1 **Isolation and Purification of Active Antimicrobial Peptides from**
2 ***Hermetia illucens* L., and Its Effects on CNE2 Cells**

3 ---- anticancer effect of antimicrobial peptides

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15 Summary Statement

- 16 1. An active antimicrobial peptide HI-3 was isolated and purified.
- 17 2. Inhibitory proliferation of CNE2 cells, but no effect on normal cells.
- 18 3. A potential antitumoral drug.

19 **Abstract:** Active antimicrobial peptide HI-3 was isolated and purified from the 5th instar
20 larvae of *Hermetia illucens* L., and its effects on proliferation, apoptosis and migration of
21 nasopharyngeal carcinoma (CNE2) cells were investigated. The expressions of telomerase
22 reverse transcriptase (hTERT) in CNE2 cells were also studied *in vitro* to elucidate the
23 mechanism involved in the action of HI-3 on CNE2 cells. Results showed that three fractions
24 (HI-1, HI-2, HI-3) were isolated from the hemolymph of *H. illucens* larvae. After purified by
25 RP-HPLC, only HI-3 showed the inhibitory activities to four strains of bacteria. It was also
26 showed that HI-3 could effectively inhibit the proliferation of CNE2 cells in a dose- and time-
27 dependent manner. Apoptosis of CNE2 cells was observed in the treatment with 160 µg/ml
28 HI-3, and the early apoptosis rate up to $27.59 \pm 1.14\%$. However, no significantly inhibitory
29 effects and apoptosis were found on human umbilical vein endothelial cells (HUV-C).
30 Moreover, HI-3 could significantly reduce the migration ability of CNE2 cells when
31 compared with that of the control. On the other hand, the levels of mRNA and protein of
32 hTERT in the HI-3 treatment were all significantly lower than that of the control. Results
33 indicated that HI-3 could inhibit the proliferation of CNE2 cells and induce the apoptosis of
34 CNE2 cells by down-regulating the telomerase activity in CNE2 cells, while no obvious effect
35 was occurred on HUV-C. It inferred that HI-3 is a potential anti-tumor drug with low toxicity
36 to normal cells.

37 **Keywords:** *Hermetia illucens*; proliferation; cell migration; apoptosis; telomerase

38 **1. Introduction**

39 More and more attentions were paid on the nasopharyngeal carcinoma (NPC) for its
 40 high incidence rates in Asia. Data from IARC showed that the incidence rates of NPC were
 41 up to 71.02% for men, which was nearly 2.45 times higher than that of women in Asian
 42 countries, especially in the country of Malaysia, Singapore, Indonesia and China
 43 (Mahdavifar et al., 2016). Currently, the traditional surgery combined with
 44 chemoradiotherapy was widely applied during its therapy. However, the radiotherapy and
 45 chemotherapy would inevitably damage the normal cells and the patient's immune systems
 46 (Ng and Lee, 2017), which more or less lead to the toxicity and severe effects in some
 47 tissues and organs (Thangavel et al., 2016). And the strong invasion ability of NPC cells and
 48 its inclination to distal metastasis made its treatments become more difficult (Jiang et al.,
 49 2014; Yang et al., 2013). Therefore, looking for a new, safe and effective anticancer agent
 50 for treatment of NPC has become a hot research direction worldwide.

51 Antimicrobial peptides (AMPs), the small molecule peptides that were firstly discovered
 52 by Boman research team, were found to have anti-bacterial, anti-viral, and anti-fungal
 53 properties. It was reported that AMPs could act rapidly to combat the invasion of potential
 54 pathogens, and thus serve to limit the extent of infection prior to activation of the adaptive
 55 immune response (Wanmakok et al., 2018). Furthermore, some of these peptides were
 56 found to display a wide range of biological activities and have been shown to exert
 57 antitumoral activity (Cerón et al., 2010). Nowadays, AMPs are considered as a potential
 58 alternative for the treatment of emerging drug-resistant infections and cancer (Riedl et al.,
 59 2011). The detailed mechanisms involved in antitumoral activities of AMPs were also

60 gradually established. Studies showed that AMPs might disrupt tumor cell membranes
 61 integrity and act on mitochondria or DNA to exert its antitumoral activity (Lemeshko, 2013).
 62 It was also reported that AMPs perform its anticancer effects by regulating the organisms'
 63 immune system. Studies have indicated that the organisms' immune defenses were enhanced
 64 by inducing dendritic cell aggregation and increasing the expression of lymphocytes after
 65 AMPs treatment, and the development of cancer was also inhibited (Huang et al., 2015).

66 In recent years, it was revealed that the telomerase might also be involved in the
 67 antitumoral mechanisms of AMPs. In normal cells, the expressions of telomerase were
 68 extremely low, or even none. However, their expression levels were significantly increased
 69 in malignant proliferative cells to protect their chromosomes and to promote the cells to
 70 proliferate indefinitely (Li et al., 2014; Ale-Agha et al., 2014). Generally, the main structure
 71 of telomerase includes telomerase reverse transcriptase (TERT) and telomerase-associated
 72 proteins (Blackburn et al., 2006). TERT, as the catalytic subunit of telomerase, plays a key
 73 role in telomerase synthesis and telomerase activity maintenance, especially in promoting
 74 the cells carcinogenesis (Borah et al., 2015). It was reported that higher levels of TERT
 75 mRNA were expressed in lung cancer-derived human cell line H1299, while lower levels in
 76 those of normal cells (Bodnar and Wright, 1998). Study also found that plasma TERT
 77 mRNA levels were significantly higher in the patients with liver cancer and prostate cancer
 78 than those in the normal group (El-Mazny et al., 2014), and the levels of TERT mRNA were
 79 closely related to various clinical and pathological conditions (Kang et al., 2013). Similar
 80 results were also reported by FU et al. (2015), which found that plasma hTERT mRNA
 81 levels in peripheral blood were significantly higher in patients with NPC than those in the

82 normal groups through the quantitative detection of telomerase hTERT mRNA. In addition,
83 the levels of telomerase hTERT mRNA were also been shown to be up-regulated, followed
84 by the G1/S blockade and chemotherapeutic drug resistance under hypoxia in NPC. Until
85 the hypoxia reversed, the telomerase activities were decreased, and chemo-resistance was
86 improved (Shi et al., 2015). From these studies, it was inferred that the telomerase activity
87 was closely related to the occurrence and development of NPC.

88 The black soldier fly, *Hermetia illucens* L. is considered as a beneficial resource insect
89 in Diptera family. Its larvae are reported as feeding on immense variety of organic material,
90 and have been used in small-scale waste management purpose to reduce manure
91 accumulations in confined animal feeding operations and the accumulations of other wastes.
92 The habit of *H. illucens* larvae, which is extremely rich in various microorganisms including
93 many pathogenic ones, implies that the immune system of this insect functions works very
94 efficiently (Park et al., 2014). Since its first report in 2013 by our research group (Xia et al.,
95 2013), AMPs of this insect, which are essential components of innate immune system of *H.*
96 *illucens* larvae, have been paid more and more attentions and been considered to have
97 potential applications in the medicine fields (Choi and Jiang, 2014; Park et al., 2015; Vogel
98 et al., 2018). AMPs of *H. illucens* have showed good antibacterial activity for gram-positive
99 bacteria, gram-negative bacteria and fungi (Elhag et al., 2017). However, no research was
100 focused on their anti-cancer activity and related mechanisms. Therefore, in the present study,
101 the AMPs were isolated and purified from the hemolymph of *H. illucens* larvae, and the
102 active components HI-3 were screened out to investigate its effects on the proliferation,
103 apoptosis and migration of nasopharyngeal carcinoma (CNE2) cells. Furthermore, the

expressions of telomerase in CNE2 cells were also studied to explore the possible mechanism of HI-3 action. We hope the results would provide theoretical basis for the research and development of the *H. illucens* AMPs as a potential antitumoral agent.

107

2 Materials and methods

2.1 Insects, bacteria and cells

H. illucens L. was provided by Zhuhai Modern Agriculture Development Center. The larvae were feed with artificial feed (wheat bran: corn flour: chick feed=5: 3: 2) and kept in a greenhouse of 27 °C, RH 80%, photoperiod 14 L: 10 D.

The four strains of bacteria *Staphylococcus aureus*, *Escherichia coli*, *Bacillus subtilis*, and *Enterobacter aerogenes* were obtained from Immunology and Pathogenic Biology Laboratory of Zunyi Medical University.

Standard strains of human CNE2 cells and human umbilical vein endothelial cells (HUV-C) were purchased from Shanghai ATCC Cell Bank of Chinese Academy of Sciences.

Tricine-SDS PAGE gel kit was purchased from Sigma; CCK-8 kit, Hoechst33342 staining kit, and Annexin V-FITC/PI double staining kit were purchased from Japan Tongren Institute of Chemistry; RT-PCR telomerase detection kit was purchased from Nanjing Kaiji Biological Co., Ltd.; hTERT antibody was purchased from ABclonal Company.

Vertical electrophoresis (Mini-PROTEAN Tetra), Horizontal electrophoresis(YCP-31DN), Automatic microplate reader(Elx-800), RT-PCR (621BR07707) were from Bio-Rad; RP-HPLC (LC-C8002) was from Shimadzu Corporation; Inverted fluorescence microscopy (IX71) was from OLYMPUS Corporation; Flow cytometry (FACS Calibur) was from Beckman Coulter Corporation.

127

128 2.2 Induction and Extraction AMPs from the larvae of *H. illucens*

129 According to the method mentioned in Xia et al (2013), the 20,000 fifth instar larvae of
 130 *H. illucens* were selected for induction. The larvae in the induction group were received
 131 abdomen acupuncture treated with *Staphylococcus aureus* (A260=2.4), while those in the
 132 control group were acupunctured with culture medium. After 24 h treatment, the hemolymph
 133 of larvae in the induction and control group was collected into Eppendorf centrifuge tubes and
 134 centrifuged at 12,000 rpm for 10 min at 4°C. Then, the supernatant was transferred into a 10
 135 kD ultrafiltration centrifuge tube and centrifuged at 12,000 rpm for 15 min at 4 °C. The
 136 ultrafiltrate was again transferred to a 3 kD ultrafiltration centrifuge tube and centrifuged
 137 under the same conditions. The retention section, which is AMP crude extract, was
 138 freeze-dried in vacuo and stored in a refrigerator at -80 °C for use.

139

140 2.3 Purification of AMPs from crude extract

141 The crude extract of AMPs was separated by RP-HPLC system. The column was the
 142 type of LC-C8002, 4.6 mm × 250 mm, 10 μm, and column temperature at 40 °C. The mobile
 143 phase was 0.1% (v/v) TFA (phase A) and acetonitrile with 0.1% TFA (phase B) at a flow rate
 144 of 0.5 ml/min. UV detector wavelength was set at 214 nm. According to the retention time of
 145 the peak, the components corresponding to each peak were collected.

146 Purity of HI-3 was also detected by RP-HPLC. And the chromatographic conditions
 147 were same as mentioned above 0.5 ml/min, detection wavelength 214 nm, temperature 40 °C.

148

149 2.4 Antibacterial activity assays

150 Four strains of bacteria, *Staphylococcus aureus*, *Escherichia coli*, *Bacillus subtilis* and
 151 *Enterobacter aerogenes*, were formulated into bacterial liquid at the concentration of 3.2

152 $\times 10^{12}$ /ml, separately. Then, 50 μ l of each bacterial liquid was evenly coated in the LB solid
153 medium. When the bacterial liquid was dry, the sterile filter paper with a diameter of 6mm,
154 which were treated with 25 μ l of Gentamicin sulfate (as positive control), saline (as negative
155 control) and purified AMPs (named as HI-1, HI-2, HI-3) separately, were placed on the
156 medium. Four replicates were set. After incubated at 37 °C for 24 h, the size of the inhibition
157 zone was observed and measured (Xia et al., 2013).

158 The value of MIC (minimum inhibitory concentration) about the component HI-3 with
159 strong antibacterial activity was detected by MH broth dilution method. Gentamicin sulfate
160 was used as positive control. Absorbance value was read at 595 nm to calculate the inhibition
161 rate Y.

$$162 \quad Y = (A_0 - A_1) / (A_0 - A_2) \times 100\%$$

163 Among them , A0 is the absorbance value in the negative control, A1 is the value in the HI-3
164 treatment, and A2 is the value in positive control.

165 MIC was recorded as the minimum inhibitory concentration at which the inhibition rate
166 was not less than 80%.

167

168 **2.5 Estimation of cytotoxicity in CNE2 cells and HUV-C**

169 To test the cell viability after treatment with HI-1, HI-2 and HI-3, CCK-8 kit was run.
170 Cells were plated at a density of 1×10^5 cells/100 μ l/well in 96-well plates for 24 h. Four
171 replicates were set for each treatment. Then, the medium was discarded and replaced by
172 different concentrations (5 μ l/ml, 10 μ g/ml, 20 μ g/ml and 40 μ g/ml) of HI-1, HI-2, HI-3,
173 respectively, or medium alone for 24 h and 48 h. This was followed by the addition of 20 μ l
174 of CCK-8 solution for 2 h at 37 °C in 5% CO₂ incubator. The optical density was measured
175 spectrophotometrically at 490 nm on a microtiter plate reader. Results were expressed as a

percentage of the inhibition rate for viable cells, and values of the medium only group were regarded as negative control.

Inhibition rate (%) = $(A_{\text{negative control}} - A_{\text{treatment}}) / A_{\text{negative control}}$

2.6 Effects of HI-3 on apoptosis and migration of CNE2 cells

2.6.1 Apoptosis of CNE2 cells

The CNE2 cells and HUV-C were maintained in RPMI-1640 and DMEM medium supplemented with 10% FBS, respectively. Cells were maintained in incubator under a fully humidified atmosphere of 95% room air and 5% CO₂ at 37 °C. Briefly, the cell density was adjusted to 1×10⁵ cells/ml, and 100 µl of cell suspensions were placed onto 96-well plates. Four replicates were set for each treatment. The medium was removed after 24 h, and HI-3 was added to cell cultures at a final concentration of 40 µg/ml, 80 µg/ml and 160 µg/ml. After incubation for 48 h at 37 °C in a humidified atmosphere with 5% CO₂, 5 µl of Hoechst33342, a DNA specific fluorescent dye, which stains the condensed chromatin of apoptotic cells more brightly than the chromatin of normal cells, was added to each well and incubated for 15 minutes at room temperature. Morphological changes in nuclear chromations of cells in control and each treatment were observed with fluorescence microscope, and the influence of HI-3 on the apoptosis rate of CNE2 cells and HUV-C was detected by flow cytometry (FCM) (Yan et al., 2015).

2.6.2 Migration of CNE2 Cells

The HUV-C and CNE2 cells suspension was prepared as the method mentioned in 2.7.1. 2 ml of cell suspension was placed into a 6-well plate and incubated at 37 °C in the incubator with 5% CO₂. After the cells were fully covered the plate, the cells in each well was

perpendicularly streaked with a 200 µl of pipette tip, followed by washing with PBS. Then, 2 ml of HI-3 diluted with 2% FBS and 0.2% colchicine was added to cell cultures at a final concentration of 160 µg/ml, while the negative control received with the same volume of solution without HI-3. After 0 h, 12 h, 24 h and 48 h incubation, the scratches were observed and photographed to calculate the mobility.

$$\text{Mobility (\%)} = (W_0 - W_K) / W_0 \times 100\%$$

Among them, W_0 is the width of scratches at 0 h, W_K is the width of scratches at 12 h, 24 h, 48 h, respectively.

2.7 RT-PCR analysis of telomerase hTERT gene expression

RT-PCR was used to analyze gene expression of telomerase hTERT in CNE2 cells treated with 160 µg/ml of HI-3 for 48 h. And the cells without treatment were set as control. The primers used for hTERT were upstream 5'-GCCGATTGTGAACATGGACTACG-3' and downstream 5'-GCTCGTAGTTGAGCACGCTGAA-3'. Primer pair for GAPDH (upstream 5'-CATCTTCTTTGCGTCGCCA-3'; downstream 5'-TTAAAAGCAGCCCTGGTGACC-3') was used as the reference gene. Reaction system involved each 1 µl of primers of upstream and downstream, 2 µl of template RNA, 2.75 µl of RT-PCR MIX (including reverse transcriptase, Taq DNA polymerase and RNase inhibitor), 25 µl of 2× reaction buffer, and RNase free water which was added to a total volume of 50 µl. The samples were denatured at 94 °C for 5 min, followed by a 40 cycles reaction: 94 °C for 30 s, 60 °C for 30 s, 72 °C for 1 min; and by the extension at 72 °C for 10 min. The 10 µl of PCR products were separated by 1% agarose gel electrophoresis, and the expressions of hTERT gene were analyzed by $2^{-\Delta\Delta C_t}$ method using GAPDH as internal reference gene.

2.8 Western blotting analysis of the telomerase hTERT protein expression

Western blotting for detecting telomerase hTERT was performed after CNE2 cells were treated with HI-3 at the final concentration of 160 µg/ml for 48 h. Briefly, the cells were harvested and the cellular protein were extracted by homogenization in 100 µl lysate on ice for 30 min. The lysates were then centrifuged at 12,000 rpm for 30 min at 4 °C. The proteins were quantified using the Bradford method, and 30 µg proteins were separated using SDS-PAGE gel and transferred onto PVDF membranes (Millipore, USA). Non-specific binding was prevented using a solution of 5% non-fat dry milk at room temperature for 1 h, and then washed with TBST for 3 times. Blots were incubated with the primary antibody diluted 1: 1000 primary antibody (for hTERT and GAPDH) diluted with 2% BSA in TBS containing 0.1% Tween-20 (TBST) overnight at 4 °C. After washing with TBST for 3 times, the blots were incubated with mouse-derived secondary antibody diluted 1: 3000 with 1% BSA in TBST for 1 h at room temperature. Following additional washing, gray-scale of specific bands was detected with ECL development.

238

239 **2.9 Statistical analysis**

Results were expressed as means ± SEM. To analyze the differences between control and treatments, single-factor analysis of variance in SPSS 20.0 software was used. Statistical differences were considered significant at a value of $P < 0.05$.

243

244 **3 Results**

245 **3.1 Isolation and purification of antimicrobial peptides**

The crude extract from the hemolymph of *H. illucens* larvae is clear and transparent, and exhibits white powder after freeze-dried in vacuo. After PR-HPLC analysis, three compounds, HI-1, HI-2 and HI-3, were well separated from the crude extract in the induced group (Figure 1-1)). And the purity of HI-3 was up to 96.1% after purification (Figure 1-2)).

250

251 3.2 Antibacterial activity of three separated components

252 As shown in Table 1, only HI-3 showed significant antibacterial activity on the all four
 253 strains of bacteria when compared with that in the negative control ($P < 0.05$). Furthermore,
 254 the antibacterial activity of HI-3 to *Bacillus subtilis* (10.84 ± 1.00 mm) *Staphylococcus*
 255 *aureus* and *Escherichia coli*, which inhibition zone diameter was 10.84 ± 1.00 mm, was
 256 significantly lower than that to *Staphylococcus aureus* (11.79 ± 1.178 mm), *Escherichia coli*
 257 (11.83 ± 0.82 mm) and *Enterobacter aerogenes* (11.41 ± 0.78 mm) ($P < 0.05$).

258

259 3.3 MIC of HI-3 to the four strains of bacteria

260 From Figure 2, it was indicated that inhibitory rates of HI-3 against the four types of
 261 bacteria were all positively correlated with the concentration of active component HI-3. After
 262 analysis, the MICs of HI-3 to *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli* and
 263 *Enterobacter aerogenes* were 80 µg/ml, 160 µg/ml, 80 µg/ml and 80 µg/ml, respectively.
 264 From these results, it can be seen that the HI-3 was less sensitive to *Bacillus subtilis* than
 265 those of the other three bacteria, which was similar to the results of antibacterial activity of
 266 HI-3.

267

268 3.4 HI-3 induces cytotoxicity on CNE2 cells

269 According to the growth curve of CNE2 cells and HUV-C detected by CCK-8 kit, CNE2
 270 cells entered logarithmic growth phase on the 2nd day, while HUV-C on the 3rd day.
 271 Therefore, CNE2 cells after 2 days of culture and HUV-C after 3 days of culture were chosen
 272 for follow-up experiments, respectively, to verify the effects of HI-1, HI-2 and HI-3 on the
 273 proliferation of the two cells.

274 The dose- and time-dependent effects of HI-1, HI-2 and HI-3 against CNE2 cells were
 275 shown in Table 2. No significant effects on the proliferation of CNE2 cells were found after
 276 treatment with HI-1 and HI-2 for 12 h, 24 h and 48 h, respectively. When the concentration of
 277 HI-3 was among 40-160 µg/ml, HI-3 exhibited significantly inhibitory activity on the
 278 proliferation of CNE2 cells when compared to that in the corresponding HI-1 and HI-2 groups
 279 ($P < 0.05$). Furthermore, the inhibitory rate on the proliferation of CNE2 cells also increased
 280 with the treatment period of HI-3 at the concentration of 40-160 µg/ml, and the maximal
 281 inhibitory rate was recorded in the 160 µg/ml HI-3 after 48 h treatment (Table 2; Figure 3).
 282 By contrast, HI-3 treatment had no significant effect on the proliferation of HUV-C ($P > 0.05$)
 283 (Data not shown).

284

285 3.5 HI-3 induced apoptosis of CNE2 cells

286 To investigate the mode of action underlying the cytotoxic activity of HI-3 at the
 287 concentrations of 40-160 µg/ml, the CNE2 cells and HUV-C were incubated with HI-3 for 48
 288 h for fluorescence microscope and FCM.

289 Representative micrographs by fluorescence microscope revealed that the CNE2 cells in the
 290 control was membrane-intact and light blue, and the emitted fluorescence was weak (Figure
 291 4-1)-A). After 48 h treatment with 40 µg/ml HI-3, increased fluorescence intensity was
 292 observed in the CNE2 cells, indicating that HI-3 disrupted the integrity of the plasma
 293 membrane, and the symptoms of early apoptosis occurred. However, the fluorescence
 294 intensity is still uniform, which meant that the chromosomal DNA was not destroyed. With
 295 the increasing HI-3 concentration, the fluorescence intensity in CNE2 cells was further
 296 improved, indicating that the permeability of the plasma membrane was gradually increased
 297 (Figure 4-1)-B, 4-1)-C). When the concentration of HI-3 was up to 160 µg/ml, the CNE2 cells
 298 exhibited the strongest fluorescence intensity, and the number of brightly stained cells with
 299 DNA damage was also increased. Furthermore, the typical characteristics of cell apoptosis,

300 such as highly aggregated and fragmented chromatin, and dispersed apoptotic bodies, were
301 appeared. These results exhibited that high concentration of HI-3 induced drastic changes in
302 the cellular morphology (Figure 4-1)-D, arrow).

303 By contrast, there were no obvious changes in the morphology of HUV-C after treated with
304 different concentrations of HI-3 for 48 h (Figure 4-2)).

305 Results from FCM detection showed that exposure to HI-3 at the concentrations of 40-160
306 $\mu\text{g/ml}$ for 48h caused a dose-dependent increase in the apoptosis rate of CNE2 cells compared
307 to that of the control cells. And the apoptosis rate in all the treatments was all significantly
308 higher than that in the control ($P < 0.05$), as well as higher than that in the corresponding
309 HUV-C. The results demonstrated that HI-3 induced apoptosis of CNE2 cells after 48 h
310 exposure (Figure 5-1); 5-3)). Same to the fluorescence microscope results, HI-3 exposure did
311 not resulted in significantly improved apoptosis rate in the HUV-C (Figure 5-2); 5-3)).

312

313 **3.6 HI-3 inhibited the Migration of CNE2 cells**

314 After making a wound with a pipette tip, it was observed that HI-3 effectively inhibited the
315 migration of CNE2 cells in time-dependent manners when compared to the untreated control
316 cells. The migration rate of CNE2 cells exposed to 160 $\mu\text{g/ml}$ HI-3, which was $24.43 \pm 0.47\%$,
317 $61.5 \pm 0.04\%$ and $80 \pm 0.33\%$, respectively, were all significantly lower than that of cells in
318 the control ($50.32 \pm 0.24\%$, $91.17 \pm 0.15\%$ and 100%) ($P < 0.05$) (Figure 6).

319

320 **3.7 Effect of HI-3 on telomerase hTERT gene expression in CNE2 cells**

321 As showed in Figure 14, the brightness of 28S band is about 2 times of that of 18S band,
322 and no tailing phenomenon occurred, indicating that the RNA quality is qualified without
323 degradation and DNA contamination. After HI-3 treatment for 48 h, the expression of hTERT

mRNA was significantly down-regulated in the CNE2 cells compared with that in the control ($P < 0.05$) (Figure 7-1); Table 3). Simultaneously, telomerase hTERT protein expression also significantly decreased. The expression of hTERT protein in the control cells (1.19 ± 0.21) was significantly higher than that in the HI-3 treated cells (0.63 ± 0.12) by gray value analysis ($P < 0.05$) (Figure 7-2), 7-3)).

4 Discussion

In this study, we demonstrated that a small molecule peptide HI-3, purified from the hemolymph of *H. illucens* larvae after acupuncture induction with *Staphylococcus aureus*, showed inhibitory effects on both gram-positive and gram-negative bacteria, as well as on the proliferation of CNE2 cells to some extent. It was also found that HI-3 could induce the apoptosis and inhibit the migration of CNE2 cells. Further studies confirmed that HI-3 could significantly inhibit the expression of hTERT. An interesting observation in this study is that HI-3 had more deleterious effects towards CNE2 cells than toward normal cells. Its antitumor activity towards CNE2 cells was unlike that of chemotherapeutic agents, for they cannot discriminate between normal and cancer cells. These results support our assumption that HI-3 may act on a potential antitumor drug without toxic development.

After acupuncture induction with *Staphylococcus aureus*, three components were separated from the hemolymph of *H. illucens* larvae. However, only HI-3 showed different degrees of antibacterial activities against all selected bacteria, which was consistent with the broad-spectrum antibacterial effects of AMPs reported in the previous studies. Generally, AMPs exert their antibacterial activity through the destruction of the plasma membrane (Lee et al., 2015a; Nguyen et al., 2011). Due to their amphipathic nature, most of AMPs are positively charged and can interact with the negatively charged phospholipid bilayer on the bacterial surface by electrostatic action or with other anions on the membrane to form ion channels on the plasma membrane (Huang et al., 2010). It was found that the AMP attacins

350 from the silkworm could inhibit the growth of gram-negative bacteria by inhibiting the
351 synthesis of membrane proteins; and moricin, another antibacterial peptide, could exert its
352 antimicrobial activity by increasing membrane permeability (Ravi et al., 2011). Though the
353 plasma membranes of CNE2 cells were disrupted by HI-3 treatment in this study, whether the
354 mechanism of HI-3 against bacteria was through this action still need further study.

355 AMPs isolated from insects, including melittin, cecropin related peptides and magainins
356 have been shown to exhibit antitumoral activity for cells derived from mammalian tumors
357 (Lee et al., 2015b; Su et al., 2015). In the present study, HI-3 at the concentration of 40-160
358 µg/ml also exhibited the proliferation inhibition of CNE2 cells in a dose- and time- dependent
359 manner. However, the negative control cells HUV-C were not affected by HI-3 treatment.
360 These results were similar to the study of Wang et al. (2012), which found that the AMP
361 temporin-1CEa have different degrees of inhibition against the growth of various types of
362 tumor cells, while normal human erythrocytes and HUVSMCs cells were not affected.
363 Different studies have attempted to explain the mechanisms that the tumor cells are more
364 sensitive to AMPs treatments (Wang et al., 2016). For the surface of tumor cells membrane
365 holds more negatively charged phosphatidylserine, abnormal expressed polysaccharide
366 proteins and increased sialylation when compared with the normal cells, some investigations
367 have determined that one of its antitumoral mechanisms was through destructing the cell
368 membrane, which was similar to that of the antibacterial activity. For example, Slaninová et al.
369 (2012) demonstrated that AMP from wild-type bee venom exerted the cytotoxic effects on
370 tumor cells through enhancing the permeability of tumor cell membranes. Chang et al. (2011)
371 reported that the AMP tilapia hepcidin(TH)1-5 could bind to the membranes of HepG2 and
372 HeLa tumor cells, breaking the cell membrane through a process similar to that of cytolysis,
373 and eventually lead to cell necrosis. In addition, the toxicity of AMP D-peptide from beetles
374 against tumor cells mainly depended on the negative charge carried by phosphatidylserine in
375 the tumor cell membrane (Iwasaki et al., 2009). In present study, fluorescence intensity in
376 CNE2 cells increased with the increasing concentration of HI-3 in a dose-dependent manner,

377 indicating that the target site of HI-3 might also be the membrane. Furthermore, the increasing
378 apoptosis rates in CNE2 cells after HI-3 treatment might also be related with the gradually
379 improved membrane permeability, though more researches should be investigated.

380 HI-3 was able to inhibit the migration of CNE2 cells to a certain extent according to our
381 cell scratch assay. Generally, tumor cells have a strong ability of invasion and metastasis.
382 Distal metastasis and subsequent increased malignant proliferative capacity are among the
383 major problems during the oncotherapy. Relevant study revealed that an amphibian AMP
384 Temporin-1CEa could inhibit the invasion and metastasis of melanoma A375 cells whereby
385 regulating the release of metalloproteinase-2 and vascular growth factor (Zhang, 2015).
386 However, few studies have focused on the specific mechanisms concerning the migration of
387 cancer cells treated with AMP. The deep research remains to be explored.

388 Higher activity telomerase could be detected in malignant proliferative cancer cells.
389 Therefore, telomerase is considered as an important and effective target for anti-tumor
390 therapy (Chen et al., 2016). For example, the growth inhibition of human colon cancer
391 HCT166 cells by AZT (3'-Azido-3'-deoxythymidine) was mediated by inhibiting telomerase
392 activity and hTERT gene expression (Hu and Xu, 2017). Our study also found that hTERT
393 gene expression and hTERT protein expression were significantly decreased after HI-3
394 treatment, indicating that the down-regulating of telomerase activity was involved in the
395 inhibition of NPC. On the other hand, it was reported that in addition to its function of
396 maintaining intracellular DNA and chromosomes stability, telomerase is also involved in the
397 regulation of mitochondrial function and gene expression during tumorigenesis (Chiodi and
398 Mondell, 2012). For hTERT is the key protein of telomerase synthesis, it might also be
399 involved in the action of telomerase in the occurrence and development of cancer. However,
400 the regulation effect of telomerase and hTERT in the HI-3 induced inhibition of proliferation
401 of CNE2 cells still need further investigation. And whether the mitochondrial pathway was
402 induced in the HI-3 action also remains to be explored.

403 From these results, we concluded that HI-3 has the potential for development as a new
404 type of antitumoral agent, for HI-3 is less toxic to normal cells. It was confirmed that HI-3
405 might exert its antitumoral effect through down-regulating the expression of hTERT.
406 However, the specific mechanism involved in the HI-3 still need deep investigations.

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410 **Competing interests**

411 The authors have declared that no competing interests exist.

412 **Author contributions**

413 Zhong Tian and Qun Feng performed the experiments, Hongxia Sun and Ye Liao drafted
414 and revised the manuscript, Lianfeng Du and Rui Yang performed the data analyses, Xiaofei
415 Li and Yufeng Yang helped perform the analysis with constructive discussions, and Qiang
416 Xia designed the experiments.

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541 **Figure captions**

542 **Figure 1** Separation crude extract from the hemolymph of *H. illucens* larvae by RP-HPLC

543 1) Separation of crude extract; 2) Purity detection of HI-3 by RP-HPLC

544

545 **Figure 2** MIC of HI-3 against four strains of bacteria

546

547 **Figure 3** Effects of HI-3 on proliferation inhibition rates of CNE2 Cells and HUV-C after 48

548 h treatment

549 Note: # means significant difference between the CNE2 cells group and HUV-C group under

550 the same concentration at the levels of 0.05. Δ means this significant difference at the levels

551 of 0.01.

552

553 **Figure 4** Effects of HI-3 on morphology of CNE2 cells and HUV-C (400 $\times$)

554 Note: 1) CNE2 cells A: Negative control; B: 40 μ g/ml; C: 80 μ g/ml; D: 160 μ g/ml

555 2) HUV-C A: Negative control; B: 40 μ g/ml; C: 80 μ g/ml; D: 160 μ g/ml

556

557 **Figure 5** Apoptosis rates of CNE2 cells and HUV-C after treated with HI-3

558 Note: 1) CNE2 cells A: Negative control; B: 40 μ g/ml; C: 80 μ g/ml; D: 160 μ g/ml

559 2) HUV-C A: Negative control; B: 40 μ g/ml; C: 80 μ g/ml; D: 160 μ g/ml

560 3) Apoptosis rate of HUV-C and CNE2 cells after treated with HI-3 for 48 h. $^{\#}P < 0.05$

561 means the apoptosis of CNE2 cells were significantly higher when compared with

the CNE2 cells in the negative group. $\Delta P < 0.05$ means there was significant difference between CNE2 cells and HUV-C group.

Figure 6 Effects of 160 $\mu\text{g/ml}$ of HI-3 on the migration of CNE2 cells (100 $\times$)

1) Morphology observation, N: Negative control group; P: 160 $\mu\text{g/ml}$ of HI-3 group

2) Migration rates of CNE2 cells

Figure 7 Expression of telomerase hTERT and GAPDH in CNE2 cells after treated with HI-3

1) RT-PCR analysis on hTERT gene expression, Note: 1: Negative control group; 2: 160 $\mu\text{g/ml}$ HI-3 group; 3: Standard nucleic acid molecule; 4, 5: Internal gene GAPDH;

2) Western blotting on hTERT protein expression;

3) Statistics of expression of hTERT protein.

574 Table legends

575 **Table 1** Inhibition zone diameters against the four strains of bacteria after treated with HI-1,
576 HI-2 and HI-3 (n=4, $\bar{x} \pm s$, mm)

577 Note: [#] $P < 0.05$ indicated there were significant differences in inhibition zone diameters
578 between HI-3 group and negative control. And ^Δ $P < 0.05$ indicated the inhibition zone
579 diameters in the *Bacillus subtilis* treatment were significantly lower when compared with the
580 *Staphylococcus aureus* and *Escherichia coli* treatments in the HI-3 group.

581

582 **Table 2** Effects of HI-1, HI-2 and HI-3 on proliferation inhibition rates of CNE2 cell (n=4,
583 $\bar{x} \pm s$, Inhibition rate : %)

584 Note: [#] $P < 0.05$ indicated that there were significant differences in the inhibition rates
585 between HI-3 group and HI-1/HI-2 group under the same concentration. ^Δ $P < 0.05$ indicated
586 that there were significant differences in inhibition rates between different time at the same
587 concentration of HI-3 group.

588

589 **Table 3** Effect of HI-3 on the expression of telomerase hTERT gene (n=6, $\bar{x} \pm s$)

590 Note: [#] $P < 0.05$ indicated that there were significant differences in expression levels between
591 HI-3 group and negative control group.

1)

2)

Figure 1

Figure 2

Figure 3

1)

2)

Figure 4

1)

2)

3)

Figure 5

2)

Figure 6

1)

2)

3)

Figure 7

Table 1

Groups	The bacterial strain			
	<i>Staphylococcus aureus</i>	<i>Bacillus subtilis</i>	<i>Escherichia coli</i>	<i>Enterobacter aerogenes</i>
Negative control	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Gentamicin sulphate	18.99±0.50	15.71±0.68	17.64±0.51	16.27±0.75
HI-1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
HI-2	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
HI-3	11.79±1.17 [#]	10.84±1.00 ^{#Δ}	11.83±0.82 [#]	11.41±0.78 [#]

Table 2

Groups	Concentrations ($\mu\text{g/ml}$)	Times		
		12h	24h	48h
HI-1	5	2.98 $\pm$ 0.20	1.43 $\pm$ 0.43	1.96 $\pm$ 0.35
	10	2.70 $\pm$ 0.19	3.07 $\pm$ 0.29	2.64 $\pm$ 0.80
	20	2.44 $\pm$ 0.13	2.60 $\pm$ 0.37	2.57 $\pm$ 0.13
	40	3.16 $\pm$ 0.47	3.53 $\pm$ 0.31	2.43 $\pm$ 0.13
	80	3.37 $\pm$ 0.33	3.90 $\pm$ 0.34	4.38 $\pm$ 0.33
	160	3.49 $\pm$ 0.57	4.17 $\pm$ 0.57	3.16 $\pm$ 0.29
HI-2	5	1.78 $\pm$ 0.24	1.08 $\pm$ 0.7	2.15 $\pm$ 0.61

	10	2.18±0.37	2.85±1.41	2.75±0.98
	20	2.93±0.78	2.48±0.29	2.29±0.06
	40	1.67±0.74	3.69±0.76	2.36±0.13
	80	3.25±0.14	3.87±0.56	4.16±0.14
	160	3.63±0.83	3.18±0.61	3.33±0.18
	5	2.18±0.94	1.83±0.76	2.28±1.42
	10	2.27±0.94	2.75±0.46	4.14±1.40
	20	1.74±0.04	4.07±1.58	3.33±0.77
HI-3	40	5.68±0.63 [#]	9.82±1.52 [#]	13.49±1.06 [#]
	80	10.94±1.43 [#]	16.21±0.77 [#]	28.09±1.84 [#]
	160	17.80±1.02 [#]	21.78±1.61 [#]	40.56±6.80 ^{#Δ}

Table 3

Groups	hTERT Ct	GAPDH Ct	ΔCt	ΔΔCt	2 ^{-ΔΔCt}
HI-3	28.43±0.53	21.84±0.34	6.58±0.54 [#]	1.51±0.54	0.37±0.15 [#]
Negative control	25.56±0.26	20.48±0.20	5.07±0.41	0.00±0.41	1.03±0.31