
|-------|-------------------------------------|-----------|
| TCTP-F | TACCTGCTCATTTGTTGGA | 72 |
| TCTP-R | GTGATTACTGTGCTTTCGGTACCTT | |
| TCTP-probe | CCTCCGCTGAAGGCCCGA | 65 |
| GAPDH-F | CCTCCCGCTTTGCTTCTT | |
| GAPDH-R | GCTGCGCAGCGCAAAAGA | |
| GAPDH-probe | CCTCCTGTCCGACAGTCAGCCGC | |
Results

Inhibition of DHA to A549 cell proliferation
The inhibition of DHA to A549 cell proliferation was investigated using MTT assay. The MTT assay relied on the mitochondrial activity of cells and represented a parameter for their metabolic activity. The cell inhibition rate was enhanced in dose and incubation time-dependent manners when the cells were treated with DHA. After incubated for 24 h, the concentration of DHA caused a minor increase in cell inhibition rate. With the increase of incubation time, the cell inhibition rate was also enhanced. The IC_{50} of DHA was 100.93 μmol/L, 36.53 μmol/L and 15.57 μmol/L for 24 h, 48 h and 72 h, respectively (Figure 1).

Up-regulation of A549 cell TCTP mRNA
The expression of A549 cell TCTP mRNA was explored under the action of 25 μmol/L and 100 μmol/L DHA. PCR results showed that both higher and lower doses of DHA caused the up-regulation of A549 cell TCTP mRNA (Figure 2). Furthermore, the real-time PCR results showed that the expression of A549 cell TCTP mRNA was more accurate and consistent with the previous PCR results. TCTP mRNA was up regulated when 100 μmol/L DHA incubated with A549 cells for 48 h (Figure 3).

Down-regulation of A549 cell TCTP protein
A549 cells were treated with two groups of DHA concentration (25 μmol/L and 100 μmol/L) for 24 h and 48 h, respectively. The TCTP protein expression of A549 cells had no obvious difference between control groups at 24 h and 48 h. At the lower dose (25 μmol/L), the TCTP protein expression of A549 cells had no obvious change compared with the control group at 24 h, while the TCTP protein expression of A549 cells was suppressed with DHA at 48 h. When the DHA concentration was increased to 100 μmol/L, the TCTP protein expression of A549 cells was obviously suppressed both at 24 h and 48 h (Figure 4).

Regulation of A549 cell TCTP protein secretion
The lower concentration of DHA (25 μmol/L) was used
for exploring the effect on TCTP secretion in A549 cells. A time-dependent increase of TCTP protein expression in A549 cells was revealed (Figure 5). The cell secretion of TCTP was not detected when DHA was incubated with cells for 6 h and 12 h. However, as time went on, the cell secretion of TCTP in the culture supernatant was increased significantly.

**Discussion**

DHA, a semi-synthetic derivative of the herbal anti-malarial drug artemisinin, can obviously inhibit the growth of a variety of cancer cells, including breast cancer, leukemia, cervical cancer, ovarian cancer, lung cancer, glioma and oral cancer (Jiao et al., 2007; Nam et al., 2007; Mu et al., 2008; Chen et al., 2009; Handrick et al., 2010). Our studies indicated that DHA inhibited the growth of A549 lung cancer cells. The viability of A549 cells was measured by MTT assay after being cultured at different times. The IC_{50} of DHA was 100.93 μmol/L, 36.53 μmol/L and 15.57 μmol/L for 24 h, 48 h and 72 h, respectively.

TCTP is a highly conserved protein widely expressed in all eukaryotic organisms. Although its biological functions involved in many cell processes are not fully elucidated, in the study, the expression of A549 cell TCTP mRNA was obviously up-regulated at the higher concentration (100 μmol/L) of DHA when DHA incubated with the cells for 48 h. While at the lower concentration and less time, the expression of A549 cell TCTP mRNA showed the minor up-regulation, suggesting that the effect of DHA on the cell TCTP was slow. The mechanism of DHA up-regulating A549 cell TCTP mRNA maybe associated with its effect on the protein expression. Many factors may influence the expression of cell TCTP mRNA, including cell lines, source of DHA, cell culture environment and drug concentration. Three kinds of drugs (DHA, sertraline and thioridazine) were reported as the direct anti-cancer drug targets for TCTP. Fujita et al demonstrated that DHA could bind to human TCTP and decrease its cellular level through promoting ubiquitination and proteasome-dependent degradation (Fujita et al., 2008; Lucibello et al., 2011).

Secreted proteins are responsible for the cross talking among cells and understanding this language could largely increase our knowledge on the molecular mechanism of neoplasia (Amson et al., 2011). In addition, extracellular matrix components and other molecules secreted by tumor cells are rich sources of potential markers and drug targets for cancer treatment (Makridakis et al., 2010). The study found that DHA promoted the cell secretions of TCTP protein in the cell culture supernatant. Moreover, the cell secretions of TCTP protein were time-dependent. The higher concentration of DHA was not suitable for the cell secretion study since it could induce cell apoptosis. Kim et al analyzed the secretome of transformed bronchial epithelial cells (1198 and 1170-I), the parental immortalized normal cells (BEAS-2B) and non-transformed cells (1799) (Kim et al., 2008). The levels of TCTP were significantly increased in the conditioned media of both transformed cell lines when compared with those of BEAS-2B and 1799 cells. These proteins were also presented in significantly higher concentrations in plasma and tissue samples of patients with lung cancer by comparison to the controls.

In conclusion, DHA can inhibit the proliferation of A549 lung cancer cells, increase TCTP mRNA expression in A549 cells and reduce its protein level, which is consistent with previous reports. Besides, it can also facilitate A549 cells to secrete TCTP protein. Therefore, TCTP may be a potential target for NSCLC in cancer therapy, which is helpful to the diagnosis and treatment of lung cancer.
References

Acunzo J, Baylot V, So A2, et al (2014). TCTP as therapeutic target in cancers. Cancer Treat Rev, [Epub ahead of print].

Al-Hashimi MM, Wang XJ. (2014). Trend analysis of lung cancer incidence rates in Ninawa province, Iraq, from 2000 to 2010—decrease and recent stability. Asian Pac J Cancer Prev, 15, 385-90.

Amson R, Pece S, Lespagnolet A, et al (2011). Reciprocal repression between P53 and TCTP. Nat Med, 18, 91-9.

Amson R, Pece S, Marine JC, et al (2013). TPT1/TCTP-regulated pathways in phenotypic reprogramming. Trends Cell Biol, 23, 37-46.

Baylot V, Katsogiannou M, Andrieu C, et al (2012). Targeting TCTP as a new therapeutic strategy in castration-resistant prostate cancer. Mol Ther, 20, 2244-56.

Chen H, Sun B, Wang S, et al (2010). Growth inhibitory effects of dihydroartemisinin on pancreatic cancer cells: involvement of cell cycle arrest and inactivation of nuclear factor-kappaB. J Cancer Res Clin Oncol, 136, 897-903.

Chen T, Li M, Zhang R, et al (2009). Dihydroartemisinin induces apoptosis and sensitizes human ovarian cancer cells to carboplatin therapy. J Cell Mol Med, 13, 1358-70.

Choi S, Min HJ, Kim M, et al (2009). Proton pump inhibitors exert anti-allergic effects by reducing TCTP secretion. PLOS One, 4, 478-96.

Cui L, Liu XX, Jiang Y, et al (2014). Effects of dihydroartemisinin on pancreatic cancer cells: involvement of cell cycle arrest and inactivation of nuclear factor-kappaB. J Cancer Res Clin Oncol, 136, 897-903.

Deng W, Long L, Li JL, et al (2014). Mortality of major cancers in guangxi, china: sex, age and geographical differences from 1971 and 2005. Asian Pac J Cancer Prev, 15, 1567-74.

Dong X, Yang B, Li Y, et al (2009). Molecular basis of the acceleration of the GDP-GTP exchange of human ras homolog enriched in brain by human translationally controlled tumor protein. J Biol Chem, 284, 23754-64.

Fathallah RM, Dajani R (2013). Comparison of population based cancer incidence rates among Circassians, Chechans and Arabs in Jordan (1996-2005). Asian Pac J Cancer Prev, 14, 6035-40.

Fujita T, Felix K, Pinkaew D, et al (2008). Human fortilin is a molecular target of dihydroartemisinin. FEBS Lett, 582, 1055-60.

Handrick R, Ontikatze T, Bauer KD, et al (2010). Dihydroartemisinin induces apoptosis by a Bak-dependent intrinsic pathway. Mol Cancer Ther, 9, 2497-510.

Huang XE, Tian GY, Cao J, et al (2013). Pemetrexed as a novel plasma biomarker for oral cancer: from quantitative proteomics to post-transcriptional study. J Proteomics, 77, 154-66.

Lucibello M, Gambacurta A, Zonfrillo M, et al (2011). TCTP is a critical survival factor that protects cancer cells from oxidative stress-induced cell-death. Exp Cell Res, 317, 2479-89.

Makridakis M, Vlahou A (2010). Secretome proteomics for discovery of cancer biomarkers. J Proteomics, 73, 2291-305.

Miao X, Chen YB, Xu SL., et al (2013). TCTP overexpression is associated with the development and progression of glioma. Tumour Biol, 34, 3357-61.

Molina JR, Adjei AA, Jett JR (2006). Advances in chemotherapy of non-small cell lung cancer. Chest, 130, 1211-9.

Mu D, Zhang W, Chu D, et al (2008). The role of calcium, P38 MAPK in dihydroartemisinin-induced apoptosis of lung cancer PC-14 cells. Cancer Chemother Pharmacol, 61, 639-45.

Nagano-Ito M., Ichikawa S. (2012). Biological effects of Mammalian translationally controlled tumor protein (TCTP) on cell death, proliferation, and tumorigenesis. Biochem Res Int, 204960.

Nam W, Tak J, Ryu JK et al (2007). Effects of artesinin and its derivatives on growth inhibition and apoptosis of oral cancer cells. Head Neck, 29, 335-40.

Rasheed SA, Effertth T, Asangani IA, et al (2010). First evidence that the antimalarial drug artesunate inhibits invasion and in vivo metastasis in lung cancer by targeting essential extracellular proteases. Int J Cancer, 127, 1475-85.

Sun Q, Teong B, Chen IF, et al (2014). Enhanced apoptotic effects of dihydroartemisinin-aggregated gelatin and hyaluronan nanoparticles on human lung cancer cells. J Biomed Mater Res B Appl Biomater, 102, 455-62.

Susini L, Besse S, Duflaut D et al (2008). First evidence that the antimalarial drug artesunate inhibits invasion and in vivo metastasis in lung cancer by targeting essential extracellular proteases. Int J Cancer, 127, 1475-85.

Wang F, Hu C, Hua X, et al (2013). Translationally controlled tumor protein, a dual functional protein involved in the immune response of the silkworm, Bombyx mori. PLoS One, 8, e69284.